Government of **Western Australia**
Department of **Mines and Petroleum**

EXPLANATORY NOTES FOR THE GASCOYNE PROVINCE

by S Sheppard, SP Johnson, MTD Wingate, CL Kirkland, and F Pirajno

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Explanatory notes for the Gascoyne Province

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Abstract

This review summarizes our present geological understanding of the Proterozoic Gascoyne Province in the northwest of Western Australia. The province is located at the western end of the Capricorn Orogen, a major zone of tectonism formed between the Archean Yilgarn and Pilbara Cratons. The Gascoyne Province comprises six fault-bounded zones of granitic and medium- to high-grade metamorphic rocks. Although the province has been commonly regarded as a Paleoproterozoic entity, it has an extended history of reworking and reactivation until the late Neoproterozoic. Basement to the province consists of the Glenburgh Terrane, which comprises granitic rocks of the Halfway Gneiss with igneous crystallization ages typically between 2660 and 2430 Ma, psammitic and pelitic rocks of the Moogie Metamorphics deposited between 2240 and 2125 Ma, and a 2005–1970 Ma Andean-type batholith (Dalgaringa Supersuite). The Glenburgh Terrane is exotic to both its bounding Archean cratons. There are two parts to this Record: the first provides a synthesis of the geological history of the province, along with a summary of the gaps in our knowledge, whereas the second part contains detailed descriptions of all the stratigraphic units within the Gascoyne Province, and the tectonic events recorded in the province.

KEYWORDS: Gascoyne Province, Capricorn Orogen, Glenburgh Terrane, Proterozoic, deformation, regional geology, geochronology, structural geology

Introduction

Current program

The current program of remapping in the Gascoyne Province[1] by the Geological Survey of Western Australia (GSWA) began in 1996 as the 'Southern Gascoyne Complex project', with the objective of increasing the geological understanding of the province to support more effective mineral exploration. This was to be achieved with geological mapping sufficiently detailed for display at 1:100 000 scale, along with U–Pb zircon geochronology by secondary ion mass spectrometry (SIMS), using the sensitive high resolution ion microprobe (SHRIMP) at the John de Laeter Centre at Curtin University of Technology. The results were to be produced primarily in hard-copy 1:100 000 series maps with accompanying explanatory notes and reports (Fig.1).

Previous work

Up until the mid–1970s, no systematic mapping in the Gascoyne Province had been undertaken. In 1975, Daniels summarized what was known about the province for GSWA Memoir 2 (Daniels, 1975). In what was indicative of the poor state of knowledge of the Gascoyne Province at that time, his interpretation was based on '… photogeological interpretation of parts of the GLENBURGH[2] and MOUNT PHILLIPS Sheet areas, [and] several critical traverses across the area...' First-edition mapping of the province was undertaken in the mid- to late-1970s, the results of which are summarized in GSWA Report 15 (Williams, 1986). Geological investigations undertaken prior to about 1983 are summarized in that report, and in the Explanatory Notes that accompany the various map sheets (Elias and Williams, 1980; van de Graaf et al., 1980; Williams et al., 1983a,b; Hocking et al., 1985a,b). Some Sm–Nd isotopic data on granitic rocks collected during the mapping program were published by Fletcher et al. (1983), who hinted at accretion of Proterozoic material to the Archean Yilgarn Craton. At this time, the province was widely regarded as the product of an 'ensialic', that is intracratonic, orogeny (Daniels, 1975; Horwitz and Smith, 1978; Gee, 1979; Williams et al., 1986).

From the early 1980s up until 1996, little new work was done in the Gascoyne Province. However, work in tectonic units to the north and south of the province was to have a major influence on interpretations of the Gascoyne Province. Muhling (1986; 1988) studied the metamorphic and structural evolution of Archean gneisses

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[1] Formerly 'Gascoyne Complex'. For explanation see p. 4.

[2] Capitalized names refer to 1:100 000 series map sheets unless otherwise stated.

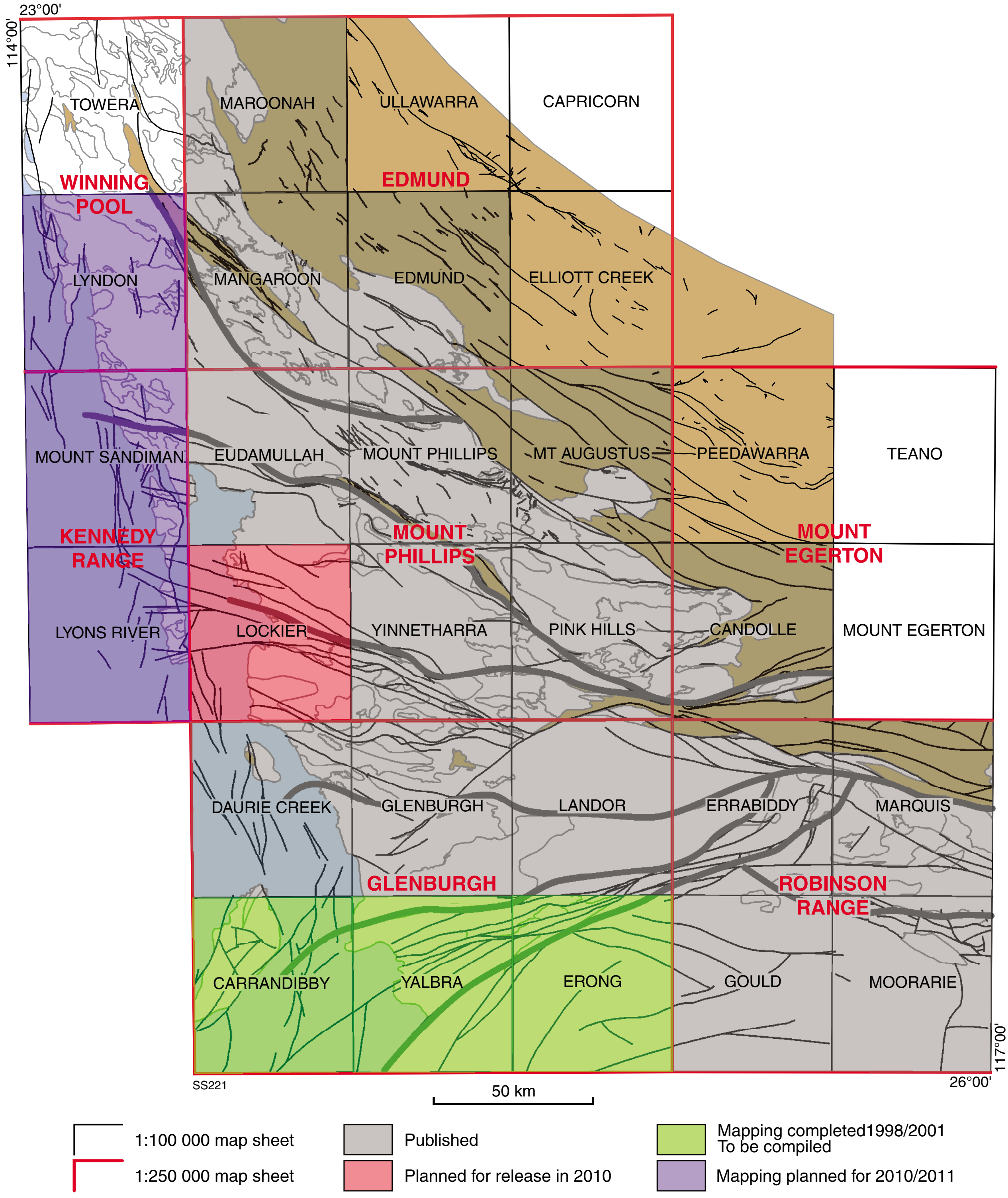

Figure 1. Index of published, mapped and planned 1:100 000k geological maps for the Gascoyne Province. The location of 1:250 000k maps sheets is shown for reference. This set of explanatory notes covers Gascoyne Province units on those maps that have previously been published or are planned for release in 2010.

along the northern edge of the Yilgarn Craton adjacent to the Gascoyne Province. She identified an episode of Proterozoic crustal shortening followed by significant uplift and granite intrusion, and interpreted this in terms of regional north–south compression, and suggested that the Capricorn Orogen marked a zone of collision between the Yilgarn and Pilbara Cratons. This explicit statement of the recognition of horizontal tectonics was a clear break from earlier interpretations that emphasized the importance of vertical tectonics. In the Ashburton and Ophthalmia Fold Belts to the north of the Gascoyne Province, Tyler and Thorne (1990), Thorne and Seymour (1991), and Tyler (1991) produced a major reinterpretation of the tectonic setting of the Capricorn Orogen. They concluded that the structural, metamorphic, and sedimentological characteristics of the rocks along the northern margin of the orogen are consistent with them having been produced by collision of the Archean Yilgarn and Pilbara Cratons at c. 1800 Ma.

In the early 1990s, two Honours theses were completed on structural and mineralogical aspects of rare-element bearing pegmatites in the centre of the Gascoyne Province (Hardy, 1992; Trautman, 1992). Pearson (1996), Pearson and Taylor (1996), and Pearson et al. (1996) examined the petrogenesis of carbonatites and rare-earth element (REE) mineralization in the Gifford Creek area in the northeastern part of the province. Pearson's PhD study was notable because it marked the first application of SHRIMP U–Pb geochronology in the Gascoyne Province. In addition, Davies (1998) examined tungsten mineralization in skarns related to granites at the northern end of the province.

Nomenclature and definition

Gascoyne Province

Williams (1986) defined the Gascoyne Province as '… the deformed and high-grade metamorphic core zone of the early Proterozoic Capricorn Orogen. It comprises voluminous granitoid intrusions, mantled–gneiss domes, metamorphosed and partly melted sedimentary rocks, and remobilized Archaean basement gneiss'. A 'province' was defined in GSWA Memoir 2 as 'An area of the earth's crust in which the rocks have some geological character, or combination of characters, in common; these are usually either age, metamorphic grade, structural style, or type of mineralization' (Trendall, 1975, p. 30). In GSWA Memoir 3, the term 'province' was abandoned, as it was felt that this two-dimensional term was inappropriate for what are three-dimensional objects. The term 'complex' was applied '…to the main metamorphic and igneous components of all the orogens. Thus, much of the Gascoyne Province of Memoir 2 becomes the Gascoyne Complex of the Capricorn Orogen…' (Trendall, 1990, p. 197). However, 'complex' is used as a lithostratigraphic term (e.g. Gifford Creek Complex: Pearson et al., 1996) and should not be applied to a tectonic unit. Therefore, use of the term 'Gascoyne Complex' is discontinued, and the term 'Gascoyne Province' is reinstated.

The term Gascoyne Province is used here to refer to granitic and medium- to high-grade metamorphic rocks at the western end of the Capricorn Orogen, *including* the former Mount James Formation (now Mount James Subgroup), which was previously considered to unconformably overlie the province (Hunter, 1990). Rocks of the Gascoyne Province are unconformably overlain by sedimentary rocks of the Edmund Basin to the east and by sedimentary rocks of the Carnarvon Basin to the west. The southern boundary of the province is marked by the Errabiddy Shear Zone. To the north, metasedimentary rocks of the Gascoyne Province pass with decreasing metamorphic grade into low-grade metasedimentary rocks of the upper Wyloo Group, in particular the Ashburton Formation (Williams, 1986).

The Gascoyne Province is divided into several east–southeasterly trending structural and metamorphic zones (Fig. 2), each of which is characterized by a unique geological history. The zones are bounded by major faults or shear zones, but none represents an exotic terrane. Rather, each zone reflects a somewhat different response than its neighbours to the multiple reworking events that distinguish the Gascoyne Province from other units in the Capricorn Orogen (Fig. 3, Table 1).

Basement to the Gascoyne Province

The oldest crust in the Gascoyne Province is the Glenburgh Terrane, which is exposed in the Paradise, Mooloo, Mutherbukin, and Limejuice Zones in the southern part of the province (Fig. 4a), but probably continues farther north as basement under the zones of younger reworking and granite magmatism (Selway, 2008; Selway et al., 2009). The Glenburgh Terrane comprises: (1) granitic rocks of the Halfway Gneiss with igneous crystallization ages of 2660 and 2430 Ma; (2) psammitic and pelitic rocks of the Moogie Metamorphics deposited between 2240 and 2125 Ma; and (3) a 2005–1970 Ma granitic Andean-type batholith (Dalgaringa Supersuite) and associated volcanic-arc related metasedimentary rocks of the Camel Hills Metamorphics (Johnson et al., 2010). Rocks of the Halfway Gneiss were previously considered to represent reworked Yilgarn Craton (Williams, 1986; Myers, 1990), but the bulk of the Halfway Gneiss has igneous crystallization ages younger than c. 2600 Ma, of which there is no equivalent in the Yilgarn Craton. The Glenburgh Terrane is probably exotic to both the Yilgarn and Pilbara Cratons. The southern limit of the terrane is marked by the Errabiddy Shear Zone (Figs 2, 4a), and the northern limit is marked by the Talga Fault (Fig. 4a; Selway, 2008; Selway et al., 2009).

Metasedimentary units

The 'Morrissey Metamorphic Suite' of Williams (1986) has been resolved into four separate metasedimentary rock packages, each with group status: the Moogie Metamorphics, deposited between 2240 and 2125 Ma; the Camel Hills Metamorphics, deposited between 2000 and 1955 Ma; the Leake Spring Metamorphics, deposited between 1840 and 1810 Ma; and the Pooranoo Metamorphics, deposited between 1760 and1680 Ma.

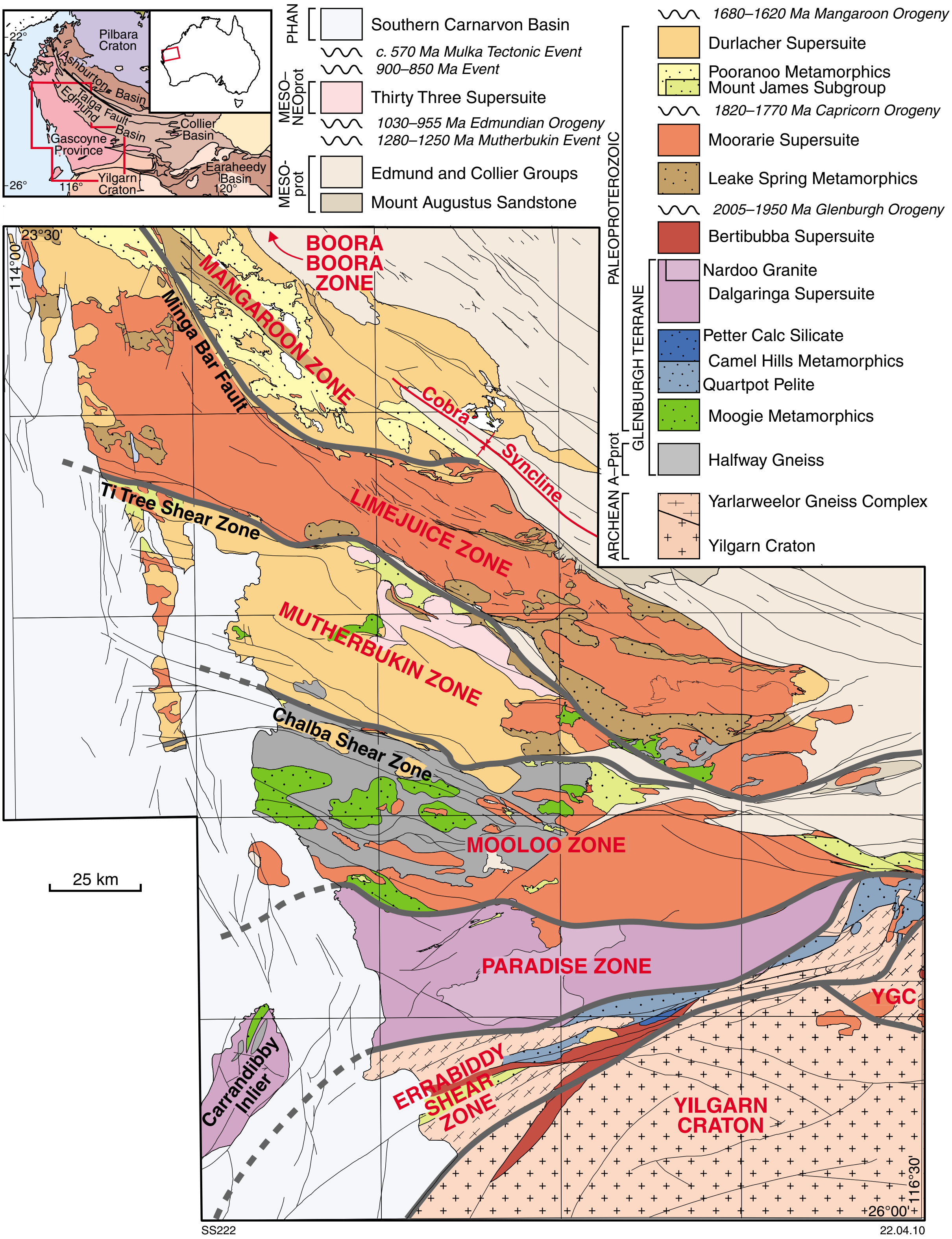

Figure 2. **Simplified map of the Gascoyne Province showing division of the region into structural-metamorphic zones. For details on this subdivision, see Table 1. Abbreviations. YGC — Yarlarweelor Gneiss Complex.**

The Leake Spring Metamorphics (Fig. 4b) was formerly known as the 'Morrissey Metamorphics' (e.g. Martin et al., 2007; Martin et al., 2008a; Sheppard et al., 2008a,b), and before that, the 'Morrissey Metamorphic Suite' (Williams et al., 1978; Williams et al., 1983a; Williams, 1986). However, the type areas for most of the rock units in the original 'Morrissey Metamorphic Suite' (Williams et al., 1978) have been reassigned to different stratigraphic units; therefore, the names 'Morrissey Metamorphic Suite' and 'Morrissey Metamorphics' are no longer valid.

The former Mount James Formation has been elevated to a subgroup within the Pooranoo Metamorphics (Fig. 4c); the two units have the same field relationships and similar depositional ages. The Mount James Subgroup was originally only recognized where it was not affected by late Paleoproterozoic or Meso- to Neoproterozoic reworking; equivalent rocks affected by the reworking were incorporated into the 'Morrissey Metamorphic Suite'.

Granitic units

Granitic rocks in the Gascoyne Province were previously thought to be of two main ages: Archean granites that were migmatized in the Proterozoic, and granites related to the Proterozoic Capricorn Orogeny. These were further divided into 'Early-Stage Gneissic Granitoids' and 'Late-Stage Granitoids' (Williams, 1986). All the granites have now been subdivided and assigned to five main supersuites, largely on the basis of SHRIMP U–Pb zircon geochronology. These supersuites are the 2005–1970 Ma Dalgaringa Supersuite, the 1965–1945 Ma Bertibubba Supersuite, the 1820–1775 Ma Moorarie Supersuite, the 1680–1620 Ma Durlacher Supersuite, and the 995–955 Ma Thirty Three Supersuite (Fig. 2). The Dalgaringa Supersuite is restricted to the southern edge of the Glenburgh Terrane, predominantly in the Paradise Zone (Figs 2–4a). The Bertibubba Supersuite is the first common element to the Glenburgh Terrane and Yilgarn Craton (Figs 3, 4a), and is interpreted as having stitched these two terranes. The Moorarie and Durlacher Supersuites were emplaced across much of the Gascoyne Province, whereas the Thirty Three Supersuite is apparently confined to the northern part of the Mutherbukin Zone in the centre of the province (Fig. 3).

Tectonomagmatic events

SHRIMP U–Pb geochronological studies show that the Gascoyne Province was primarily shaped by four main orogenic events: the 2005–1950 Ma Glenburgh Orogeny, the 1820–1770 Ma Capricorn Orogeny, the 1680–1620 Ma Mangaroon Orogeny, and the 1030–955 Ma Edmundian Orogeny (Fig. 3). However, SHRIMP U–Pb monazite and zircon geochronology is beginning to reveal that the province also underwent several additional cryptic events that were either of too low a grade to be recorded in the growth of new metamorphic zircon, or were completely overprinted by one or more of the four main orogenic episodes. Unlike the main orogenic events, these lower grade tectonic events were not accompanied by voluminous magmatism.

Main orogenic events

The age of the Glenburgh Orogeny is taken to be roughly equivalent to the combined age range of the Dalgaringa Supersuite and deformed parts of the Bertibubba Supersuite. Two discrete tectono-metamorphic episodes are recognized within this orogeny (D_{1g} and D_{2g}), both of which have been dated directly from the growth of new metamorphic zircon and monazite (Fig. 3). The D_{1g} event is dated at c. 2000 Ma, although field evidence suggests that this event was more protracted (i.e. from 2005 to 1985 Ma) than suggested by the metamorphic zircon results (Johnson et al., 2010). The D_{2g} event — dated from metamorphic zircon and monazite in migmatized pelitic and semipelitic rocks of the Moogie and Camel Hills Metamorphics — is dated between 1965 and 1950 Ma (Johnson et al., 2010) and coincides with intrusion of the Bertibubba Supersuite (Fig. 3).

The Capricorn Orogeny broadly coincided with emplacement of the Moorarie Supersuite. Three tectonometamorphic episodes (D_{1-3n}) are recognized from field relationships, although the ages of these events are poorly constrained owing to the lack of a metamorphic zircon 'fingerprint'. The oldest reliably dated intrusions in the Moorarie Supersuite are about 1820 Ma, although two apparently older dated intrusions of leucocratic muscovite–biotite granite from GLENBURGH (Occhipinti and Sheppard, 2001, p. 24) — that were previously used to place a maximum age on the Capricorn Orogeny — appear to contain only inherited zircon. The youngest intrusion involved in the Capricorn Orogeny is dated at c. 1775 Ma, although SHRIMP U–Pb dating of thin metamorphic zircon rims in a sample of quartzite from the Moogie Metamorphics (GSWA 187403, Wingate et al., 2009) in the Mutherbukin Zone, indicates a date of c. 1770 Ma (at least locally representing D_{3n}); this is currently taken to be the younger age limit to the orogeny.

The Mangaroon Orogeny is interpreted to have coincided with emplacement of the 1680–1620 Ma Durlacher Supersuite (Fig. 3), the oldest and youngest intrusions of which are dated at 1677 ± 5 Ma and 1619 ± 15 Ma. Two distinct tectonometamorphic events are recognized in the Mangaroon Orogeny (D_{1m} and D_{2m}). The first (D_{1m}) was coincident with the older magmatic phases at c. 1675 Ma (Fig. 3) and the second appears to have immediately followed D_{1m}, deforming c. 1675 Ma granites but generally not affecting c. 1660 Ma granites.

The age of the Edmundian Orogeny is currently based on geochronological studies from the Nardoo Hills area, along the northern edge of the Mutherbukin Zone on MOUNT PHILLIPS and YINNETHARRA. The oldest metamorphic age recorded so far, is given by a single SHRIMP U–Pb metamorphic monazite age of c. 1030 Ma obtained from a medium-grade pelite in the Mutherbukin Zone. The minimum age is constrained by an undeformed rare-element pegmatite that yielded a SHRIMP U–Pb monazite age of c. 955 Ma (Sheppard et al., 2007). Porphyritic and leucocratic tourmaline-bearing granites and pegmatites of the Thirty Three Supersuite appear to have been intruded during the waning stages of the Edmundian Orogeny; however, these granitic rocks have failed to yield any magmatic zircon and so their precise age is

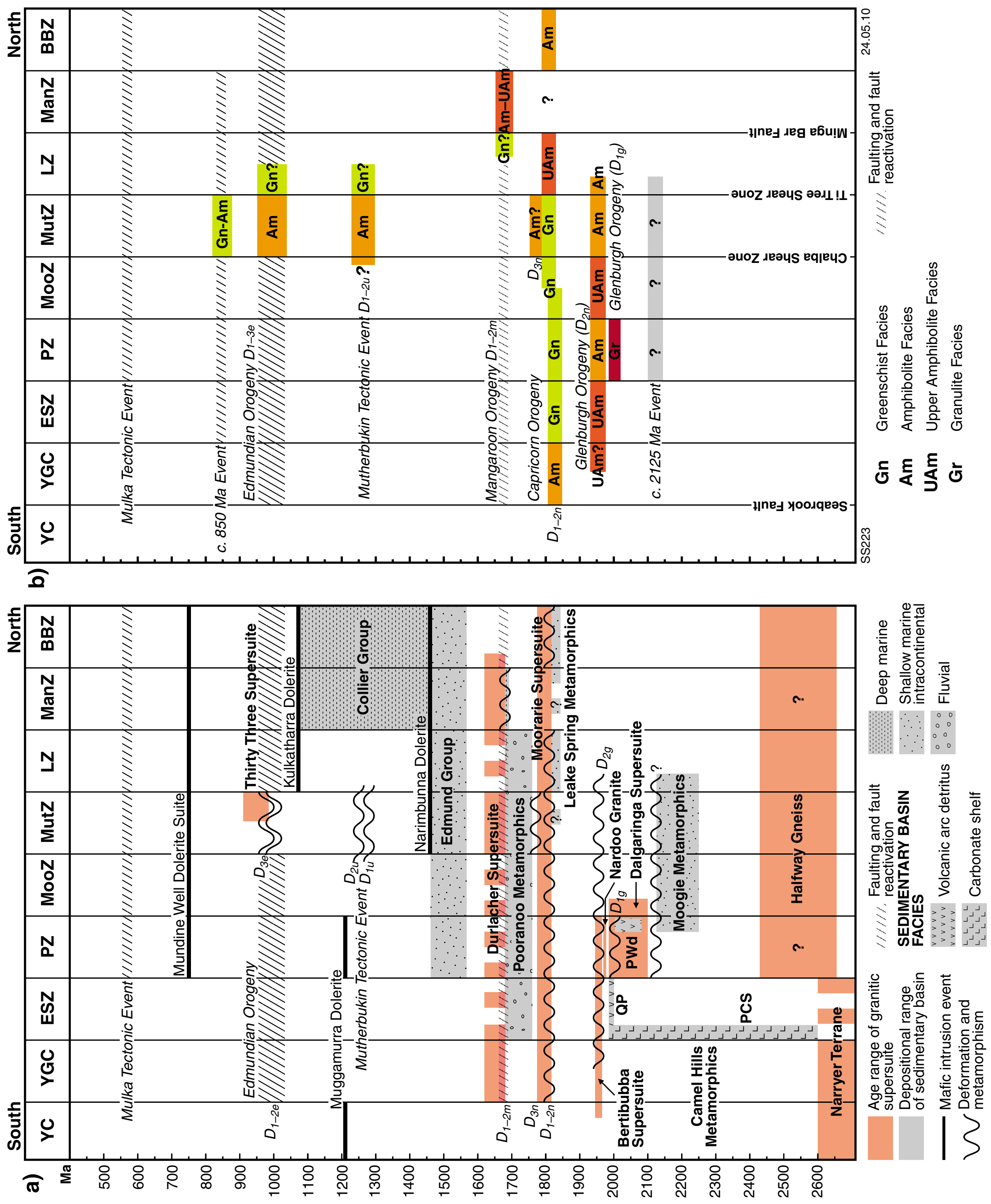

Figure 3. Time-space plots for the Gascoyne Province (a) Lithostratigraphic units and (b) metamorphic events. Zone boundary abbreviations. BBZ — Boora Boora Zone, ESZ — Errabiddy Shear Zone, LZ — Limejuice Zone, ManZ — Mangaroon Zone, MooZ — Mooloo Zone, MutZ — Mutherbukin Zone, PZ — Paradise Zone, YC — Yilgarn Craton, YGC — Yarlarweelor Gneiss Complex. Abbreviations in Time-space plot. PS — Petter Calc-silicate, QP — Quartpot Pelite, PWd — Paradise Well diatexite.

Table 1. Zone boundaries in the Gascoyne Province

Yilgarn Craton – Narryer Terrane	Characterized by granitic rocks older than c. 2.6 Ga with some gneisses older than c. 3.3 Ga. No Paleoproterozoic or younger reworking
Yarlarweelor Gneiss Complex	Characterized by granitic rocks older than c. 2.6 Ga typical of the Yilgarn Craton, which have been intensely reworked during the 1820–1770 Ma Capricorn Orogeny. Contains voluminous Moorarie and Durlacher Supersuite granites
Errabiddy Shear Zone	Zone of intense shearing and interleaving of lithologies from the Yilgarn Craton and the Glenburgh Terrane. Intensely deformed and metamorphosed during the D_{2g} event (1965–1950 Ma) of the Glenburgh Orogeny
Paradise Zone	Characterized by the voluminous intermediate to felsic arc-related batholith of the Dalgaringa Supersuite (2005–1970 Ma). Deformed during both the D_{1g} and D_{2g} events of the Glenburgh Orogeny
Mooloo Zone	Dominated by gneissic and siliciclastic lithologies of the Glenburgh Terrane. Intensely deformed and metamorphosed during the D_{2g} event of the Glenburgh Orogeny and overprinted by pervasive low grade metamorphism during the 1820–1770 Ma Capricorn Orogeny. Contains abundant felsic intrusions of the Moorarie Supersuite
Mutherbukin Zone	Characterized by voluminous felsic batholithic granites of the Durlacher Supersuite, and multiply deformed and metamorphosed during several events during the Paleo- to Neoproterozoic, including the 1280–1250 Ma Mutherbukin Tectonic Event, the 1030–955 Ma Edmundian Orogeny and a c. 850 Ma event
Limejuice Zone	Dominated by voluminous granites of the Moorarie Supersuite that comprise the Minnie Creek batholith. Deformed and metamorphosed during the 1820–1770 Ma Capricorn Orogeny
Mangaroon Zone	Marked by intense deformation and metamorphism during the 1680–1620 Ma Mangaroon Orogeny with the production of abundant migmatitic melts in pelitic and semipelitic lithologies of the Pooranoo Metamorphics. Intrusion of voluminous granitic batholiths of the Durlacher Supersuite
Boora Boora Zone	This zone is characterized by abundant medium-grade metasedimentary rocks of the Leake Spring Metamorphics which may grade into metasedimentary rocks of the upper Wyloo Group. Contains foliated to gneissic granites of the Moorarie Supersuite

currently unknown. The main tectonometamorphic fabric, a composite S_1–S_2 fabric (corresponding to D_{1e} and D_{2e} deformation), is dated from metamorphic monazite and zircon to between 1030 and 995 Ma (Sheppard et al., 2007; Johnson et al., 2009), and a later crenulation cleavage (S_3, i.e. a D_{3e} event) is dated between 995–955 Ma (Sheppard et al., 2007).

Low- to medium-grade tectonic events

Geochronology of metamorphic zircon and monazite from pelitic schists of the Moogie Metamorphics in the Mooloo Zone suggests that rocks of the Glenburgh Terrane were subject to an event of undetermined metamorphic grade at c. 2125 Ma (Johnson et al., 2010). This event may or may not be related to the waning stages of the 2215–2145 Ma Ophthalmian Orogeny (Rasmussen et al., 2005), which is primarily known from the northern margin of the Capricorn Orogen (Blake and Barley, 1992; Powell and Horwitz, 1994; Martin et al., 2000; Rasmussen et al., 2005).

Unpublished SHRIMP U–Pb monazite ages from pelitic schists and metamorphic titanite from alkaline granites within the Mutherbukin Zone indicate an episode of medium-grade metamorphism and deformation between 1280 and 1250 Ma (Johnson et al., 2009). This event, known as the Mutherbukin Tectonic Event, is responsible for the production of an intense upright schistosity in metasedimentary rocks and a widely developed foliation to gneissic banding within metamorphosed granites throughout much of the Mutherbukin Zone.

In addition, continental reactivation during the Neoproterozoic is evident from an anastomosing network of shear zones and reactivated faults cutting the Gascoyne Province and Bangemall Supergroup. A period of faulting at c. 850 Ma is suggested by an unpublished, preliminary SHRIMP U–Pb monazite age from a low-grade metasedimentary rock in the Ti Tree Syncline, and a younger dextral shearing event — known as the Mulka Tectonic Event — is based on an $^{39}Ar/^{40}Ar$ in situ muscovite age of c. 570 Ma from the Chalba Shear Zone (Fig. 3; Bodorkos and Wingate, 2007).

Geological history and tectonic models

Early models for the evolution of the Gascoyne Province emphasized vertical movements of the crust (rather than plate tectonic processes) and lithological correlations across the Capricorn Orogen (Daniels, 1975; Horwitz and Smith, 1978; Gee, 1979; Williams et al., 1986). The province was therefore interpreted as the 'core' of an intracratonic orogen. These ideas were superceded in the late 1980s and 1990s by tectonic models that invoked

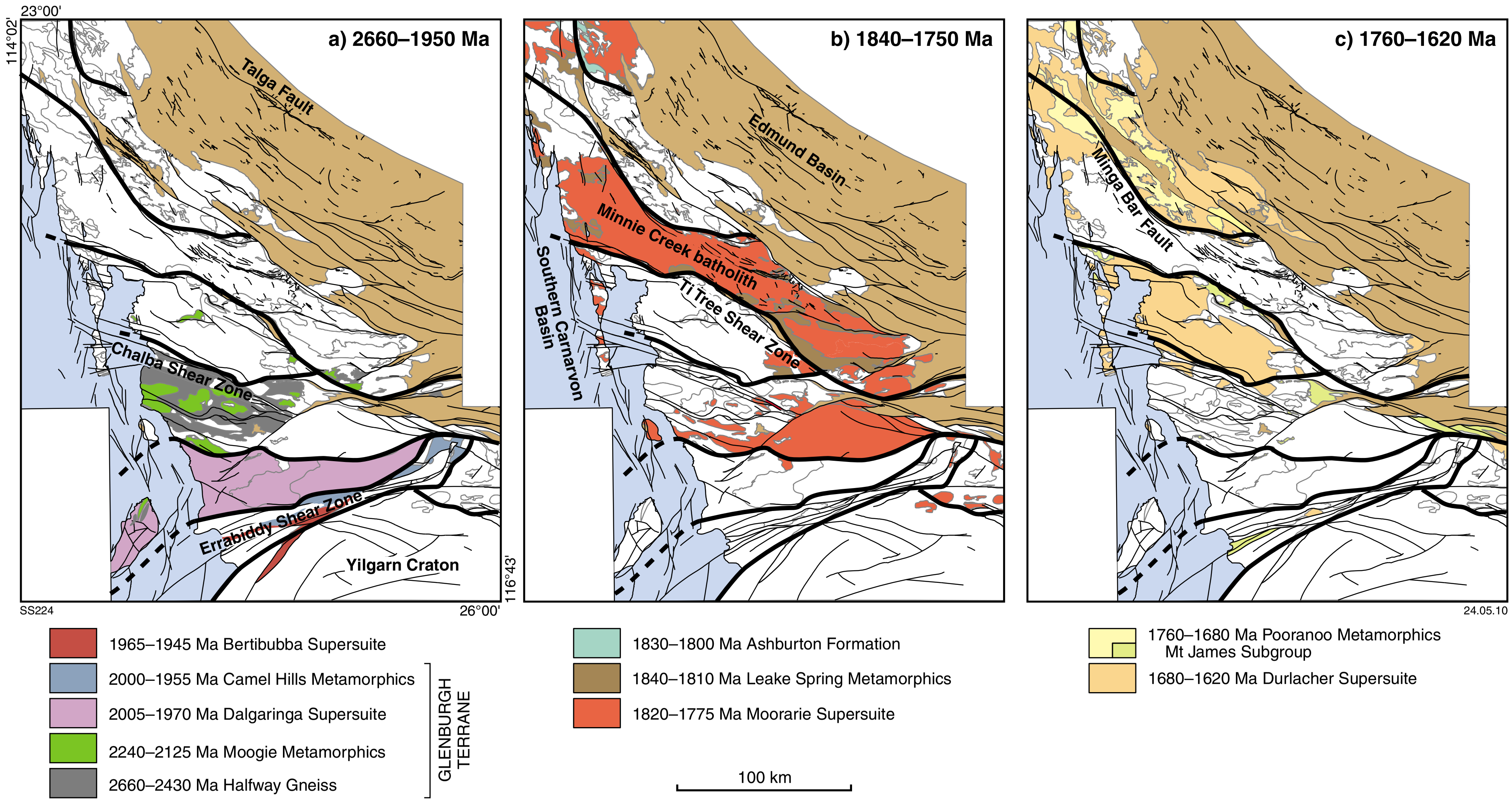

Figure 4. Distribution of major rock units in the Gascoyne Province: a) Rock units belonging to the Glenburgh Terrane (2660–1950 Ma) and the syntectonic Bertibubba Supersuite; b) 1840–1750 Ma units that were deformed and metamorphosed during the 1820–1770 Ma Capricorn Orogeny; c) post-Capricorn Orogeny units that were affected by the 1680–1620 Ma Mangaroon Orogeny.

subduction and collision between the Pilbara and Yilgarn Cratons during the Capricorn Orogeny (Muhling, 1988; Tyler and Thorne, 1990). A program of remapping and SHRIMP U–Pb geochronology has shown that elements of both models are correct: the province formed during two Paleoproterozoic collisions marked by the Ophthalmian and Glenburgh Orogenies, but thereafter the province records a prolonged history of intracontinental reworking.

The Glenburgh Terrane: an exotic entity in the Capricorn Orogen

The Glenburgh Terrane comprises granitic rocks of the Halfway Gneiss, with igneous crystallization ages between 2660 and 2430 Ma, psammitic and pelitic rocks of the Moogie Metamorphics deposited between 2240 and 2125 Ma, and a 2005–1970 Ma granitic batholith (Dalgaringa Supersuite). The Halfway Gneiss comprises moderately- to strongly-deformed, variably pegmatite-banded, meso- and leucocratic granitic gneisses. Although the protoliths to these gneisses have crystallization ages between 2660 and 2430 Ma, they contain a host of inherited zircon which suggest a history ranging back to c. 3.55 Ga. The early history of the terrane was dominated by crustal recycling without the addition of juvenile material; however, significant crustal growth took place between 2.70 and 2.43 Ga predominantly by juvenile processes most likely within a supra-subduction zone setting (Johnson et al., in prep.). Although the Halfway Gneiss and Yilgarn Craton appear to show a common period of magmatic activity from 2.7 to 2.6 Ga, the isotopic compositions and evolution of these magmatic suites are distinctly different (Johnson et al., in prep.). The majority of crustal growth in the Halfway Gneiss is dated at 2.60 – 2.43 Ga, a period of magmatic and tectonic quiescence in the Yilgarn Craton. Combined with information from its earlier magmatic and isotopic evolution it is apparent that the Halfway Gneiss and Yilgarn Craton did not share a common history until their juxtaposition during the Glenburgh Orogeny (Johnson et al., 2010, in prep.).

Several lines of evidence indicate that the Glenburgh Terrane is exotic to *both* its bounding Archean cratons. First, the Halfway Gneiss has no age counterparts in the Pilbara Craton (Johnson et al., in prep.) and did not share a common tectonomagmatic history with the Yilgarn Craton (Johnson et al., in prep.). Second, the Dalgaringa Supersuite and Moogie Metamorphics are not present in the Yilgarn Craton (the Moogie Metamorphics may be a time equivalent of some units in the lower Wyloo Group on the southern margin of the Pilbara Craton). Third, a magnetotelluric survey (MT) (Selway, 2008; Selway et al., 2009) has shown that the Glenburgh Terrane has a different electrical character to both of the cratons (Fig. 5a). The MT survey confirms that the southeast-dipping Errabiddy Shear Zone marks the southern limit of the Glenburgh Terrane, and indicates that the northern boundary is sharp, steep to north-dipping and coincides with the Talga Fault (Fig. 5a).

The timing of collision between the Glenburgh Terrane and Pilbara Craton (or accretion of the Glenburgh Terrane to the Pilbara Craton) is difficult to determine, because the suture is covered by metasedimentary rocks of the Paleoproterozoic Ashburton Formation and Mesoproterozoic Bangemall Supergroup. There is circumstantial evidence to indicate that the two came together during the 2215–2145 Ma Ophthalmian Orogeny: the Ophthalmia Fold Belt is a north-verging fold-and-thrust belt, with a deformation style consistent with a collision between the Pilbara Craton and a continent to the south (Blake and Barley, 1992). Depositional age constraints for the Moogie Metamorphics, the oldest package of metasedimentary rocks in the Glenburgh Terrane, are between 2240 and 2125 Ma (Johnson et al., 2010), and thus broadly coeval with the Ophthalmian Orogeny. It is postulated that they may have either been derived directly from the orogenic front in a foreland basin (Fig. 6a) or as a pre-collisional extensional back arc or retro-arc deposit (Fig. 6a) (Johnson et al., 2010). These metasedimentary rocks were also affected in part by an event of undetermined metamorphic grade at c. 2125 Ma which may record the waning stages of the Ophthalmian Orogeny (Johnson et al., 2010).

Sheppard et al. (2004) and Occhipinti et al. (2004) interpreted the Dalgaringa Supersuite as an Andean-type batholith developed above a northwest-dipping subduction zone along the southern edge of the Glenburgh Terrane. The exposed parts of the Dalgaringa Supersuite have been dated by SHRIMP U–Pb zircon geochronology to between 2005 and 1970 Ma (Sheppard et al., 2004). However, detrital zircons extracted from the Quartpot Pelite of the Camel Hills Metamorphics have a significant proportion of dates between 2080 and 2000 Ma (Johnson et al., 2010). These zircons have evolved Lu–Hf isotopic compositions, indicating they also originated in an Andean-type magmatic system (Johnson et al., 2010). This suggests that magmatism associated with the Dalgaringa arc extends back further than was previously recognized (within a proto-Dalgaringa arc; Fig. 6b) and that these older parts are either currently unexposed or have been tectonically removed/eroded during subsequent orogenic events (Johnson et al., 2010). The initiation of arc magmatism at c. 2080 Ma (Fig. 6b) occurred shortly after the c. 2125 Ma event that affected the Moogie Metamorphics. This time interval is consistent with the initiation of plate subduction beneath the Glenburgh Terrane being a result of plate reorganization following ocean closure and amalgamation between the Glenburgh Terrane and the Pilbara Craton. Outboard of, and possibly derived from, the continental arc, sedimentary protoliths to the Quartpot Pelite of the Camel Hills Metamorphics were deposited after c. 2000 Ma (Fig. 6c; Johnson et al., 2010). Sedimentary protoliths to the Petter Calc-silicate of the Camel Hills Metamorphics were probably deposited on the passive margin of the Yilgarn Craton at, or before, this time (Fig. 6c).

Deformation and metamorphism associated with the D_{1g} event of the Glenburgh Orogeny is entirely restricted to rocks of the Dalgaringa arc in the Paradise Zone (Fig. 3).

Decametre-scale strips of pelitic diatexite intercalated with the Dalgaringa gneisses contain a high-temperature and moderate- to high-pressure mineral assemblage indicating that metamorphism peaked in the range ~800–1000°C and 7–10 kbar (Johnson et al., 2010). This high-T, moderate-P metamorphism has been dated directly by SHRIMP U–Pb geochronology of metamorphic zircon extracted from the pelitic diatexite at c. 2000 Ma, coeval with intrusion of the arc-related magmas. The D_{1g} event is interpreted to reflect construction of the Dalgaringa arc in the middle crust (Fig. 6c; Johnson et al., 2010).

Collision of the combined Glenburgh Terrane – Pilbara Craton with the Yilgarn Craton was marked by medium- to high-grade metamorphism throughout the Errabiddy Shear Zone and southern Glenburgh Terrane during the D_{2g} event. The D_{2g} event has been dated directly at 1965–1950 Ma by SHRIMP U–Pb geochronology of metamorphic zircon and monazite from high-grade pelitic and semi-pelitic rocks of the Moogie and Camel Hills Metamorphics (Johnson et al., 2010). Widespread development of subhorizontal fabrics (indicating large horizontal shortening components) and the ubiquitous presence of migmatitic textures and now-retrogressed garnet and sillimanite porphyroblasts in pelitic to semi-pelitic lithologies, indicate that metamorphism occurred at high temperature and moderate pressure (Johnson et al., 2010). The D_{2g} event was accompanied by intrusion of the granitic Bertibubba Supersuite (Johnson et al., 2010), which is the first common element to the northern margin of the Yilgarn Craton, the Yarlarweelor Gneiss Complex, the Errabiddy Shear Zone, and the Paradise Zone of the Glenburgh Terrane (Fig. 3); therefore suturing of the combined Glenburgh Terrane – Pilbara Craton with the Yilgarn Craton and assembly of the West Australian Craton (WAC) was complete by this time. All metamorphic assemblages formed during the Glenburgh Orogeny were replaced by lower metamorphic grade equivalents during the Capricorn Orogeny and younger events.

Late Paleoproterozoic to late Neoproterozoic intracontinental reworking and reactivation

Following collision of the Pilbara Craton – Glenburgh Terrane with the Yilgarn Craton during the Glenburgh Orogeny, the history of the Capricorn Orogen is dominated by more than one billion years of episodic intracontinental reworking and reactivation.

The Capricorn Orogeny

The protoliths of medium-grade, mainly siliciclastic, metasedimentary rocks of the Leake Spring Metamorphics were deposited across at least the northern two-thirds of the Gascoyne Province (Fig. 4b). At the northern end of the province, in the Boora Boora Zone, these metasedimentary rocks may grade northwards into lower grade metasedimentary rocks of the upper Wyloo Group, in particular the Ashburton Formation (Williams, 1986; Myers, 1990). The Leake Spring Metamorphics were first deformed and intruded by granites of the Moorarie Supersuite, which includes the Minnie Creek batholith, during the Capricorn Orogeny. The Moorarie Supersuite comprises monzogranite and granodiorite, with subordinate to minor syenogranite, tonalite, and quartz diorite. Most of the rocks contain biotite as the sole ferromagnesian mineral although, in the southern part of the province, biotite(–muscovite–tourmaline)-bearing monzogranite and granodiorite are also common. Small gabbro intrusions and some gabbroic inclusions in granites are present in the Minnie Creek batholith, but are absent elsewhere in the supersuite.

Structures and metamorphic mineral assemblages related to the Capricorn Orogeny, and granites of the accompanying Moorarie Supersuite, are recognized across the province and in adjacent tectonic units (Thorne and Seymour, 1991; Occhipinti et al., 1998; Sheppard and Swager, 1999; Occhipinti and Myers, 1999*; Krapež and McNaughton, 1999; Pirajno et al., 2000; Sheppard and Occhipinti, 2000; Sheppard et al., 2003; Martin et al., 2005). The style, grade, and significance of metamorphism during the D_{1n} to D_{3n} events of the Capricorn Orogeny are difficult to define because peak metamorphic assemblages have been widely retrogressed during subsequent orogenic events. However, deformation and metamorphism were probably related to the main intrusive pulses of the Moorarie Supersuite.

D_{1n} and D_{3n} were relatively localized events, being restricted to the southern and central parts of the province, respectively, whereas D_{2n} appears to have been the main tectonothermal episode, affecting most of the province. In the Yarlarweelor Gneiss Complex (Fig. 3) there is a clear distinction between D_{1n} and D_{2n}. The first event D_{1n} is also present in the Paradise Zone and southern part of the Mooloo Zone. It is characterized by pervasive reworking of Archean granites, gneisses, and supracrustal rocks at medium to high grade. The age is constrained to between 1805 and 1800 Ma (Sheppard and Swager, 1999; Occhipinti and Myers, 1999; Sheppard and Occhipinti, 2000) as intrusions of variably deformed Dumbie Granodiorite dated at 1811–1804 Ma are cross-cut by undeformed plutons and dykes of the 1800–1796 Ma Scrubber Granite.

The second event D_{2n}, which was the most pervasive, is present in most zones of the province (Fig. 3). In the Yarlarweelor Gneiss Complex and Errabiddy Shear Zone D_{2n} is characterized by reactivation of discrete faults or shear zones at low to medium grade (Sheppard and Swager, 1999; Occhipinti and Myers, 1999; Sheppard and Occhipinti, 2000). In the Errabiddy Shear Zone garnet–sillimanite-bearing pelitic and psammitic schists of the Camel Hills Metamorphics were retrogressed to chlorite–sericite schists. The age of this event in the Yarlarweelor Gneiss Complex and Errabiddy Shear Zone is poorly constrained, but affected variably deformed monzogranite dykes of the Moorarie Supersuite, one of which is dated at c. 1795 Ma.

* The D_{1n} and D_{2n} events were referred to respectively as 'D_{2n}' and 'D_{3n}' by Sheppard and Swager (1999) and Occhipinti and Myers (1999). These authors identified a 'D_{1n}' event, which was subsequently assigned to the Glenburgh Orogeny (Sheppard and Occhipinti, 2000).

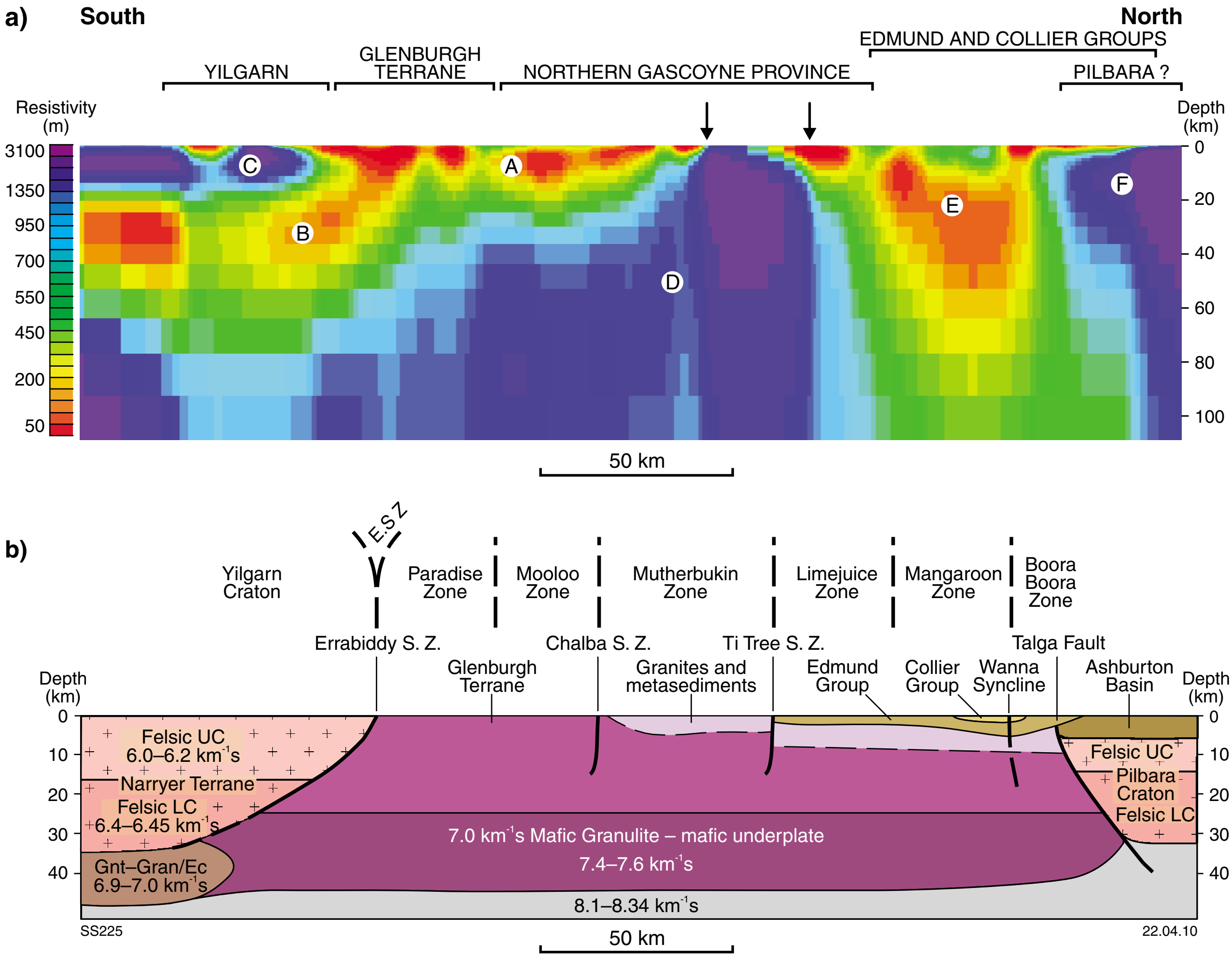

Figure 5. **a) 2D model of magnetotelluric data collected from a traverse across the Gascoyne Province (Selway, 2008; Selway et al., 2009). The low resistivity features A, B, and E are interpreted to represent the Glenburgh Terrane. Note that the Glenburgh Terrane dips southward at B, under the Yilgarn Craton at the location of the Errabiddy Shear Zone. However, subduction of oceanic crust prior to the collision of the Yilgarn Craton and Glenburgh Terrane during the 2005–1950 Ma Glenburgh Orogeny was to the north under the Glenburgh Terrane. The Yilgarn (C) and Pilbara (F) Cratons are regions of high resistivity. The highly resistive area apparent at D (between the two arrows) is an artifact of the data, resulting from the loss of data in stations in this area. For more details on the modelling parameters and interpretation of data see Selway (2008) and Selway et al. (2009); b) Composite cartoon cross section through the Gascoyne province, combining the magnetotelluric and passive seismic geophysical data from Selway (2008) and Drummond (1981), respectively. Gnt-Gran/Ec = garnet granulite to eclogite. Both the MT and geophysical cross sections are at the same scale.**

In the northern part of the Mooloo Zone on southern Yinnetharra and Pink Hills, abundant intrusions of Dumbie Granodiorite are undeformed. In the basement rocks M_{2n} metamorphism was of low grade and mainly responsible for the wholesale destruction and retrogression of high-grade metamorphic assemblages formed during the Glenburgh Orogeny (Johnson et al., 2010). Predominant garnet–sillimanite-bearing pelitic and psammitic schists of the Moogie Metamorphics were retrogressed to chlorite–sericite- and chloritoid-bearing schists. The widespread presence of chloritoid as a stable phase (pseudomorphing garnet and as a matrix phase) in both pelitic and psammitic rocks (Spear and Cheney, 1989) throughout the northern Mooloo Zone indicates that metamorphism in this part of the province peaked at 425–500°C and at relatively low pressures (less than about 4 kbar). Detrital zircon extracted from a quartz–chlortite–sericite psammitic schist of the Moogie Metamorphics on the southern part of Lockier were partially recrystallized during this event. A single metamorphic zircon rim dated at 1788 ± 12 Ma (1σ) was interpreted as the time of low grade metamorphism M_{2n} coincident with the D_{2n} episode (Johnson et al., 2010).

Within the Mutherbukin Zone, the effect of the Capricorn Orogeny ($D_{1–3n}$) is difficult to distinguish due to the intense structural and metamorphic overprints induced during the Mutherbukin Tectonic Event and Edmundian Orogeny. However, detrital zircon extracted from quartzites of the Moogie Metamorphics in the northwestern part of Yinnetharra, have been partially recrystallized. New metamorphic zircon as growths around around older grains have been dated (U–Pb) by SHRIMP at 1772 ± 6 Ma (Johnson et al., 2010). However, the lack of associated

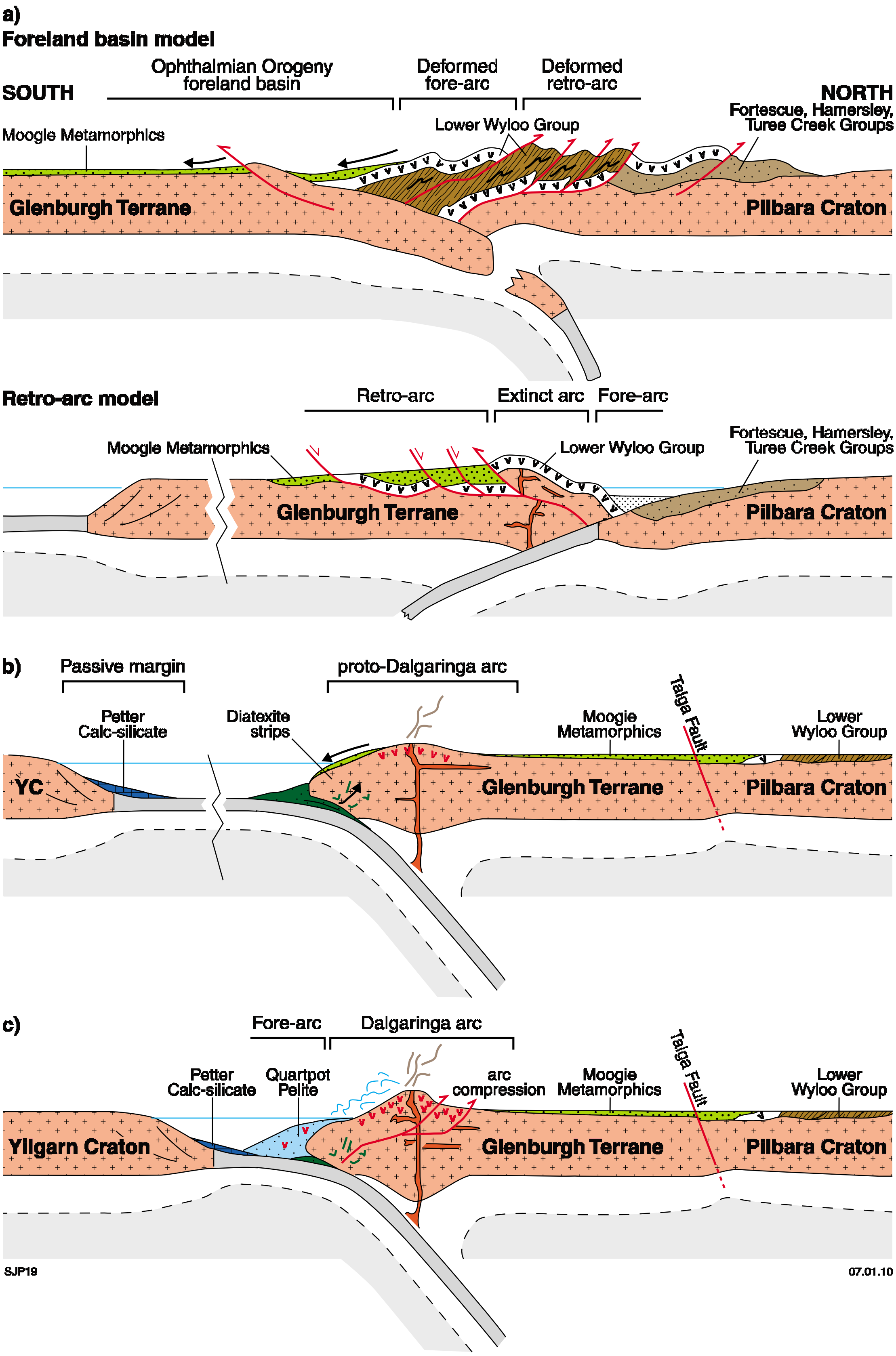

Figure 6. Cartoon cross sections for the evolution of the southern margin of the Glenburgh Terrane. a) Provenance of the Moogie Metamorphics between 2240–2125 Ma. Two tectonosedimentary models are illustrated — a foreland basin model and a retro-arc model; b) provenance of the diatexite strips within the Dalgaringa Supersuite and the Petter Calc-silicate at 2080–2000 Ma; and c) provenance of the Quartpot Pelite at 2000–1985 Ma, during D_{1g} deformation and metamorphism. Sections after Johnson et al., (2010).

tectonic fabrics in these rocks make it difficult to determine if this age dates low-grade metamorphism associated with D_{2n} or D_{3n} event.

On northern Pink Hills in the Limejuice Zone, pelitic rocks of the Leake Spring Metamorphics contain relict gneissic fabrics and contain a lower-greenschist retrograde mineral assemblage (M_{3n}) that replaced a former higher grade granoblastic M_{2n} assemblage of garnet–sillimanite–?cordierite–biotite–quartz, suggesting that middle to upper amphibolite facies conditions were reached during the D_{2n} event. Strongly deformed to mylonitized granites of the Middle Spring Granite, contain similar high-grade fabrics to those in the adjacent Leake Spring Metamorphics. A moderately deformed portion of the Middle Spring Granite has been dated at 1788 ± 7 Ma. This unit is intruded by undeformed, but magmatically layered granites of the Rubberoid Granite, two samples of which have been dated to 1791–1786 Ma. These results suggest that high-grade deformation and metamorphism accompanied intrusion of the Middle Spring Granite, and that D_{2n} in the Limejuice Zone was synchronous with emplacement of the earliest parts of the Minnie Creek Batholith at c. 1790 Ma.

The effects of the D_{3n} event are only present (or preserved) in the Limejuice Zone where the high-grade D_{2n} gneissic fabrics are folded about upright fold hinges into local- and regional-scale close to isoclinal folds with the production of a crenulation schistosity parallel to the axial surfaces of the folds. Associated M_{3n} metamorphism appears to have been low-grade and was responsible for the downgrading and retrogression of the amphibolite facies M_{2n} metamorphic assemblage. There are no direct age constraints on D_{3n}, although c. 1770 Ma metamorphic zircon present in quartzites of the Moogie Metamorphics in the northern part of the Mutherbukin zone may date M_{3n} rather than M_{2n}.

The Capricorn Orogeny has been widely interpreted as the result of oblique collision of the Yilgarn and Pilbara Cratons (e.g. Tyler and Thorne, 1990; Evans et al., 2003), but Sheppard (2004) suggested that there are a number of features lacking in the observed rock associations and geochronological data that are at odds with the collisional model. These include a lack of volcanic or volcaniclastic rocks in the Leake Spring Metamorphics, no evidence of magmatism leading up to the supposed collision, and the composition of the Moorarie Supersuite granites, which is indicative of crustal recycling. These arguments are expanded upon by Sheppard et al. (2010). Therefore we propose that the Capricorn Orogeny is an intracontinental reworking event that may reflect the far-field effects of plate collisions elsewhere in the supercontinent of Nuna (Columbia) that the West Australian Craton may have belonged (e.g. Rogers and Santosh, 2002; Evans and Raub, 2008). Metamorphism associated with the orogeny appears to be a thermal response to the input of stocks and plutons (many of which were syn-tectonic) of Moorarie Supersuite granites, especially those of the Minnie Creek batholith.

The Mangaroon Orogeny

At c. 1700 Ma, siliciclastic sedimentary protoliths of the Pooranoo Metamorphics were deposited across most of the Gascoyne Province (Fig. 4c). A well-defined stratigraphy consisting of fluvial conglomerate and sandstone overlain by shallow-marine sandstone lies at the base. This is known as the Mount James Subgroup, which is up to 700 m thick. These rocks are present from the Errabiddy Shear Zone through to the Limejuice Zone (Fig. 3). In the northern part of the Limejuice Zone, and in the Mangaroon Zone, these rocks grade upwards into turbiditic sandstone, siltstone, and shale that appear to mark a deepening of the basin to the north. SHRIMP U–Pb geochronology of detrital zircons from the Mount James Subgroup indicate that these sediments were deposited after c. 1760 Ma but prior to deformation and intrusion of Durlacher Supersuite granites at c. 1670 Ma. The depositional age of the turbiditic rocks in the Mangaroon Zone is well constrained by the youngest detrital zircon population at 1680 ± 13 Ma and granite plutons that intruded the metasedimentary rocks at 1677 ± 5 Ma (Sheppard et al., 2005).

Granitic magmas of the Durlacher Supersuite were intruded across much of the province, but are particularly voluminous within the Mangaroon and Mutherbukin Zones, and in the Yarlarweelor Gneiss Complex (Fig. 4c). In the Mangaroon Zone, the supersuite comprises biotite- and muscovite-bearing monzogranite, granodiorite, and syenogranite, and some muscovite–tourmaline(–biotite) monzogranite. South of the Limejuice Zone, the granitic intrusions comprise biotite monzogranite and biotite–muscovite monzogranite and syenogranite.

During the Mangaroon Orogeny, pervasive medium- to high-grade metamorphism and deformation appear to have been confined to the Mangaroon Zone (Fig. 3). Elsewhere in the province, and in the Yarlarweelor Gneiss Complex (Sheppard and Swager, 1999), deformation may have consisted of fault and shear zone reactivation. There is also Ar–Ar age determinations that provide evidence of fault and shear zone reactivation during the Mangaroon Orogeny in northern and eastern parts of the Capricorn Orogen (Sheppard et al., 2006; Pirajno et al., 2009).

In the Mangaroon Zone, the Mangaroon Orogeny encompasses complex and progressive deformation and metamorphism, and has been divided into two deformation and metamorphic ‘events’ (D_{1m} and D_{2m}) which were probably broadly associated with intrusion of voluminous granite plutons of the Durlacher Supersuite. During D_{1m}, the Pooranoo Metamorphics were metamorphosed in the amphibolite to upper amphibolite facies with the production of gneissic fabrics and extensive melting of pelitic and semi-pelitic rocks, although the grade of metamorphism appears to be lower in the northern half of the Mangaroon Zone where migmatites are less common. The D_{2m} event appears to have immediately followed the D_{1m} event, and was responsible for the production of a pervasive schistosity, metre- to kilometre-scale upright folds, and retrogression of D_{1m} metamorphic minerals to greenschist facies assemblages. Many granites of the Durlacher Supersuite with igneous crystallization ages of c. 1675 Ma or older were deformed during D_{2m}. Hence this is a minimum age constraint for D_{2m}.

The northern and central parts of the Gascoyne Province have similar early geological histories (Fig. 3), suggesting that this crust is contiguous under the Mangaroon Zone. The lack of volcanic and plutonic activity immediately preceding the Mangaroon Orogeny, either within or flanking the Mangaroon Zone, also precludes the orogeny being related to closure of an ocean. Instead, the Mangaroon Orogeny represents an episode of intracontinental reworking which may be a far-field response to events along the southern convergent margin of the combined North Australian – West Australian Craton (Sheppard et al., 2005).

Mesoproterozoic sedimentation and tectonism

Following the Mangaroon Orogeny, fine-grained siliciclastic sediments and carbonates were deposited initially in the Edmund Basin and then the Collier Basin, both of which unconformably overlie the Gascoyne Province. These basins were a response to intracratonic reactivation of the Capricorn Orogen, and sedimentation (at least in the lower part of the Edmund Group) appears to have been controlled principally by the Talga Fault (Martin et al., 2008b); a major crustal structure that appears to be the principal boundary between the Glenburgh Terrane and Pilbara Craton (Selway, 2008; Selway et al., 2009). The province was intruded by dolerite dykes that may be in part equivalent to the c. 1465 Ma dolerite sills in the Edmund Basin, and the c. 1070 Ma dolerite sills and dykes of the Warakurna large igneous province (Wingate et al., 2004). East-trending dolerite dykes in the Paradise Zone may be a continuation of c. 1210 Ma and/or c. 1070 Ma dykes intruded into the northwestern Yilgarn Craton (Wingate et al., 2005; Fig. 3).

Mutherbukin Tectonic Event

Along the northern edge of the Mutherbukin Zone on Eudamullah and Mount Sandiman, garnet–staurolite schists belonging to the Leake Spring and Pooranoo Metamorphics contain a well-developed, medium-grade, crenulation schistosity. Monazite that grew parallel to relict, folded S_{1u} fabrics within garnet and staurolite porphyroblasts yield consistent U–Pb ages of c. 1280 Ma (GSWA, unpublished data), whereas those within the main S_{2u} fabric give ages of c. 1250 Ma (GSWA, unpublished data). The main S_{2u} fabric elsewhere in the Mutherbukin Zone is represented as a pervasive tectonic foliation to gneissic banding, and is especially well developed in metagranitic rocks of the Durlacher and Moorarie Supersuites that dominate the Mutherbukin Zone. Preliminary SHRIMP U–Pb geochronology on metamorphic titanite from within strongly deformed metamorphosed alkaline granites (Tetlow Granite) have confirmed the age of the regional metamorphism and development of the regional-scale fabric to be c. 1250 Ma (GSWA, unpublished data).

The extent and significance of this event is unknown, primarily because it is difficult to differentiate their associated structures from similar grade schists to the southeast, whose fabrics are in apparent structural continuity (i.e. subparallel). Monazite in this similar fabric has been dated at 1030–995 Ma (Sheppard et al., 2007), indicating that it is associated with the younger Edmundian Orogeny.

Edmundian Orogeny

The latest Mesoproterozoic to earliest Neoproterozoic Edmundian Orogeny is best known for widespread folding and low-grade metamorphism of the Edmund and Collier Groups (Martin and Thorne, 2004). This event is also partly responsible for the prominent array of anastomosing structures present on small-scale maps and aeromagnetic images of the Edmund and Collier Groups and Gascoyne Province. SHRIMP U–Pb geochronology of monazite and xenotime from pelitic schists in the Mutherbukin Zone suggests that the Edmundian Orogeny was also responsible for reworking a southeast-striking corridor between the Chalba and Ti Tree Shear Zones (Figs 2 and 3), particularly in the Nardoo Hills area. Within this zone, garnet and staurolite or garnet and andalusite porphyroblasts were developed in pelitic and semi-pelitic rocks of the Leak Spring Metamorphics, Pooranoo Metamorphics, and Edmund Group (Fig. 3).

In rocks of the Gascoyne Province, three events (D_{1e}, D_{2e}, and D_{3e}) have been attributed to the Edmundian Orogeny, although it is not clear how these relate to the three Edmundian events (D_{1e}, D_{2e}, and D_{3e}) identified in the Bangemall Supergroup (Martin and Thorne, 2004). The first event in the Gascoyne Province (D_{1e}) is only preserved as inclusion trails within metamorphic porphyroblasts that formed during the D_{2e} event. Kilometre-scale upright folds and a crenulation schistosity that folds the earlier D_{2e} fabrics, characterize the D_{3e} event. Monazite and xenotime that grew during D_{2e} amphibolite-facies metamorphism along the northern margin of the Mutherbukin Zone, on southern Mount Phillips and northern Yinnetharra, have been dated at 1030–995 Ma (Sheppard et al., 2007; Mineral Distribution Figures). Sheppard et al., (2007) estimated pressure–temperature conditions of 3–5 kbar and 500–550°C for the garnet–staurolite–bearing schists. Further south in the central part of the Mutherbukin Zone, melt-filled pockets that developed within a c. 1665 Ma metamonzogranite cut the main gneissic fabrics (S_{2u}) associated with the D_{2u} event of the Mutherbukin Tectonic Event. Metamorphic zircon (as rims around older igneous cores) extracted from these melt pockets gave a precise SHRIMP U–Pb age of 1000 ± 8 Ma, contemporaneous with the monazite and xenotime ages. The older monazite result recorded in the pelitic schists (c. 1030 Ma) may date the earlier fabric that formed during D_{1e} (Sheppard et al., 2007). Upright folding and a schistosity that formed during D_{3e} is only loosely constrained to between 995 and 955 Ma (Sheppard et al., 2007), the younger limit defined by a rare-element pegmatite that cuts the crenulation schistosity.

Porphyritic metamonzogranites, rare-element pegmatites, and leucocratic tourmaline-bearing granites of the Thirty Three Supersuite were intruded during (and after?) the Edmundian Orogeny, and are currently only known from the northern part of the Mutherbukin Zone (Figs 2–3).

On northern YINNETHARRA and southern MOUNT PHILLIPS, foliated porphyritic granites and pegmatites intruded the garnet–staurolite schists after development of the main composite S_{1e}–S_{2e} fabric, but are deformed and overprinted by the S_{3e} fabric and folded about F_{3e} folds (i.e. post D_{2e}, pre D_{3e}). Several undeformed granite plutons, including the 'Gurun Gutta granite' (Sheppard et al., 2007) cut all of the medium-grade fabrics (S_{1e}–S_{3e}) related to the Edmundian Orogeny (Sheppard et al., 2007). These granites are typically leucocratic and are locally tourmaline-rich; they also have low concentrations of the immobile trace elements (e.g. Zr <125 ppm). Several of these plutons had been selected for U–Pb zircon dating but yielded only xenocrystic zircons, with the population in the Gurun Gutta granite dated at 1652 ± 4 Ma (Varvell, 2001). Within the other leucocratic granites dated by GSWA, the main xenocrystic population indicated U–Pb dates at c. 1665 Ma. Reconnaissance SHRIMP U–Pb geochronology of magmatic monazite from a leucocratic granite provides a preliminary age of c. 910 Ma (GSWA, unpublished data), interpreted as the time of igneous crystallization. Monazite from an undeformed rare-element pegmatite (part of a series of beryllium and tantalum–niobium pegmatites) from the same belt yielded a $^{207}Pb/^{206}Pb$ age of c. 955 Ma (Sheppard et al., 2007) suggesting a relatively long time period for intrusion of this granitic supersuite. However, it is not clear whether this age range represents a single period of protracted magmatism or several discrete pulses of intrusion.

The interval between 1050 and 1000 Ma is thought to mark assembly of the Rodinia supercontinent (e.g. Li et al., 2008, and references therein), of which the Australian continent may have been an integral part. Collision between the eastern margin of Australia and a part-assembled Rodinia is estimated at c. 1000 Ma (Li et al., 2008), the timing of which coincides with the growth of peak metamorphic phases during the Edmundian Orogeny. In all reconstructions of Rodinia (e.g. Pisarevsky et al., 2003; Li et al., 2008), the western margin of Australia (in modern coordinates), namely the West Australian Craton, is shown to face an open ocean. If so, then deformation and metamorphism associated with the Edmundian Orogeny may have been a response to plate reorganization and collisions elsewhere in Rodinia since no other impinging crustal block was present to the west.

900–850 Ma event

A preliminary SHRIMP U–Pb study of in situ monazite and xenotime in thin sections from low-grade Edmund Group slates within the Ti Tree Syncline (Limejuice Zone) has indicated dates of 900–850 Ma (GSWA unpublished data). These results are similar to several $^{40}Ar/^{39}Ar$ mica dates (960–820 Ma) obtained on various rock units from the Errabiddy Shear Zone and southern Gascoyne Province (Occhipinti, 2007). Although the extent and significance of the 900–850 Ma event has yet to be fully determined, it may represent a period of extensive low-temperature (<325°C), fault and shear zone reactivation that resulted in exhumation of parts of the province (Occhipinti, 2007; Sheppard et al., 2007).

Mulka Tectonic Event

Rocks of the Gascoyne Province and Bangemall Supergroup, between the northeastern side of the Cobra Syncline and the Chalba Shear Zone (Fig. 2), are cut by a network of anastomosing shear zones and brittle–ductile faults. These commonly have well-developed dextral strike-slip shear-sense indicators, and they produced dextral offsets of dykes of the c. 755 Ma Mundine Well Dolerite Suite (Fig. 7). White mica on both the C-planes and S-planes of an S–C fabric within the Chalba Shear Zone was dated in situ (via infra-red laser) using the $^{40}Ar/^{39}Ar$ method. Coarse-grained C-plane crystals yielded variable dates that probably reflect excess Ar and partial resetting, whereas fine-grained S-plane material yielded a single date of 570 ± 10 Ma (Bodorkos and Wingate, 2007). This result is consistent with the field relationships of the shear zones, which cut c. 755 Ma dolerite dykes. The dextral shear zones represent an episode of intracontinental reactivation, the timing of which coincides with other 'pan-African' events related to the assembly of the Gondwana supercontinent (e.g. Meert 2003; Johnson et al., 2005; Collins and Pisarevsky 2005).

Architecture

Utilizing field mapping and geochronology, the Gascoyne Province has been divided into eight structural-metamorphic zones largely bounded by east-southeasterly trending faults or shear zones (Figs 2–3; Table 1). Although each zone is characterized by a distinctive and episodic history of deformation, metamorphism, and granitic magmatism, the zones are *not* exotic terranes. The most important of the zone-bounding structures are the Talga Fault (mostly unexposed), Minga Bar Fault, Ti Tree Shear Zone, the Chalba Shear Zone, and the Errabiddy Shear Zone (Figs 3 and 8). The attitudes, depth extents, and kinematic histories of these structures are not well known, particularly for the Minga Bar Fault.

The magnetotelluric (MT) survey conducted in the western Capricorn Orogen showed a clear electrical contrast between the Gascoyne Province and Yilgarn Craton across the Errabiddy Shear Zone, which dips about 45° to the south (Fig. 5a; Selway, 2008; Selway et al., 2009). The magnetotelluric data also show a clear electrical distinction between the Glenburgh Terrane and Pilbara Craton across a vertical or steeply north-dipping structure roughly coincident with the Talga Fault (Fig. 5a; Selway et al., 2009). The exotic nature of the Glenburgh Terrane, relative to the Pilbara and Yilgarn Cratons, is also supported by a study of P-wave tomography in northwestern Australia (Abdulah, 2007). Maps of P-wave seismic perturbation at 35 km depth (Abdulah, 2007) show a wedge-shaped region of slow velocities corresponding to the Glenburgh Terrane, with sharp boundaries to regions of higher velocity of the Pilbara and Yilgarn Cratons. These boundaries coincide with the locations of sutures identified from surface studies and the magnetotelluric survey. Figure 5b shows a summary cross-section across the Gascoyne Province, integrating results from surface studies with MT modelling and published passive seismic data.

The Minga Bar Fault

The Minga Bar Fault (Figs 2, 4c) separates Moorarie Supersuite granites of the Minnie Creek batholith, that were statically metamorphosed at upper greenschist to epidote–amphibolite facies during the Mangaroon Orogeny, from migmatites and gneisses that were strongly deformed and metamorphosed at upper amphibolite facies conditions during the Mangaroon Orogeny. The fault is largely unexposed, but is a prominent feature on small-scale aeromagnetic images and appears to be a major crustal structure as is defined on an aeromagnetic 1000 m upward continuation model (Fig. 8).

Adjacent to the Minga Bar Fault on the western edge of Mangaroon, porphyritic biotite monzogranite of the Minnie Creek batholith is moderately to strongly foliated. Phyllonites derived from this porphyritic biotite monzogranite are juxtaposed against unmetamorphosed, weakly strained, and openly folded Edmund Group sandstones by the Minga Bar Fault, suggesting that the majority of deformation in the shear zone must have predated deposition of the Edmund Group: that is, older than c. 1620 Ma. Therefore, deformation in the Minga Bar Fault is most likely related to the Mangaroon Orogeny.

The general absence of a stretching lineation suggests that the rocks underwent non-rotational strain. Locally, a steeply dipping stretching lineation defined by biotite or chlorite is developed, and is associated with asymmetric K-feldspar porphyroclast tails implying southwest-side-up on steep normal or reverse faults.

The Ti Tree Shear Zone

The Ti Tree Shear Zone (Figs 2–4 and 8) is a major Meso- to Neoproterozoic structure that separates similar aged rocks of contrasting metamorphic grade. In the northern part of the Mutherbukin Zone, on the southern side of the Ti Tree Shear Zone, pelitic and semi-pelitic schists of the Pooranoo and Leake Spring Metamorphics were metamorphosed in the amphibolite facies. These schists widely developed staurolite and garnet porphyroblasts and peak pressure–temperature conditions have been estimated at 3–5 kb and 500–550°C (Sheppard et al., 2007). On the northern side of the Ti Tree Shear Zone, the same packages of pelitic and semi-pelitic schist were only metamorphosed in the lower to mid greenschist facies (Fig. 3). Further south on southern Pink Hills, on the southern side of the Ti Tree Shear Zone, rocks belonging to the upper parts of the Edmund Group developed abundant andalusite and garnet porphyroblasts. Peak pressure–temperature conditions were only slightly lower than those further north (<3 kbar and <550 °C). Elsewhere in the Gascoyne Province, rocks of the Edmund and Collier Groups have only been metamorphosed to the lowermost greenschist facies.

Throughout the Mutherbukin Zone, metamorphism was accompanied by deformation with the development of anastomosing, ductile shear zones and regional-scale tight to isoclinal folds. In contrast, on the northeastern side of the Ti Tree Shear Zone, in the Limejuice Zone, Edmundian-aged metamorphism peaked in the lower greenschist facies and was accompanied by brittle to brittle–ductile faults and open to tight folds, as observed throughout the Edmund and Collier Groups. The contrast in metamorphic regimes on either side of the shear zone (at least in the northern part of the Mutherbukin Zone) suggests that there has been at least 5 km of vertical displacement on this fault. The Ti Tree Shear Zone is parallel to the kilometre-scale upright folds that formed during the D_{3e} event, but truncates metamorphic assemblages (essentially isograds) that formed during D_{2e}, suggesting that at least some of this exhumation may have occurred during the latter stages of the Edmundian Orogeny. However, preliminary metamorphic monazite dates obtained from greenschist facies Edmund Group slates within the Ti Tree Syncline indicate that low grade metamorphism and fault reactivation took place at 900–850 Ma. It is possible that some of the 5 km vertical displacement on the Ti Tree Shear Zone may have occurred during this (or subsequent) reworking event(s).

The co-planar nature of these successive faulting and shearing events with the Ti Tree Shear Zone, and the multiple reworking events recorded in the Mutherbukin Zone (Fig. 3), indicate that this region represents an inherently weak part of the Gascoyne Province crust and that the Ti Tree Shear Zone is located above, or forms part of, a major crustal structure (Fig. 8). The original attitude of the Ti Tree Shear Zone is unclear but in order to bury the Pooranoo Metamorphics and Leake Spring Metamorphics to depths equivalent to at least 3–5 kb (i.e. ~7–12 km), this shear zone may have been a thrust during the Edmundian Orogeny.

The Chalba Shear Zone

The Chalba Shear Zone (Fig. 2) is a 5–10 km-wide zone of interlinked brittle to brittle–ductile faults that primarily record dextral strike-slip movements during the c. 570 Ma Mulka Tectonic Event (Figs 3 and 7). However, it may have been active during the Edmundian Orogeny and the Mutherbukin Tectonic Event. The Chalba Shear Zone does not separate rocks of contrasting age or metamorphic grade and appears to have been predominantly strike-slip in character, developed at relatively low metamorphic grade. All faults currently have a steep attitude and are distinguished from older faults where they offset dolerite dykes of the c. 755 Ma Mundine Well Dolerite Suite. Because these dykes are readily apparent on both aeromagnetic and Landsat images, they can be used as markers to estimate the movement displacements on individual faults or collectively as a regional-scale fault system.

Mulka-aged faults are present across the province where individual faults have a dextral offset generally in the order of 10–100 m; however, these faults are particularly concentrated within discrete corridors such as the Chalba Shear Zone (Fig. 7) and within the Ti Tree Syncline. An estimate of fault offsets across the region (Fig. 7c) shows that not only can displacements across individual faults in these zones be as large as 1–4 km, but smaller-scale movements in the order of 100–500 m across a greater density of faults leads to significant cumulative regional-

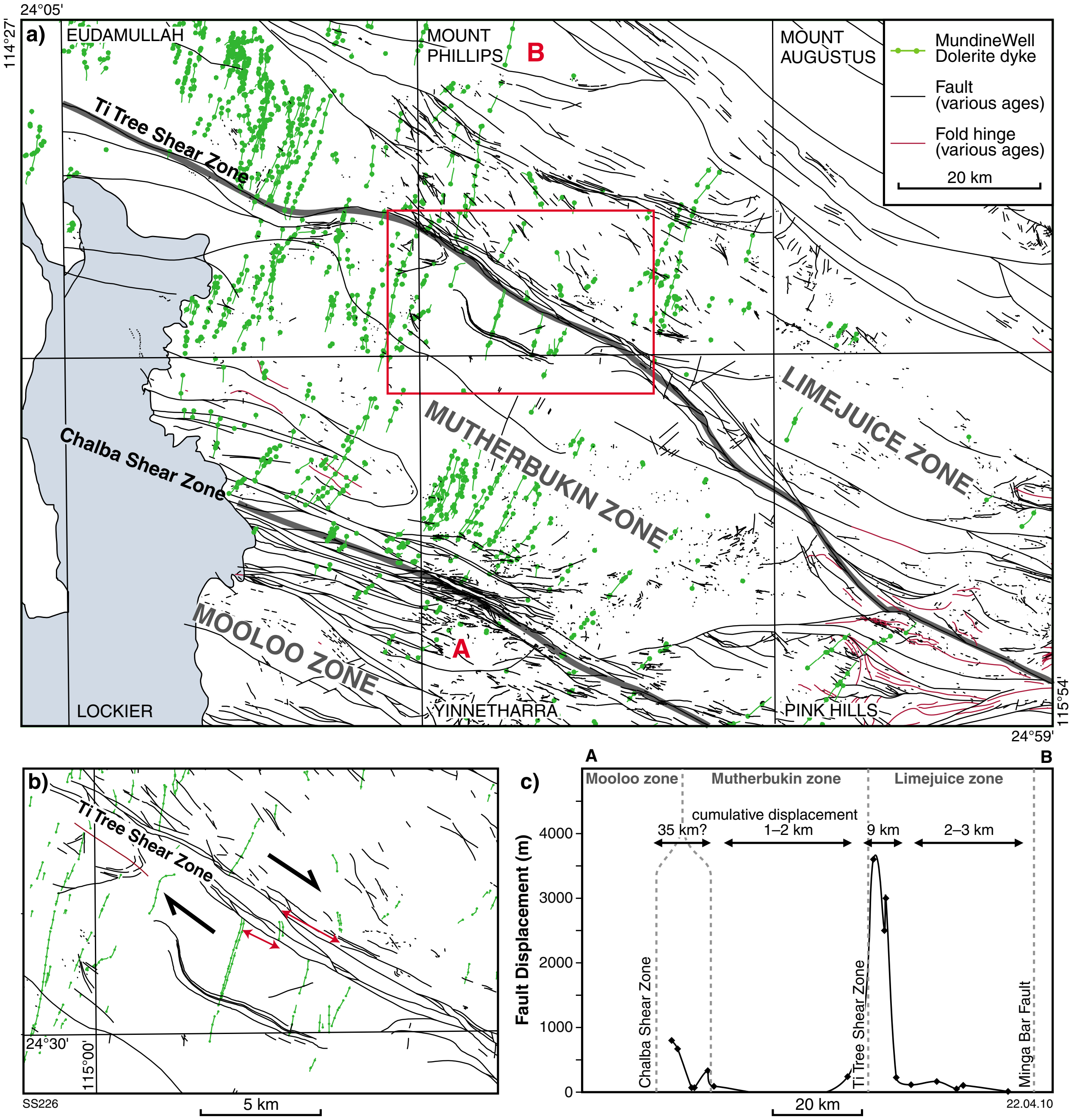

Figure 7. a) Map of the central part of the Gascoyne Province showing Mulka-aged (c. 570 Ma) fault displacements on c. 755 Ma Mundine Well Dolerite Suite dykes. Location of b) is shown by the highlighted box. The location of the calculated fault offsets along A and B in graph (c) is shown in the main map.

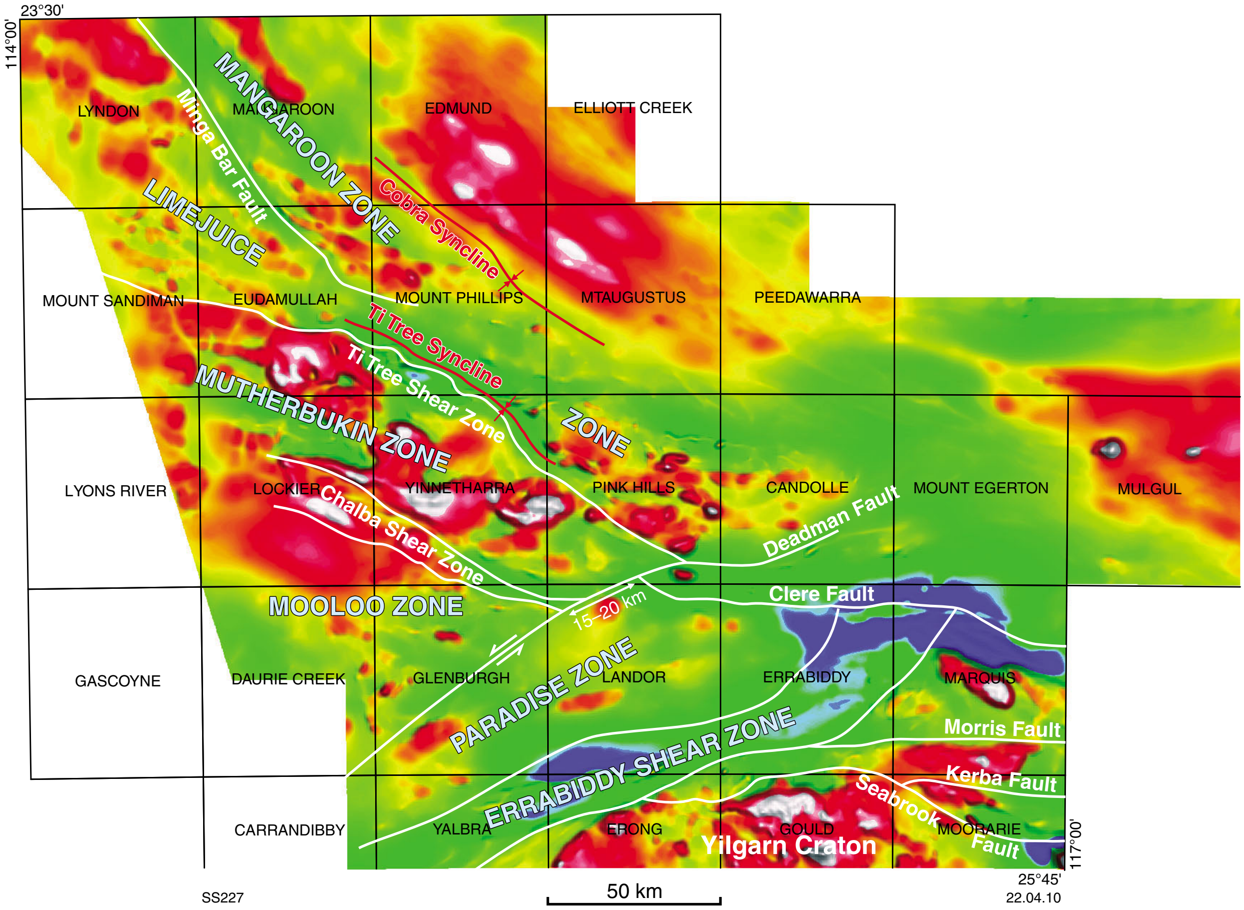

Figure 8. 1000 m upward continuation model of reduced to pole (RTP) regional-scale (500 m line spacing) aeromagnetic data over the Gascoyne Province, showing the location of the major surficial faults.

scale displacements. Directly north of the Ti Tree Shear Zone, a relatively low density of faults is observed compared with the area further to the north (Fig. 7a,b). Nevertheless, each of these faults has a large displacement resulting in a regional dextral cumulative displacement of about 9 km across a zone roughly 5 km wide (Fig. 7c). In the Limejuice Zone to the north and the Mutherbukin Zone to the south, much smaller cumulative regional dextral movements of 2–3 km across 25 km and 1–2 km across 35 km, respectively, are estimated from offsets of the Mundine Well dykes (Fig. 7c). Fault displacements are much more difficult to determine in the Chalba Shear Zone because there are considerably fewer dolerite dykes on which to calculate the movements. On a regional scale, the Mundine Well Dolerite Suite appears to terminate against the northern margin of the Chalba Shear Zone and this may be due to the dyke swarm, within and to the south of the shear zone, having been dextrally displaced toward the west under the Southern Carnarvon Basin (western part of Lockier and Lyons River). Such a scenario would imply a regional displacement in the order of ~35 km or more.

Because of the high density of faults within the Chalba Shear zone, relatively small displacements in the order of 250–500 m (in comparison to those directly north of the Ti Tree Shear zone), could adequately account for the large cumulative regional displacement. Although the density of Mundine Well Dolerite dykes present in the Chalba Shear Zone is very low, faults displacements were still able to be calculated. Individual fault displacements in the order of 250–750 m have been estimated (Fig. 7c). The localization of Mulka-aged strain within discrete corridors bounding the northern and southern limits of the Mutherbukin Zone again demonstrates that this part of the Gascoyne Province crust is inherently weak and the Chalba Shear Zone is a deep-rooted structure, as is evidenced on the aeromagnetic 1000 m upward continuation model (Fig. 8). It is possible that the Chalba Shear Zone overprints a much older structure, for which there is now no evidence.

On the northwestern part of Landor (Sheppard and Occhipinti, 2000), faults belonging to the Mulka Tectonic Event appear to have been sinistrally offset by 15–20 km across a single discrete fault known as the Deadman Fault (Fig. 8). The age of this fault is not precisely known but it may relate either to late stages of the Mulka Tectonic Event or be related to Phanerozoic extensional processes that allowed the deposition within the Southern Carnarvon Basin to the west.

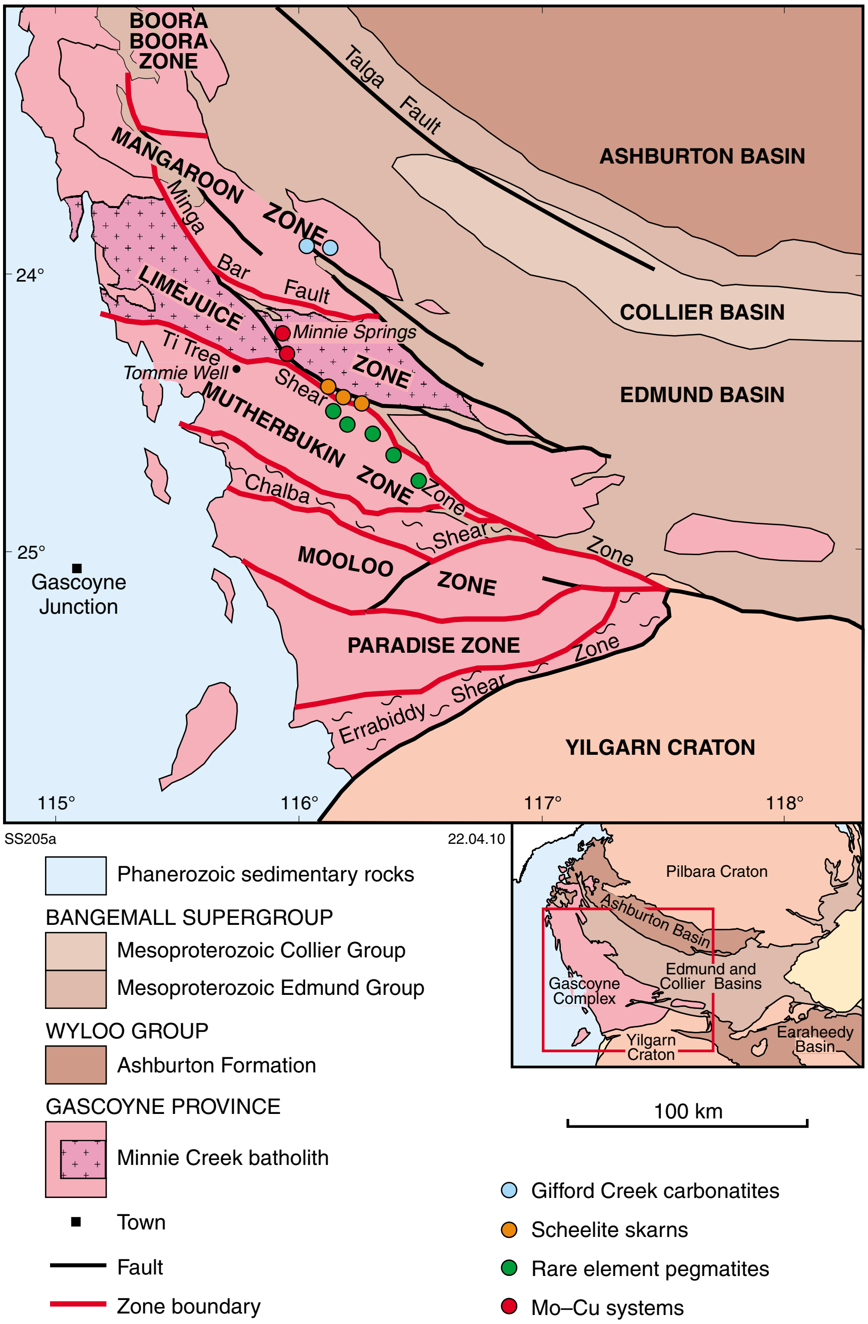

Figure 9. Location of the main mineral deposits in the Gascoyne Province, after Pirajno et al. (2009).

Mineral systems

The Gascoyne Province has traditionally been thought of solely as a Paleoproterozoic entity, but it is now clear that the province has an extended history of reworking and reactivation (Sheppard et al., 2008), which needs to be taken into account during mineral exploration. We suggest Mesoproterozoic to Neoproterozoic reworking events represent a dominant mechanism for metallogenesis in the Gascoyne Province.

Paleoproterozoic

Granites of the 1820–1775 Ma Moorarie Supersuite at the northern end of the province are associated with tungsten–skarn mineralization (Davies, 1998). In the Minnie Creek batholith, at the Minnie Springs prospect (Fig. 9), leucocratic monzogranite hosts molybdenum (copper, tungsten) mineralization which has been interpreted as both porphyry style (Sullivan, 1996) and 'intrusion-related greisen Mo–Cu–W system' (Pirajno et al., 2008, in prep.). Two styles of molybdenum mineralization have been recognized: a disseminated molybdenite mineralization, associated with pervasively greisenized granite (quartz–phengite), which is cut by quartz veins that host molybdenite flakes. The former has been dated at 1773 ± 6 Ma using Re–Os geochronology (GSWA unpublished data), which is within error of the youngest dated phases of the Minnie Creek batholith dated at 1790–1780 Ma. The molybdenite hosted in quartz veins, also dated using Re–Os, yield an age of 726 ± 11 Ma (GSWA, unpublished data). This age may be related to movements along the Ti Tree shear zone, which resulted in localized redistribution of the molybdenite in quartz veins.

Mesoproterozoic and Neoproterozoic

Carbonatite rocks comprising the Gifford Creek Carbonatite Complex (Fig. 9; formerly the Gifford Creek Complex; Pearson et al., 1995) are associated with REE, U, and iron-oxide mineralization (Pearson, 1996; Pearson et al., 1996; Pirajno et al., in prep.) and are intruded parallel to Mangaroon Orogeny aged structures. Locally these rocks intrude the base of the Edmund Group, which is consistent with limited geochronological data suggesting Meso- and Neoproterozoic igneous crystallization ages (Pearson, 1996). The igneous complex, renamed Gifford Creek Carbonatite Complex (Pirajno et al., in prep.), is accompanied by widespread alkaline metasomatism (fenitization) (Pearson, 1996; Pirajno et al., 2008). Petrographic, SEM, and XRD analyses of carbonatite and associated fenitic rocks have revealed the presence of barite, apatite, pyrochlore, celestite, monazite, and ferrocolumbite (Pirajno et al., in prep.). Fenitic alteration consists of variable amounts of orthoclase (locally forming monomineralic orthoclasite), albite, lamprophyllite, cancrinite, nepheline, sodalite, aegirine, arfevdsonite, and riebeckite. Fenitic rocks typically form irregular zones surrounding the carbonatites, but also form veins and veinlets in Pimbyana and Yangibana granites. The hematite–magnetite and quartz veins, in places altered to massive goethite, have sinuous or arcuate shapes and are associated with fenitic alteration.

Rare earth element and uranium mineralization has been recorded in the carbonatite and iron oxide veins. Flint and Abeysinghe (2000) estimated total resources of about 2.77 Mt, averaging 1.52% REE oxides.

Emplacement of the carbonatite complex is probably related to shearing and faulting during the Edmundian Orogeny, and may be associated with deep melting, thinning and erosion of the lithosphere (Foley, 2008).

Farther south in the Mutherbukin Zone, abundant Be–Nb–Ta-bearing pegmatites appear to be spatially associated with granites of the Thirty Three Supersuite (Fig. 9). One of these pegmatites is dated at c. 955 Ma (Sheppard et al., 2007), but none of the granites have been reliably dated owing to their low Zr contents. Trautman (1992) ruled out a genetic association between these rare-element pegmatites and any known granites in the area (including what is now referred to as the Thirty Three Supersuite) on the basis of reconnaissance geochemistry of the granites. However, some granites of the supersuite have a more fractionated chemistry (GSWA, unpublished data) that may be consistent with a genetic link. The pegmatite field lacks any significant zonation in rare elements, which may reflect a lack of chemical zonation in the parent magma chamber (London, 2005, 2008; p. 167–174). In the same general area, tungsten (scheelite) skarns (tourmaline-bearing calc-silicates, dominantly with actinolite, epidote and garnet) also appear to be related to leucocratic tourmaline-bearing granites (including the 'Gurun Gutta granite') of the Thirty Three Supersuite.

As noted above, at the Minnie Springs Mo–Cu–W prospect, disseminated molybdenite dated at c. 1770 Ma has been locally remobilized into discrete quartz–molybdenite veins that are parallel to the pervasive schistosity in the Ti Tree Shear Zone (Pirajno et al., 2008). It is unclear whether these veins are related to Edmundian deformation or the reworking of Edmundian structures during the subsequent Mulka Tectonic Event. Minor shear-hosted Cu mineralization in the Gascoyne Province may be related to structures formed or reactivated during the Edmundian Orogeny or Mulka Tectonic Event. Therefore, the possibility remains that events as young as c. 570 Ma affected mineral deposits in the Gascoyne Province.

Future work and gaps in knowledge

The current program of remapping has produced a much more complete understanding of the geological history of the Gascoyne Province. This has largely come about because of access to robust and precise geochronology to accompany the remapping. Nevertheless, despite the much improved understanding, there are a number of important unresolved questions and gaps in our knowledge of the province.

Age and petrogenesis of the Thirty Three Supersuite

Granites of the Thirty Three Supersuite are leucocratic and muscovite–biotite–tourmaline bearing, characteristically with low Zr contents. They have proven difficult to date using SHRIMP U–Pb zircon geochronology. Three samples have been dated, all of which contain only xenocrystic zircon. Each sample contains an almost unimodal age distribution of zircon, with a very large peak at c. 1665 or c. 1650 Ma, strongly resembling the ages of granites from the Durlacher Supersuite. However, the tourmaline-rich nature of many of the granites suggests a source enriched in boron; that is, pelitic or semi-pelitic rocks. The inherited zircon age distributions are wholly dissimilar to the detrital zircon age spectra from the Edmund or Collier Groups (Martin et al., 2008b), indicating that burial and melting of Edmund and Collier Group sediments cannot be the source of the granites. This enigma is yet to be resolved. It is possible that these granites contain magmatic monazite, and SHRIMP U–Pb geochronology of this mineral may provide more information not only on the age range of the supersuite, but on the petrogenesis and geochemical evolution of the granites through time. Further trace element studies of accessory phases might also provide evidence for their genetic relationship to the rare element-bearing pegmatites.

Crustal architecture

The MT survey across the western Capricorn Orogen indicates that the boundary between the Glenburgh Terrane and Pilbara Craton is near-vertical, and that the Errabiddy Shear Zone dips moderately to the south (Selway, 2008; Selway et al., 2009). However, the survey was unable to reveal the attitude of any other major structures that bound the structural–metamorphic zones in the Gascoyne Province — such as the Chalba Shear Zone, Ti Tree Shear Zone, or the Minga Bar Fault — owing to a lack of electrical contrast *within* the province. Furthermore, the relatively short recording times did not enable the structure of the lithospheric mantle to be determined.

There is no information about the depth of the Minnie Creek batholith or the batholithic granites of the Durlacher Supersuite in the Mangaroon Zone. The Durlacher Supersuite granites have xenocryst age components consistent with an origin by melting of siliciclastic metasedimentary rocks of the Pooranoo Metamorphics within the zone, although the thickness of the metasedimentary rocks is unknown.

Mineral systems

The Gascoyne Province has no working mines and few historical prospects of note, aside from some small-scale, rare-metal pegmatite workings. Only a handful of prospects have been tested with diamond drilling. In any province, probably the largest impediment to effective exploration targeting is a lack of robust geochronology which, as a consequence, does not enable a reliable tectonic history to be constructed (e.g. Hronsky and Groves, 2008). When the tectonic history *is* reliably known, it is then possible to examine conceptual mineral systems models for the province, complete with proxies for the key parameters in the models (Knox-Robinson and Wyborn, 1997; McCuaig and Hronsky, 2000; Hronsky and Groves, 2008). Now that there is a robust geochronological and tectonic framework for the Gascoyne Province, the challenge is to develop targeting criteria and define the mineral prospectivity of the province using a mineral systems approach.

Age of structures and metamorphic assemblages in the Mutherbukin Zone

Along the northern edge of the Mutherbukin Zone, immediately south of the Ti Tree Shear Zone, east-southeast trending metamorphic fabrics have been dated at c. 1280 and c. 1250 Ma. These fabrics swing southeast and appear to be continuous across the Mutherbukin Zone, implying that reworking in the zone is mainly Mesoproterozoic. However similar fabrics ~25 km to the east, and apparently along strike from one of the dated localities, yield monazite dates between 1030 and 995 Ma (Sheppard et al., 2007). The spatial distribution of these two sets of unrelated fabrics remains to be clarified. Much of the Mutherbukin Zone where this could be tested is dominated by granitic rocks, which are not readily amenable to phosphate dating. Preliminary dating of metamorphic titanite from metamorphosed alkaline granitic rocks suggest that the main tectonic fabric in the Mutherbukin Zone may have formed between c. 1280 and 1250 Ma.

Dynamics of the orogenic events

The long-lived and episodic nature of intracontinental reworking and reactivation in the Gascoyne Province has destroyed most of the older kinematic indicators in the shear zones and produced widespread retrogression or overprinting of older metamorphic assemblages. Even where kinematics are preserved, it is not always clear to which tectonothermal event they belong. Very little can be said confidently about the nature of metamorphism during the Glenburgh Orogeny or the Capricorn Orogeny, and virtually nothing about their tectonic regimes: for example, whether they were transpressional, strike–slip, or some other setting.

Petrogenesis of the Moorarie Supersuite

The petrogenesis of the Moorarie Supersuite is poorly known. The supersuite outcrops across the Gascoyne Province, and in adjacent tectonic units. The whole rock initial ε_{Nd} values are reasonably uniform (-8.1 to -4.5), with those of the Minnie Creek batholith relatively more evolved (-4.2 to -1.7). Most of the granites are weakly peraluminous, biotite-bearing monzogranite and granodiorite, although there are some light rare earth element (LREE)-enriched granites (notably the Dumbie Granodiorite) and biotite–muscovite(–tourmaline) granites (notably the Scrubber Granite). Most granites of the Moorarie Supersuite contain few xenocrystic zircons, hence the contributions of various possible sources remain unknown.

The emerging paradigm for granite petrogenesis suggest the presence of a significant amount of metasedimentary material in the source regions of all granites, even those regarded as classic ‘I-types’ (e.g. Gray, 1984; Keay et al., 1997; Kemp et al., 2007). To address the petrogenesis of the Moorarie Supersuite, Hf and O isotope compositions of magmatic zircon from previously dated grains is required.

Age and provenance of the Leake Spring Metamorphics

Present constraints on the age and provenance of the Leake Spring Metamorphics are provided by only two samples, which indicate maximum depositional ages of 1840 ± 4 Ma and 1961 ± 7 Ma. A minimum age of c. 1810 Ma is provided by granites that intrude the Leake Spring Metamorphics. Several other samples, previously thought to be part of the Leake Spring Metamorphics, contain detrital zircon grains that are *younger* than the 1820–1770 Ma Capricorn Orogeny; thus indicating that they are part of a younger sedimentary package, such as the Pooranoo Metamorphics. Additional detrital zircon studies are needed to better constrain the depositional age of the Leake Spring Metamorphics, and to test whether or not they are higher-grade equivalents of the Ashburton Formation as previously suggested by regional mapping. At present, it is difficult to infer the tectonic setting in which protoliths to the Leake Spring Metamorphics were deposited.

Age of the Pooranoo Metamorphics

Protoliths to the undivided Pooranoo Metamorphics in the Mangaroon Zone were deposited at c. 1680 Ma. Farther south, from the Errabiddy Shear Zone through to the Limejuice Zone, only the Mount James Subgroup (interpreted to form the base of the Pooranoo Metamorphics) outcrops. The age constraints on the subgroup are poor: it was deposited after c. 1760 Ma and prior to c. 1680 Ma. The Pooranoo Metamorphics could be a single package, or there could be an unconformity between the Mount James Subgroup and the main package of the Pooranoo Metamorphics in the Mangaroon Zone.

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Explanatory Notes

Unnamed unit (A-mgn-YNA)

Legend narrative

Granitic gneiss; locally migmatitic

Rank	Suite
Parent	Unnamed unit (A-mg-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA

Summary

Pegmatite-banded granitic gneiss is the major component of the Narryer Terrane, which forms the northwestern part of the Archean Yilgarn Craton. The gneisses were mainly derived from equigranular and porphyritic monzogranite and syenogranite, with subordinate amounts after granodiorite and tonalite. Extensive SHRIMP U–Pb zircon geochronological work in the southern and central parts of the Narryer Terrane indicates that granite protoliths to the gneisses ranged in age from 3730 to 3300 Ma. The gneisses are tectonically interleaved with mafic and ultramafic rocks, and minor metasedimentary rocks. All these rocks in turn are intruded by granites with igneous crystallization ages between c. 2750 Ma and c. 2620 Ma.

Distribution

Pegmatite-banded gneiss, predominantly derived from Archean granitic rocks of various compositions, forms the vast majority of the Narryer Terrane. Granitic gneisses of the Narryer Terrane belong to several groups (Williams and Myers, 1987; Myers, 1990) or associations (Nutman et al., 1991, 1993). The 'groups' were largely based on lithological mapping, whereas the 'associations' were mainly interpreted from SHRIMP U–Pb zircon dating. Here, all these groups and associations are placed into a general unit of 'granitic gneiss'.

Lithology

The main components of the granitic gneiss in the Narryer Terrane are:

- a pegmatite-layered monzogranitic augen gneiss composed of quartz, plagioclase, and biotite;
- a leucocratic, pegmatite-layered syenogranitic gneiss, composed of quartz, K-feldspar, and plagioclase, with minor biotite or garnet, or both; and
- a coarse, equigranular or porphyritic monzogranite composed of quartz, K-feldspar, plagioclase, biotite, and a network of pegmatite veins.

Component 1 corresponds to the Meeberrie Gneiss, and components 2 and 3 to the Dugel Gneiss (Myers and Williams, 1985). The northeastern part of the Narryer Terrane also includes mesocratic granitic gneiss derived from granodiorite and tonalite. In addition to these rock units, fault-bounded slices of tonalite and monzogranite gneiss ranging in age from c. 3500 to 3400 Ma are also present ('Eurada Gneiss'; Nutman et al., 1991). On a regional scale, the leucocratic syenogranitic gneiss of the Dugel Gneiss contains abundant dismembered sheets of metagabbro–metadolerite and metaperidotite. (Myers and Williams, 1985),

Age code	Archean	A-
Rock type	meta-igneous felsic intrusive	mg
Lithname	granitic gneiss	n
Tectonic unit code	Narryer Terrane	-YNA
Rockcode		**A-mgn-YNA**

Contact relationships

The granitic gneisses were intruded by widespread sheets of granite at 2750–2620 Ma, broadly coincident with a major episode of deformation and metamorphism (Kinny et al., 1990; Myers, 1990). These later intrusions now range from strongly banded and pegmatite-veined granitic gneiss to little-deformed, discordant sheets with igneous textures (Myers, 1990). The granitic gneisses contain fragments of the Manfred Complex, which comprises layered anorthosite, leucogabbro, gabbro, melanogabbro, and ultramafic rocks that are heterogeneously deformed and metamorphosed (Myers and Williams, 1985; Williams and Myers, 1987).

Geochronology

A-mgn-YNA	*Maximum*	*Minimum*
Age (Ma)	3731 ± 4	3302 ± 6
Age	Eoarchean	Paleoarchean
Source	Isotopic	Isotopic
References	Nutman et al. (1991)	Kinny et al. (1990)

Extensive SHRIMP U–Pb zircon geochronology in the southern and central Narryer Terrane (summarized in Nutman et al., 1993), indicates that granite protoliths to the gneisses ranged in age from 3730 to 3300 Ma. The Meeberrie Gneiss contains fragments of the Manfred Complex and is locally interleaved with a pegmatite-layered tonalitic–granodioritic gneiss for which Nutman et al. (1991) determined a SHRIMP U–Pb zircon age of c. 3730 Ma. In addition, Kinny (1987) and Kinny et al. (1988) dated samples from widespread localities of the monzogranitic component within the Meeberrie Gneiss which gave igneous zircon ages of 3680–3600 Ma. Components of the Dugel Gneiss range between 3400 and 3300 Ma (Kinny, 1987; Kinny et al., 1988; Kinny et al., 1990). The Eurada Gneiss ranges in age from c. 3500 to 3400 Ma (Nutman et al., 1991). Kinny (1987) analysed zircons from a sample of gneiss at Eurada Bore and obtained a SHRIMP U–Pb zircon age of c. 3483 Ma, which was interpreted as the igneous crystallization age of the protolith.

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Unnamed unit (A-mgnl-YNA)

Legend narrative

Leucocratic granitic gneiss; quartz–plagioclase–microcline–biotite rock; derived from biotite monzogranite and syenogranite

Rank	Formation
Parent	Unnamed unit (A-mgn-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Overlying units	A-mat-YNA, A-max-YNA, A-mwa-YNA, A-mi-YNA, A-mtq-YNA (faulted); A-gmp-YNA, A-mgmu-YNAY, A-gge-YNA, P_-MO-mgmp (intrusive)

Age code	Archean	A-
Rock type	meta-igneous felsic intrusive	mg
Lithname	granitic gneiss	n
1st qualifier	—	
2nd qualifier	leucocratic	l
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-mgnl-YNA**

Summary

Banded leucocratic granitic gneiss is the major component of the Narryer Terrane and Yarlarweelor Gneiss Complex. Leucocratic granitic gneiss consists of middle to late Archean granitic protoliths with Archean structures and fabrics preserved. In theYarlarweelor Gneiss Complex, the gneiss was reworked during the Capricorn Orogeny (see AP_-mgnl-YNAY). Archean leucocratic granitic gneiss consists of several interlayered rock types that have been repeatedly deformed and metamorphosed.

Distribution

Archean leucocratic granitic gneiss is the major component of the Narryer Terrane on MOORARIE, ERRABIDDY, and LANDOR. It forms low, rocky hills and is dissected by a close-spaced network of dendritic creeks. The gneisses are commonly weathered, but exposure is commonly good. Archean, leucocratic granitic gneiss mainly outcrops on northwestern MOORARIE, in the southwestern corner of ERRABIDDY, west of Errabiddy Homestead, and in the adjacent southeastern corner of LANDOR. On ERRABIDDY and LANDOR the gneisses are contained in a series of fault slices within the Errabiddy Shear Zone.

Lithology

Archean leucocratic gneiss is a composite of several different quartz-rich rock types ranging from tonalite to syenogranite, with monzogranite and granodiorite compositions the most abundant. The unit also includes minor amounts of mesocratic granitic gneiss (A-mgnw-YNA). There are no sharp boundaries between the leucocratic and mesocratic granitic gneiss units, and they are tectonically interleaved on both a mesoscopic and megascopic scale. Lower strain domains of the leucocratic granitic gneiss consist of foliated, coarse-grained biotite metagranite through to gneissic metagranite with a flaser fabric. The coarse-grained, leucocratic biotite metagranite contains inclusions of amphibolite and banded granitic gneiss. The two main rock types making up the Archean leucocratic gneiss are medium-grained leucocratic gneiss with thin, discontinuous layers of biotite and fine- to medium-grained, strongly banded granitic gneiss. Both rock types contain up to 10% biotite with accessory allanite, zircon, and apatite, and trace magnetite. Abundant secondary epidote and sericite, recrystallization of quartz, and fine-grained granophyric textures reflect a later, lower grade metamorphic event.

Contact relationships

Leucocratic granitic gneiss is tectonically interleaved with metamorphosed ultramafic rock (A-mat-YNA, A-max-YNA), amphibolite (A-mwa-YNA), metamorphosed banded iron-formation (A-mi-YNA), and quartzite gneiss (A-mtq-YNA). The leucocratic granitic gneiss is intruded by a range of late Archean and Paleoproterozoic granites, in the form of plugs, sheets, veins, and dykes. The intrusive rocks include mesocratic, strongly porphyritic biotite monzogranite (A-gmp-YNA); augen gneiss and metamorphosed, coarse-grained porphyritic biotite metamonzogranite (A-mgmu-YNAY); medium-grained, even-textured biotite monzogranite (A-gge-YNA); and medium- to very coarse-grained metagranite and pegmatite (P_-MO-mgmp).

Geochronology

A-mgnl-YNA	*Maximum*	*Minimum*
Age (Ma)	3381 ± 22	3292 ± 4
Age	Paleoarchean	Paleoarchean
Source	Isotopic	Isotopic
References	Kinny et al., 1987	Nelson, 1998

Two samples of reworked leucocratic granitic gneiss (AP_-mgnl-YNAY) from the Yarlarweelor Gneiss Complex have been dated using SHRIMP U–Pb zircon geochronology. Nutman et al. (1991) reported an age of 3298 ± 6 Ma for a sample of banded, even-textured, reworked granitic gneiss on MOORARIE. A sample of foliated leucocratic granite from a low-strain zone of reworked gneiss on MOORARIE gave a crystallization age of 3292 ± 4 Ma for the granite precursor (Nelson, 1998; Occhipinti and Myers, 1999). Both samples are representative of a rock type that forms much of the leucocratic gneiss unit in the Yarlarweelor Gneiss Complex, and its non-reworked equivalent, the Narryer Terrane. These two ages are comparable to igneous crystallization ages of 3400–3300 Ma determined by Kinny (1987) and Kinny et al. (1988) for a leucocratic, pegmatite-layered syenogranitic gneiss (Dugel Gneiss: Myers and Williams, 1985; Myers, 1988) in the Mount Narryer region.

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Unnamed unit (A-mgnw-YNA)

Legend narrative

Mesocratic granitic gneiss; quartz–plagioclase–biotite(–hornblende–microcline) rock; derived from granodiorite and tonalite

Rank	Formation
Parent	Unnamed unit (A-mgn-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Overlying units	A-mgnl-YNA, A-mwa-YNA, A-mkq-YNA, A-mi-YNA, A-mtq-YNA, A-mat-YNA, A-max-YNA (faulted); A-gmp-YNA, A-mgmu-YNAY, A-gge-YNA (intrusive)

Summary

Mesocratic granitic gneiss is a minor component of the Narryer Terrane and its reworked equivalent, the Yarlarweelor Gneiss Complex. Mesocratic granitic gneiss consists of Archean granitic protoliths with Archean structures and fabrics preserved. Reworked gneiss outcrops in the Yarlarweelor Gneiss Complex, and is a composite of Archean and Paleoproterozoic components.

Distribution

Archean mesocratic granitic gneiss is a minor component of the Narryer Terrane on ERRABIDDY and LANDOR. The mesocratic gneiss forms low, rounded hills with extensive outcrop. The gneiss is commonly weathered, but fresh exposures are locally present.

Lithology

The mesocratic granitic gneiss is a fine- to medium-grained, strongly banded, biotite-rich rock with thin layers of pegmatite and quartzofeldspathic material. The mesocratic granitic gneiss is commonly porphyritic. It contains up to 30% round and oval phenocrysts and porphyroclasts of microcline. In strongly deformed zones the porphyroclasts are attenuated into thin, discontinuous quartzofeldspathic layers. The porphyritic gneiss locally grades into veins and sheets of mesocratic porphyritic biotite monzogranite (A-gmp-YNA). In lower strain domains the precursor rocks consist of mafic granodiorite and tonalite. The rocks are biotite-bearing, with accessory allanite, zircon, apatite, and iron oxide minerals. Allanite (now hydrated) commonly forms prominent prismatic crystals, and locally forms porphyroclasts.

Age code	Archean	A-
Rock type	meta-igneous felsic intrusive	mg
Lithname	granitic gneiss	n
1st qualifier	—	
2nd qualifier	mesocratic	w
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-mgnw-YNA**

Contact relationships

Archean mesocratic granitic gneiss (A-mgnw-YNA) is tectonically interleaved with Archean leucocratic granitic gneiss (A-mgnl-YNA), amphibolite (A-mwa-YNA), calc-silicate gneiss (A-mkq-YNA), metamorphosed banded iron-formation (A-mi-YNA), quartzite (A-mtq-YNA), and metamorphosed ultramafic rock (A-mat-YNA, A-max-YNA). Plugs, dykes, and veins of late Archean monzogranite (A-gmp-YNA, A-mgmu-YNAY, A-gge-YNA) intrude across the Archean gneissic layering and Archean structures in the mesocratic granitic gneiss. However, locally the gneiss includes deformed late Archean granite intrusions (A-gmp-YNA, A-gge-YNA).

Geochronology

A-mgnw-YNA	*Maximum*	*Minimum*
Age (Ma)	3352	2630
Age	Paleoarchean	Neoarchean
Source	Inferred	Inferred
References	Nelson, 1998a	Nelson, 1998b

Archean mesocratic granitic gneiss (A-mgnw-YNA) has not been dated directly. However, the gneiss is intruded by a series of late Archean granites, including mesocratic porphyritic biotite monzogranite (A-gmp-YNA) and equigranular, biotite-rich granodiorite (A-gge-YNA), which have been dated at 2630 ± 4 Ma (Nelson, 1998b) and 2608 ± 3 Ma (Nelson, 1998c), respectively. These dates provide a minimum age for crystallization of the protoliths and formation of the gneissic fabrics. The reworked equivalent of the gneiss, mesocratic granitic gneiss (AP_-mgnw-YNAY), contains an oldest component with a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 3352 ± 3 Ma (Nelson, 1998a).

References

Nelson, DR 1998a, 142853: granite gneiss, Jubilee Well rockhole; Geochronology Record 369: Geological Survey of Western Australia, 4p.

Nelson, DR 1998b, 142906: coarse porphyritic monzogranite, Beedarry Bore; Geochronology Record 331: Geological Survey of Western Australia, 4p.

Nelson, DR 1998c, 142907: biotite monzogranite dyke, Bilja Well; Geochronology Record 332: Geological Survey of Western Australia, 4p.

Unnamed unit (A-mgmu-YNAY)

Legend narrative

Foliated, porphyritic biotite metamonzogranite with coarse round phenocrysts of K-feldspar, locally comprises augen gneiss

Rank	Formation
Parent	Unnamed unit (A-mgm-YNAY)
Tectonic units	CAPRICORN OROGEN, Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Overlying units	A-gme-YNA, P_-MO-mgmp (intrusive)
Underlying units	A-mgnl-YNA, AP_-mgnl-YNAY (intrusive)

Summary

Foliated, porphyritic biotite metamonzogranite and augen gneiss forms a series of sheets that intrude granitic gneisses within the Errabiddy Shear Zone on ERRABIDDY. The sole rock type is a foliated to gneissic, strongly porphyritic biotite metamonzogranite with round phenocrysts of K-feldspar, mainly 2–5 cm in diameter. The unit is dated at c. 2600 Ma.

Distribution

Foliated, porphyritic biotite metamonzogranite and augen gneiss forms a series of sheets that intrude Archean and reworked leucocratic granitic gneisses on ERRABIDDY. The largest sheet, which is centred on Bullaroo Hill, is over 15 km long and almost 5 km wide. Augen gneiss and porphyritic granite outcrop as low ridges covered in tors and boulders, or as extensive pavements.

Lithology

Least-deformed parts of the foliated, porphyritic biotite metamonzogranite and augen gneiss have about 30–40% round phenocrysts of microcline in a medium-grained (2–3 mm) groundmass. Most of the samples are strongly deformed. Microcline porphyroclasts commonly have deformation lamellae and ribbon microperthite textures. The groundmass consists of extensively recrystallized quartz, microcline, and plagioclase, with seams of biotite, sericite, and epidote. Igneous plagioclase is variably replaced by fine-grained sericite, epidote, and albite–oligoclase.

Age code	Archean	A-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	—	
2nd qualifier	augen	u
Tectonic unit code	Yarlarweelor Gneiss Complex	-YNAY
Rock code		**A-mgmu-YNAY**

Contact relationships

Foliated, porphyritic biotite metamonzogranite and augen gneiss intruded both Archean and reworked leucocratic granitic gneiss (A-mgnl-YNA, AP_-mgnl-YNAY). West-southwest of Errabiddy Homestead, the metamonzogranite and augen gneiss is intruded by veins or dykes of medium-grained, equigranular biotite monzogranite (A-gme-YNA). Foliated, porphyritic biotite metamonzogranite and augen gneiss outcrops northwest of Dewar Bore on eastern ERRABIDDY, where it is extensively intruded by sheets and veins of medium- to very coarse-grained metagranite and pegmatite (P_-MO-mgmp).

Geochronology

A-mgmu-YNAY	*Maximum*	*Minimum*
Age (Ma)	2630	2608 ± 3
Age	Neoarchean	Neoarchean
Source	Inferred	Isotopic
References	Nelson, 1998a	Nelson, 1998b

Foliated, porphyritic biotite metamonzogranite and augen gneiss about 1 km east of Bullaroo Hill on eastern ERRABIDDY was sampled for SHRIMP U–Pb zircon geochronology (GSWA 142903). The sample is a strongly foliated, coarse-grained porphyritic metamonzogranite. All zircon crystals analysed have high U contents, and many grains have probably lost radiogenic Pb (Nelson, 1999). Seven analyses yield a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 2594 ± 4 Ma, interpreted by Nelson (1999) as the minimum age of crystallization of the monzogranite. Two zircons indicate a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 2605 ± 2 Ma, and another zircon a $^{207}Pb^{*}/^{206}Pb^{*}$ date of 2616 ± 4 Ma, and may date crystallization of the melt or represent xenocrysts. A minimum age for the unit is provided by cross-cutting dykes of equigranular biotite monzogranite (A-gme-YNA), a sample of which (GSWA 142907) is dated at 2608 ± 3 Ma (Nelson, 1998b).

References

Nelson, DR 1998a, 142906: coarse porphyritic monzogranite, Beedarry Bore; Geochronology Record 331: Geological Survey of Western Australia, 4p.

Nelson, DR 1998b, 142907: biotite monzogranite dyke, Bilja Well; Geochronology Record 332: Geological Survey of Western Australia, 4p.

Nelson, DR 1999, 142903: foliated porphyritic biotite monzogranite, Bullaroo Hill; Geochronology Record 329: Geological Survey of Western Australia, 4p.

Unnamed unit (A-mwa-YNA)

Legend narrative

Amphibolite; fine- to medium-grained, aphyric hornblende–plagioclase rock and medium-grained porphyritic hornblende–plagioclase rock; locally includes metagabbro and metaleucogabbro

Rank	Subgroup
Parent	Unnamed unit (A-mw-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Overlying units	P_-MO-mgmp
Underlying units	A-mgnl-YNA, A-mgnw-YNA, AP_-mgnl-YNAY, AP_-mgnw-YNAY

Summary

Lenses and strips of fine- and medium-grained amphibolite are extensively interleaved with granitic gneisses in the Yarlarweelor Gneiss Complex. Field relationships suggest that the amphibolites represent metamorphosed dolerite dykes and veins, and that they were intruded during more than one magmatic event.

Distribution

Lenses and strips of fine- and medium-grained amphibolite are extensively interleaved with the granitic gneisses in the Yarlarweelor Gneiss Complex on Errabiddy, Marquis, and Moorarie. A few of the amphibolites display complex refolded fold patterns, but others cut the gneissic layering and show evidence for only one generation of folding. The amphibolites, therefore, probably comprise two (or more) generations of mafic magmatism. Most of the amphibolites are about 1–3 m wide and up to 40–50 m long, although a few may exceed 100 m in length. About 2 km north of Weedarra Bore, however, individual amphibolite layers up to 10 m thick are traceable for several hundred metres or more along strike. Locally, the amphibolites form boudinaged pods less than 10 m long in strongly deformed granitic gneiss. In most areas the amphibolites comprise less than 5% of the outcrop, but in places they may comprise up to 30–40%. The presence of a large body of layered amphibolite near 13 Mile Well on Marquis reported by Elias and Williams (1980) could not be substantiated.

Lithology

Most of the amphibolites are fine grained, or fine- to medium-grained (grain size of <2 mm) and equigranular, with a weak compositional banding. The amphibolites have a polygonal texture and are composed of green hornblende and plagioclase (andesine) with minor quartz and titanite, and accessory apatite. Clinopyroxene may be absent or comprise up to 20% of the rock. In some samples clinopyroxene forms cores to hornblende, suggesting that it is a relict from a higher grade metamorphic assemblage or the igneous protolith.

Age code	Archean	A-
Rock type	meta-igneous mafic	mw
Lithname	amphibolite	a
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-mwa-YNA**
Additional lithologies:	metagabbro	

Contact relationships

Contacts between the amphibolites and granitic gneisses are usually tectonic and parallel to the compositional banding in the gneisses. Locally, however, some amphibolites are discordant at a low angle to the banding in the gneisses, indicating that the amphibolites were originally mafic dykes. Along with the granitic gneisses, the amphibolites are intruded by medium- to very coarse-grained metagranite and pegmatite (P_-MO-mgmp). In the Archean granitic gneisses (A-mgnl-YNA, A-mgnw-YNA) amphibolite is intruded by late Archean (≤2630 Ma) granites (A-gme-YNA, A-gmp-YNA).

Geochronology

A-mwa-YNA	*Maximum*	*Minimum*
Age (Ma)	–	–
Age	Archean	Paleoproterozoic
Source	Inferred	Inferred
References	–	–

In the Archean granitic gneisses (A-mgnl-YNA, A-mgn-YNA), amphibolite is intruded by various late Archean (≤2630 Ma) granites (A-gme-YNA, A-gmp-YNA, A-gge-YNA), indicating that the majority of the amphibolite is Archean. However, in the reworked granitic gneisses (AP_-mgnl-YNAY, AP_-mgn-YNAY), amphibolites that truncate the gneissic layering must be Paleoproterozoic in age.

References

Elias, M and Williams, SJ 1980, Robinson Range, W.A.: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 32p.

Unnamed unit (A-mwax-YNA)

Legend narrative

Amphibolite gneiss; fine- to medium-grained, hornblende–plagioclase–clinopyroxene rock; granoblastic texture

Rank	Formation
Parent	Unnamed unit (A-mwa-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Overlying units	P_-MO-mgmp
Underlying units	AP_-mgnl-YNAY

Summary

Although amphibolite is widely distributed throughout the Narryer Terrane and Yarlarweelor Gneiss Complex, amphibolite containing clinopyroxene (A-mwax-YNA) is common only along the southern part of the Yarlarweelor Gneiss Complex on MARQUIS.

Distribution

Amphibolite gneiss containing brown hornblende and clinopyroxene is common along the southern edge of MARQUIS. As with the other varieties of amphibolite in the Narryer Terrane (A-mwa-YNA, A-mwoa-YNA), those containing clinopyroxene form lenses and strips up to a few metres wide and tens of metres long.

Lithology

Amphibolite gneiss comprises brown hornblende–plagioclase–clinopyroxene–iron-oxide minerals or clinopyroxene–plagioclase–green-hornblende–iron-oxide minerals. Clinopyroxene constitutes up to 20% of the rock. These rocks have a polygonal or amoeboid granoblastic texture, and the plagioclase is labradorite in composition.

Age code	Archean	A-
Rock type	meta-igneous mafic	mw
Lithname	amphibolite	a
1st qualifier	—	
2nd qualifier	clinopyroxene	x
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-mwax-YNA**

Contact relationships

Amphibolite gneiss with clinopyroxene is tectonically interleaved with reworked leucocratic granitic gneiss.

Geochronology

A-mwax-YNA	*Maximum*	*Minimum*
Age (Ma)	–	1813
Age	Archean	Paleoproterozoic
Source	Inferred	Inferred
References	–	Nelson, 1998

Amphibolite gneiss with clinopyroxene has not been dated directly, and age constraints are poor. Locally, the amphibolites appear to truncate gneissic layering in the granitic gneisses, but it is not clear as to whether this fabric is solely Archean or, in part, Paleoproterozoic. The amphibolite is intruded by dykes and veins of porphyritic to equigranular, medium- to very coarse-grained metagranite and pegmatite (P_-MO-mgmp) dated at 1813 ± 8 Ma, which provides a minimum age for the amphibolite.

References

Nelson, DR 1998, 142849: foliated coarse-grained monzogranite, northeast of White Well; Geochronology Record 365: Geological Survey of Western Australia, 4p.

Unnamed unit (A-moa-YNA)

Legend narrative

Amphibolite after porphyritic microgabbro, gabbro, and leucogabbro

Rank	Suite
Parent	Unnamed unit (A-mo-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Overlying units	P_-MO-mgmp
Underlying units	AP_-mgnl-YNAY

Summary

Amphibolite after porphyritic microgabbro, gabbro, and leucogabbro outcrops extensively in the Narryer Terrane and Yarlarweelor Gneiss Complex, although it is never abundant.

Distribution

Layers of metamorphosed porphyritic microgabbro, gabbro, and leucogabbro are widespread on southern MARQUIS, but much less abundant than the aphyric amphibolites. As with the other varieties of amphibolite in the Narryer Terrane (A-mwa-YNA, A-mwax-YNA), those containing clinopyroxene form lenses and strips up to a few metres wide and tens of metres long

Lithology

Most layers of amphibolite after porphyritic microgabbro, gabbro, and leucogabbro are fine to medium grained; some layers have fine-grained aphyric margins. In places, thicker layers of the amphibolite include metamorphosed leucogabbro. Porphyritic amphibolite has a polygonal texture and comprises green hornblende and plagioclase (andesine) with minor quartz and titanite, and accessory apatite. Former plagioclase phenocrysts now consist of polygonal-textured domains of fine-grained plagioclase.

Age code	Archean	A-
Rock type	meta-igneous mafic intrusive	mo
Lithname	amphibolite derived from intrusive rock	a
Tectonic unit code	Narryer Terrane	-YNA
Rock code	–	**A-moa-YNA**

Contact relationships

Plagioclase-phyric amphibolite is tectonically interleaved with reworked leucocratic granitic gneiss.

Geochronology

A-moa-YNA	*Maximum*	*Minimum*
Age (Ma)	–	1813
Age	Archean	Paleoproterozoic
Source	–	Inferred
References	–	Nelson, 1998

Amphibolite after porphyritic microgabbro, gabbro, and leucogabbro has not been dated directly, and age constraints are poor. Locally, the amphibolites may truncate gneissic layering in the granitic gneisses, but it is not clear as to whether this fabric is solely Archean or, in part, Paleoproterozoic. The amphibolite is intruded by dykes and veins of porphyritic to equigranular, medium- to very coarse-grained metagranite and pegmatite (P_-MO-mgmp) dated at 1813 ± 8 Ma, which provides a minimum age for the amphibolite.

Reference

Nelson, DR 1998, 142849: foliated coarse-grained monzogranite, northeast of White Well; Geochronology Record 365: Geological Survey of Western Australia, 4p.

Unnamed unit (A-mat-YNA)

Legend narrative

Fine- to medium-grained serpentine–talc–magnetite–calcite(–tremolite–titanite) rock after peridotite

Rank	Suite
Parent	Unnamed unit (A-ma-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Underlying units	AP_-mgnl-YNAY

Summary

Metamorphosed peridotite forms numerous layers and lenses interleaved with granitic gneisses along the northern edge of the non-reworked Narryer Terrane and in the Yarlarweelor Gneiss Complex.

Distribution

Metamorphosed peridotite outcrop as lenses and narrow layers about 6 km southwest (Zone 50, MGA 555840E 7204840N) and 13 km south-southwest (Zone 50, MGA 555940E 7197740) of Cardingie Bore near the western edge of MARQUIS, and west of Errabiddy Homestead on southwestern ERRABIDDY. Most outcrops are contained within an east-northeasterly trending belt about 6 km long and less than a kilometre wide, which extends onto LANDOR. Individual lenses are up to 50 m wide and a kilometre long. The lenses outcrop as narrow, blocky ridges up to about 30 m high. These rocks weather to a dark-brown colour, but are dark green on fresh surfaces.

Lithology

Metamorphosed peridotite is typically fine and medium grained and massive, although where cut by narrow shear zones, the rocks are fine grained and strongly foliated. The rocks are composed of serpentine, talc, granular magnetite, and calcite, with minor tremolite and titanite, and were derived from medium- to low-grade metamorphism of peridotite. Domains of decussate talc crystals up to 5 mm long, with fine-grained serpentine inclusions, are contained within a matrix of serpentine and talc. Fine-grained magnetite and calcite typically line grain boundaries of the coarser grained talc. The rocks show pervasive and fracture-related alteration to fine-grained talc–chlorite rock.

Age code	Archean	A-
Rock type	meta-igneous ultramafic intrusive	ma
Lithname	serpentinite derived from intrusive rock	t
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-mat-YNA**

Contact relationships

The contacts between metamorphosed peridotite layers and the enclosing leucocratic granitic gneiss are not exposed, but are inferred to be faulted.

Geochronology

A-mat-YNA	*Maximum*	*Minimum*
Age (Ma)	–	2630
Age	Archean	Neoarchean
Source	–	Inferred
References	–	Nelson, 1998

There are few constraints on the age of the metamorphosed peridotite. The metamorphosed peridotite is probably tectonically interleaved with leucocratic granitic gneisses (A-mgnl-YNA). The gneissic fabric in these rocks is intruded by late Archean granites dated at c. 2630 Ma or younger (A-gmp-YNA), which provides a minimum age for the metapyroxenite.

Reference

Nelson, DR 1998, 142906: coarse porphyritic monzogranite, Beedarry Bore; Geochronology Record 331: Geological Survey of Western Australia, 4p.

Unnamed unit (A-maxs-YNA)

Legend narrative

Tremolite schist; after pyroxenite

Rank	Formation
Parent	Unnamed unit (A-max-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Overlying units	A-gmp-YNA, A-gge-YNA
Underlying units	A-mgnl-YNA, A-mgnw-YNA, AP_-mgnl-YNAY (faulted)

Summary

Metamorphosed pyroxenite is a very minor rock type in the Narryer Terrane, where it is tectonically interleaved with granitic gneisses.

Distribution

Rare layers of metamorphosed pyroxenite outcrop on western MARQUIS, and about 2.8 km south-southeast of K13 Well (Zone 50, MGA 507900E 7183470N) on southwestern ERRABIDDY.

Lithology

Metamorphosed pyroxenite layers comprise tremolite (–clinopyroxene)–iron-oxide with accessory apatite, or tremolite–chlorite–magnetite–ilmenite. Tremolite crystals may contain cores of pale-green to bluish-green ?pargasite.

Age code	Archean	A-
Rock type	meta-igneous ultramafic intrusive	ma
Lithname	metapyroxenite derived from intrusive rock	x
1st qualifier	—	
2nd qualifier	schistose	s
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-maxs-YNA**

Contact relationships

Layers of metamorphosed pyroxenite are tectonically interleaved with reworked leucocratic granitic gneiss.

Geochronology

A-maxs-YNA	*Maximum*	*Minimum*
Age (Ma)	–	2630
Age	Archean	Neoarchean
Source	–	Inferred
References	–	Nelson, 1998

There are few constraints on the age of the metamorphosed pyroxenite. The metapyroxenite is tectonically interleaved with leucocratic granitic and mesocratic granitic gneisses (A-mgnl-YNA, A-mgnw-YNA). The gneissic fabric in these rocks is intruded by late Archean granites dated at c. 2630 Ma or younger (A-gmp-YNA), which provides a minimum age for the metapyroxenite.

Reference

Nelson, DR 1998, 142906: coarse porphyritic monzogranite, Beedarry Bore; Geochronology Record 331: Geological Survey of Western Australia, 4p.

Unnamed unit (A-mus-YNA)

Legend narrative

Ultramafic schist, metapyroxenite, serpentinite

Rank	Subgroup
Parent	Unnamed unit (A-mu-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Underlying units	AP_mgnl-YNAY (faulted)

Summary

Ultramafic schist is restricted to several narrow layers on western Marquis in the Yarlarweelor Gneiss Complex.

Distribution

Ultramafic schist is restricted to several layers about 6 km southwest (Zone 50, MGA 555840E 7204840N) and 13 km south-southwest (Zone 50, MGA 555940E 7197740N) of Cardingie Bore near the western edge of Marquis, which are tectonically interleaved with granitic gneisses.

Lithology

Ultramafic schist is fine grained and pale brown. The layers are composed of fine-grained serpentine, talc, granular magnetite, and calcite, and were derived from medium- to low-grade metamorphism of ultramafic rocks.

Age code	Archean	A-
Rock type	meta-igneous ultramafic volcanic or undivided	mu
Lithname	ultramafic schist, volcanic or undivided	s
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-mus-YNA**

Geochronology

A-mus-YNA	*Maximum*	*Minimum*
Age (Ma)	–	–
Age	Archean	Neoarchean
Source	–	–
References	–	–

Unnamed unit (A-mi-YNA)

Legend narrative

Metamorphosed banded iron-formation; grunerite–quartz–magnetite(–hematite) and quartz–magnetite(–hematite) rocks

Rank	Group
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Overlying units	A-gme-YNA, A-gmp-YNA, A-gge-YNA (intrusive)
Underlying units	A-mgnl-YNA, A-mgnw-YNA, AP_-mgnl-YNAY, AP_-mgnw-YNAY (faulted)

Summary

Metamorphosed banded iron-formation is a widespread rock type throughout the granitic gneisses in the Narryer Terrane, and in its reworked equivalent, the Yarlarweelor Gneiss Complex. Layers of metamorphosed banded iron-formation commonly form narrow, blocky ridges. The rocks comprise quartz–magnetite(–hematite) and grunerite–quartz–magnetite(–hematite).

Distribution

Metamorphosed banded iron-formation is a widespread rock type throughout the granitic gneisses in the Narryer Terrane, and in its reworked equivalent, the Yarlarweelor Gneiss Complex. Metamorphosed banded iron-formation consists of lenses and layers up to a few metres thick. The layers are commonly discontinuous, having been dismembered during deformation and disrupted by intrusion of younger granites. Some layers can be traced along strike for several hundred metres, and thicker layers are about a kilometre or more in length. Many layers are readily identified on the 1:25 000-scale colour aerial photographs because of their dark colour and apron of ironstone rubble. The layers commonly form narrow, blocky ridges. Layers of metamorphosed banded iron-formation are abundant in two belts on southern MARQUIS — one trending west-southwesterly from Weedarra Bore, and the second trending east-northeasterly from Red Peak Bore — and on ERRABIDDY in the Errabiddy Shear Zone west of Errabiddy Homestead, and in a belt that extends eastwards from Orient Bore in the southeastern corner of ERRABIDDY.

Lithology

The metamorphosed banded iron-formation layers on MARQUIS and MOORARIE are composed of a fine- to medium-grained, quartz–magnetite(–hematite) rock, which is either weakly banded or granular. Very fine grained crystals of tourmaline are a trace component in most samples. There are also a few layers of grunerite-bearing metamorphosed iron-formation. In contrast with the metamorphosed iron-formation on MARQUIS and MOORARIE, grunerite is abundant in iron formation layers in the Archean granitic gneisses west of Errabiddy Homestead. The most common assemblage is fine-grained grunerite–quartz–magnetite(–hematite).

Age code	Archean	A-
Rock type	metasedimentary other chemical: meta-iron formation	
Lithname	meta-iron formation	mi
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-mi-YNA**

Contact relationships

Metamorphosed banded iron-formation is a widespread rock type tectonically interleaved with the Archean granitic gneisses (A-mgnl-YNA, A-mgnw-YNA) and reworked granitic gneisses (AP_-mgnl-YNAY, AP_-mgnw-YNAY). Contacts between metamorphosed iron-formation and the enclosing granitic gneisses are tectonic and parallel to banding in the gneisses. The layers are commonly intruded and disrupted by late Archean granites (A-gme-YNA, A-gmp-YNA, A-gge-YNA) and medium- to very coarse-grained metagranite and pegmatite (P_-MO-mgmp).

Geochronology

A-mi-YNA	*Maximum*	*Minimum*
Age (Ma)	–	2630
Age	Archean	Neoarchean
Source	–	Inferred
References	–	Nelson, 1998

Metamorphosed banded iron-formation is probably late Archean in age, by analogy with the Mount Narryer region (Williams and Myers, 1987). It is intruded by late Archean granites (A-gme-YNA, A-gmp-YNA, A-gge-YNA) with igneous crystallization ages of c. 2630 Ma or less.

References

Nelson, DR 1998, 142906: coarse porphyritic monzogranite, Beedarry Bore; Geochronology Record 331: Geological Survey of Western Australia, 4p.

Williams, IR and Myers, JS 1987, Archaean geology of the Mount Narryer region, Western Australia: Geological Survey of Western Australia, Report 22, 32p.

Unnamed unit (A-mtq-YNA)

Legend narrative

Foliated quartzite; minor quartz–diopside gneiss

Rank	Formation
Parent	Unnamed unit (A-mt-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Underlying units	A-mngl-YNA, AP_-mngl-YNAY (faulted)

Summary

Foliated quartzite is widespread in the Narryer Terrane and Yarlarweelor Gneiss Complex as layers tectonically interleaved with the granitic gneisses. The layers range in thickness from several centimetres to several metres, and include quartzite and quartz–diopside rocks.

Distribution

Archean quartzite and quartz–diopside rock is common in the northeastern corner of MOORARIE, south and south-southeast of Lucys Bore on western MARQUIS, and it also forms large, resistant ridges southwest of K13 Well on southwestern ERRABIDDY and about 9 km south-southeast of Pines Bore on the eastern edge of ERRABIDDY. Quartzite and quartz–diopside rocks are white or very pale green, and commonly outcrop as rocky, narrow ridges. Quartzite forms layers from a few tens of centimetres up to 20 m thick, whereas layers of quartz–diopside rock are less than about 5 m thick.

Lithology

Quartzite contains at most, a few percent of diopside, tremolite–actinolite, microcline, and accessory tourmaline. Quartz–diopside rocks contain about 80–90% quartz, with clinopyroxene, tremolite–actinolite, plagioclase, and microcline. A small outcrop of quartz–kyanite schist is present in the western part of MOORARIE. Outcrops of quartzite and quartz–diopside rock south-southeast of Pines Bore include some metamorphosed feldspathic sandstone.

Age code	Archean	A-
Rock type	metasedimentary siliciclastic: psammite	mt
Lithname	quartzite	q
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-mtq-YNA**

Contact relationships

Quartzite and quartz–diopside rock are tectonically interleaved with Archean and reworked leucocratic granitic gneisses (A-mngl-YNA, AP_-mngl-YNAY).

Geochronology

A-mtq-YNA	*Maximum*	*Minimum*
Age (Ma)	3100	2700
Age	Mesoarchean	Neoarchean
Source	Inferred	Inferred
References	Compston and Pidgeon, 1986; Nutman et al., 1991	Wilde and Pidgeon, 1990

No quartzite or quartz–diopside rocks were sampled for SHRIMP U–Pb zircon geochronology during the remapping. However, detrital zircons from a large number of samples from the Narryer Terrane farther to the southwest have been dated using SHRIMP U–Pb zircon methods (e.g. Froude et al., 1983; Compston and Pidgeon, 1986; Kober et al., 1989; Kinny et al., 1990; Maas and McCulloch, 1991; Nutman et al., 1991; Wilde et al., 2001). Quartzites from Mount Narryer and Jack Hills have maximum depositional ages of c. 3280 and c. 3000 Ma, respectively. Quartzites at Jack Hills are intruded by a c. 2700 Ma granite (Wilde and Pidgeon, 1990), indicating that the bulk of the quartzites were deposited in the late Archean.

References

Compston, W and Pidgeon, RT 1986, Jack Hills, evidence of more very old detrital zircons in Western Australia: Nature, v. 321, p. 766–769.

Froude, DO, Ireland, TR, Kinny, PD, Williams, IS, Compston, W, Williams, IR and Myers, JS 1983, Ion microprobe identification of 4100–4200 Myr-old terrestrial zircons: Nature, v. 304, p. 616–618.

Kinny, PD, Wijbrans, JR, Froude, DO, Williams, IS and Compston, W 1990, Age constraints on the geological evolution of the Narryer Gneiss Complex, Western Australia: Australian Journal of Earth Sciences, v. 37, p. 51–69.

Kober, B, Pidgeon, RT and Lippolt, HJ 1989, Single-zircon dating by stepwise Pb-evaporation constrains the Archean history of detrital zircons from the Jack Hills, Western Australia: Earth and Planetary Science Letters, v. 91, p. 286–296.

Maas, R and McCulloch, MT 1991, The provenance of Archean clastic metasediments in the Narryer Gneiss Complex, Western Australia: Trace element geochemistry, Nd isotopes, and U–Pb ages for detrital zircons: Geochimica et Cosmochimica Acta, v. 55, p. 1915–1932.

Nutman, AP, Kinny, PD, Compston, W and Williams, IS 1991, SHRIMP U–Pb zircon geochronology of the Narryer Gneiss Complex, Western Australia: Precambrian Research, v. 52, p. 275–300.

Wilde, SA and Pidgeon, RT 1990, Geology of the Jack Hills metasedimentary rocks, in Third International Archean Symposium, Perth, 1990, Excursion Guidebook edited by SE Ho, JS Glover, JS Myers, and JR. Muhling: University of Western Australia, Geology Department and University Extension, Publication no. 21, p. 82–95.

Wilde, SA, Valley, JW, Peck, WH and Graham, CM 2001, Evidence from detrital zircons for the existence of continental crust and oceans on the Earth 4.4 Gyr ago: Nature, v. 409, p. 175–178.

Unnamed unit (A-mkq-YNA)

Legend narrative

Calc-silicate gneiss; fine- to coarse-grained plagioclase–quartz–diopside–tremolite(–microcline) and diopside–tremolite–titanite rocks

Rank	Subgroup
Parent	Unnamed unit (A-mk-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Underlying units	A-mgnl-YNA, AP_-mgnl-YNAY

Summary

Calc-silicate gneiss forms layers up to 3 m wide interleaved with the granitic gneisses in the Yarlarweelor Gneiss Complex and Narryer Terrane. Calc-silicate gneiss comprises the assemblages clinopyroxene–tremolite–actinolite(–titanite) and clinopyroxene–tremolite–actinolite–quartz–plagioclase–microcline.

Distribution

Calc-silicate gneiss forms narrow layers tectonically interleaved with the granitic gneisses, and is a minor rock type on MARQUIS, MOORARIE, ERRABIDDY, and LANDOR. It is only abundant in the southeastern corner of MARQUIS. Calc-silicate gneiss forms discontinuous lenses or layers typically less than 3 m wide and up to a few hundred metres long. West and south of Deep Well (Zone 50, MGA 599340E 7190640N) in the southeastern part of the sheet area, a few calc-silicate layers up to about 50 m thick are traceable along strike for up to 1.5 km. The calc-silicate rocks are pale green on a fresh surface, but typically weather to a reddish-brown exterior.

Lithology

Many of the calc-silicate gneiss layers are compositionally banded, with alternations of tremolite- and clinopyroxene-rich bands with quartz-rich bands, up to several centimetres thick. The calc-silicate rocks range from fine to coarse grained, with radiating bundles of pale green tremolite–actinolite or clinopyroxene within the compositional banding. Locally, quartz–diopside rock and quartzite are interlayered with the calc-silicate rocks. The calc-silicate rocks can be divided into two main types based on the abundance or paucity of quartz and plagioclase. Both rock types may be fine or coarse grained.

Quartz-poor rocks commonly have decussate textures, and are characterized by assemblages of clinopyroxene, tremolite–actinolite, and titanite, with less than a few percent of plagioclase and quartz. Coarser grained tremolite may be intergrown with clinopyroxene, but some tremolite has enclosed and partly replaced crystals of clinopyroxene. Quartz-rich rocks are composed of clinopyroxene, tremolite–actinolite, quartz, plagioclase, and microcline. The quartz and feldspar contents of the rocks range from about 30% up to nearly 80%. Most of the rocks have decussate or polygonal textures, but rare examples of granoblastic or amoeboid polygonal textures are present in assemblages with abundant clinopyroxene. Both quartz-poor and quartz-rich rocks contain minor to abundant, fine-grained, secondary clinozoisite–epidote, albite, and sericite.

Age code	Archean	A-
Rock type	metasedimentary carbonate	mk
Lithname	calc-silicate rock	q
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-mkq-YNA**

Contact relationships

Contacts between the calc-silicate gneiss and granitic gneiss are tectonic, but veins of medium- to very coarse-grained metagranite and pegmatite (P_-MO-mgmp) intruded the calc-silicate rocks.

Geochronology

A-mkq-YNA	*Maximum*	*Minimum*
Age (Ma)	3100	2700
Age	Mesoarchean	Neoarchean
Source	Inferred	Inferred
References	Compston and Pidgeon, 1986; Nutman et al., 1991	Wilde and Pidgeon, 1990

The age of the calc-silicate gneiss is unknown, but the presence of a few refolded folds and the parallelism of the contacts to the banding in the gneiss imply that they were interleaved early in the structural history of the area. By analogy with similar rock types interleaved with early and late Archean granitic gneisses in the Mount Narryer region (Williams and Myers, 1987), the protoliths to the calc-silicate gneisses are probably late Archean in age.

References

Compston, W and Pidgeon, RT 1986, Jack Hills, evidence of more very old detrital zircons in Western Australia: Nature, v. 321, p. 766–769.

Nutman, AP, Kinny, PD, Compston, W, and Williams, IS 1991, SHRIMP U–Pb zircon geochronology of the Narryer Gneiss Complex, Western Australia: Precambrian Research, v. 52, p. 275–300.

Wilde, SA and Pidgeon, RT 1990, Geology of the Jack Hills metasedimentary rocks, in Third International Archean Symposium, Perth, 1990, Excursion Guidebook edited by SE Ho, JS Glover, JS Myers, and JR. Muhling: University of Western Australia, Geology Department and University Extension, Publication no. 21, p. 82–95.

Williams, IR and Myers, JS 1987, Archean geology of the Mount Narryer region, Western Australia: Geological Survey of Western Australia, Report 22, 32p.

Unnamed unit (A-mkqx-YNA)

Legend narrative

Quartz–diopside rock and calc-silicate gneiss

Rank	Formation
Parent	Unnamed unit (A-mkq-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Underlying units	A-mngl-YNA, AP_-mngl-YNAY (faulted)

Summary

Quartz–diopside rock and calc-silicate gneiss are widely distributed as thin layers or lenses throughout the Narryer Terrane, although they are never abundant.

Distribution

Quartz–diopside rock and calc-silicate gneiss has a similar distribution to quartzite (A-mtq-YNA) and calc-silicate gneiss (A-mkq-YNA) in the Yarlarweelor Gneiss Complex and Narryer Terrane, but is much less abundant. Quartz–diopside rocks are very pale green, form layers less than about 5 m thick, and commonly outcrop as rocky, narrow ridges.

Lithology

Quartz–diopside rocks contain about 80–90% quartz, with clinopyroxene, tremolite–actinolite, plagioclase, and microcline.

Age code	Archean	A-
Rock type	metasedimentary carbonate	mk
Lithname	calc-silicate rock	q
1st qualifier	—	
2nd qualifier	clinopyroxene	x
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-mkqx-YNA**

Contact relationships

Quartz–diopside rock and calc-silicate gneiss are tectonically interleaved with Archean and reworked leucocratic granitic gneisses (A-mngl-YNA, AP_-mngl-YNAY).

Geochronology

A-mkqx-YNA	*Maximum*	*Minimum*
Age (Ma)	3100	2700
Age	Mesoarchean	Neoarchean
Source	Inferred	Inferred
References	Compston and Pidgeon, 1986; Nutman et al., 1991	Wilde and Pidgeon, 1990

Quartz–diopside rock and calc-silicate gneiss are inferred to be late Archean in age by analogy with quartzite (A-mtq-YNA) and calc-silicate gneiss (A-mkq-YNA).

References

Compston, W and Pidgeon, RT 1986, Jack Hills, evidence of more very old detrital zircons in Western Australia: Nature, v. 321, p. 766–769.

Nutman, AP, Kinny, PD, Compston, W, and Williams, IS 1991, SHRIMP U–Pb zircon geochronology of the Narryer Gneiss Complex, Western Australia: Precambrian Research, v. 52, p. 275–300.

Wilde, SA and Pidgeon, RT 1990, Geology of the Jack Hills metasedimentary rocks, in Third International Archean Symposium, Perth, 1990, Excursion Guidebook edited by SE Ho, JS Glover, JS Myers, and JR. Muhling: University of Western Australia, Geology Department and University Extension, Publication no. 21, p. 82–95.

Unnamed unit (A-g-YNA)

Legend narrative

Granitic rocks, undivided; metamorphosed

Rank	Supersuite
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA

Summary

Granitic gneiss of the Narryer Terrane was widely intruded by sheets of granite at 2750–2620 Ma (Kinny et al., 1990; Myers, 1990). These granites now range from strongly banded and pegmatite-veined gneiss to little-deformed, discordant sheets with igneous textures (Myers, 1990). Two samples of undeformed and unmetamorphosed granite on ERRABIDDY have crystallization ages of c. 2630 Ma and c. 2610 Ma.

Distribution

Sheets, plugs and dykes of undeformed and unmetamorphosed granite are distributed throughout the Narryer Terrane.

Lithology

Late Archean granite intrusions in the Narryer Terrane comprise medium-grained, equigranular biotite monzogranite (A-gme-YNA), mesocratic porphyritic biotite monzogranite (A-gmpw-YNA) with round phenocrysts of microcline up to 5 cm in diameter, and mesocratic, medium-grained, equigranular or weakly porphyritic granodiorite (A-gge-YNA).

Age code	Archean	A-
Rock type	Igneous granitic	g
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-g-YNA**

Contact relationships

Late Archean granite sheets, plugs, and dykes intrude Archean granitic gneiss and tectonically interleaved mafic and metasedimentary rocks of the Narryer Terrane.

Geochronology

A-g-YNA	*Maximum*	*Minimum*
Age (Ma)	2630 ± 4	2608 ± 3
Age	Neoarchean	Neoarchean
Source	Isotopic	Isotopic
References	Nelson, 1998a	Nelson, 1998b

References

Kinny, PD, Wijbrans, JR, Froude, DO, Williams, IS and Compston, W 1990, Age constraints on the geological evolution of the Narryer Gneiss Complex, Western Australia: Australian Journal of Earth Sciences, v. 37, p. 51–69.

Myers, JS 1990, Part 1 — Summary of the Narryer Gneiss Complex, in Third International Archean Symposium, Perth, 1990, Excursion Guidebook edited by SE Ho, JS Glover, JS Myers, and JR Muhling: University of Western Australia, Geology Department and University Extension, Publication no. 21, p. 62–71.

Nelson, DR 1998a, 142906: coarse porphyritic monzogranite, Beedarry Bore; Geochronology Record 331: Geological Survey of Western Australia, 4p.

Nelson, DR 1998b, 142907: biotite monzogranite dyke, Bilja Well; Geochronology Record 332: Geological Survey of Western Australia, 4p.

Unnamed unit (A-gge-YNA)

Legend narrative

Mesocratic, equigranular to weakly porphyritic, biotite granodiorite; minor grey, weakly porphyritic, fine-grained tonalite; metamorphosed

Rank	Formation
Parent	Unnamed unit (A-gg-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Overlying units	A-gme-YNA
Underlying units	A-mgnw-YNA, A-mgnl-YNA

Summary

Equigranular, biotite granodiorite is a very minor component of the Narryer Terrane and Yarlarweelor Gneiss Complex. It forms a small, multiphase intrusion in the Yarlarweelor Gneiss Complex, and several sheet-like bodies within fault slices of Archean granitic gneiss in the Errabiddy Shear Zone. The pluton in the Yarlarweelor Gneiss Complex also contains dark-grey, weakly porphyritic, fine-grained tonalite.

Distribution

Equigranular, biotite granodiorite forms the bulk of a complex, multiphase intrusion centred about 3 km west-southwest of Mount Marquis on MARQUIS. It forms a pluton, which is about 3.5 km long and 2 km wide, with two smaller exposures (<0.1 km^2) about 2 and 3.5 km north of the main pluton. Several sheet-like intrusions of equigranular, biotite-rich granodiorite intrude Archean granitic gneisses in the southeastern corner of LANDOR. The largest of these intrusions extends eastwards onto ERRABIDDY. The intrusions are up to 2 km long and up to 400 m wide, and were emplaced sub-parallel to the trend of the layering in the gneisses. Where east-northeasterly trending shear zones cut the granodiorite, it resembles mesocratic granitic gneiss. Equigranular biotite granodiorite forms rounded hills or low rises, mainly covered with boulders and small tors, as well as whalebacks and large pavements.

Lithology

The most abundant rock type is grey, medium-grained, equigranular or weakly porphyritic granodiorite. Plagioclase phenocrysts constitute a few percent of the rock. Locally the rock is a tonalite or mesocratic monzogranite. Angular and lenticular inclusions of fine-grained mafic rock up to 20 cm long, and clots of fine-grained biotite less than 5 mm in diameter, are widespread in all rock types. In most samples, quartz is extensively recrystallized to fine-grained aggregates. Plagioclase is largely replaced by albite–oligoclase and fine-grained epidote and sericite. Microperthite crystals display deformation lamellae and ribbon-like zones of fine-grained recrystallized K-feldspar. Accessory minerals are apatite, zircon, allanite, and either magnetite or ilmenite, or both.

In the pluton on MARQUIS, the granodiorite has locally intruded and broken up a dark-grey, weakly porphyritic, fine-grained tonalite. The fine-grained tonalite is composed of a few percent plagioclase phenocrysts in a fine-grained groundmass of plagioclase (andesine), quartz, biotite, sparse microcline, and accessory allanite, zircon, and apatite. Fine-grained secondary epidote and titanite are abundant.

Fine-grained, mafic inclusions are a minor, but widespread component of the biotite granodiorite. In the northern part of the pluton on MARQUIS, the inclusions are locally abundant (e.g. Zone 50, MGA 570140E 7203950N). The inclusions are lenticular or subangular, and most are about 2–7 cm long. Many of the inclusions have a slightly coarser grained, 2–3 mm-wide biotite-rich rim. The dark-grey, weakly porphyritic, fine-grained tonalite phase contains up to about 10–30% of the same mafic inclusions.

Age code	Archean	A-
Rock type	Igneous granitic	g
Lithname	granodiorite	g
1st qualifier	even-grained/even textured/ equigranular	e
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-gge-YNA**
Additional lithologies	tonalite	

Contact relationships

Equigranular, biotite-rich granodiorite intrudes Archean granitic gneisses (A-mgnw-YNA, A-mgnl-YNA). On LANDOR, the granodiorite is intruded by dykes and veins of Neoarchean pale-grey, medium-grained, equigranular biotite granite (A-gme-YNA). Equigranular granodiorite is intruded by foliated and weakly banded, medium-grained, equigranular monzogranite (P_-MO-gmeb) about 3 km southwest of Round Yard Bore (Zone 50, MGA 570430E 7207040N and 570540E 7208140N) on MARQUIS. At the latter locality, veins of the monzogranite intrude grey, gneissic, biotite granodiorite, and are folded along with the host rock. The granodiorite is also intruded by medium- to coarse-grained, porphyritic monzogranite of the Discretion Granite, 3 km southwest of Round Yard Bore (Zone 50, MGA 570540E 7208030N) and 2 km southwest of Mount Marquis (Zone 50, MGA 572230E 72033150N).

Geochronology

A-gge-YNA	*Maximum*	*Minimum*
Age (Ma)	–	2608
Age	Neoarchean	Neoarchean
Source	–	Inferred
References	–	Nelson, 1998

The equigranular biotite granodiorite has not been dated directly. However, on ERRABIDDY, the granodiorite is intruded by equigranular, biotite monzogranite (A-gme-YNA) dated at 2608 ± 3 Ma (Nelson, 1998), indicating that the granodiorite is Archean.

References

Nelson, DR 1998, 142907: biotite monzogranite dyke, Bilja Well; Geochronology Record 332: Geological Survey of Western Australia, 4p.

Unnamed unit (A-gme-YNA)

Legend narrative

Equigranular, medium-grained, biotite monzogranite; locally quartz–sericite schist; massive to strongly foliated; metamorphosed

Rank	Formation
Parent	Unnamed unit (A-gm-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Overlying units	P_-MO-mgp
Underlying units	A-mgnl-YNA, A-mgnw-YNA

Summary

Dykes, veins and small plutons of Neoarchean equigranular, medium-grained monzogranite are widespread in the Narryer Terrane. At c. 2610 Ma, they are amongst the youngest rocks in the terrane, intruding a wide range of granitic gneisses and supracrustal rocks. Many of the monzogranites are undeformed or weakly deformed, although in the Errabiddy Shear Zone the rocks may be strongly deformed. Elsewhere in the Yarlarweelor Gneiss Complex, equigranular, medium-grained monzogranite becomes part of the Paleoproterozoic gneissic fabric.

Distribution

Dykes, veins, and sheets of pale-grey, medium-grained, equigranular biotite granite are abundant in Archean gneisses of the Narryer Terrane on ERRABIDDY, and LANDOR, and on the western part of MOORARIE. Medium-grained, equigranular biotite granite forms thick sheets or lenticular plugs up to about 600 m wide west and southwest of Errabiddy Homestead. Elsewhere, the granite forms veins and thin dykes up to about 1 m wide. Heterogeneously deformed equigranular biotite monzogranite also outcrops in the western part of MOORARIE. This granite outcrops as low hills and along small breakaways in a belt that extends south-southwest from Three Corners Bore into the Curran Bore area. The granite is poorly exposed and, for the most part, covered by a thin layer of colluvium and quartz-vein rubble. Between Bedaburra Pool and Southern Cross Well, a massive, equigranular, fine- to medium-grained biotite monzogranite outcrops in a few places amongst quartz-vein rubble. Medium-grained, equigranular biotite granite also forms an elliptical pluton, about 3 km wide and 5 km long, south-southwest of Cockarra Well across the boundary between ERRABIDDY and GOULD to the south.

Lithology

Medium-grained, equigranular biotite monzogranite is mostly massive or weakly foliated, but in the Errabiddy Shear Zone locally it is strongly foliated where overprinted by narrow, east-northeasterly trending shear zones. In central western MOORARIE the monzogranite is commonly strongly foliated, and in places comprises quartz–sericite schist. The monzogranite includes a rare, weakly porphyritic variety with up to 5% tabular phenocrysts of microcline commonly about 5 mm long. Biotite (~10%) is the sole mafic mineral. Accessory minerals consist of ilmenite, magnetite, apatite, zircon, monazite, and allanite. A low-grade metamorphic overprint is evident from replacement of igneous plagioclase by ?albite, sericite, and clinozoisite, and titanite rims on ilmenite crystals. In addition, most of the quartz has been recrystallized to fine-grained polygonal aggregates.

Age code	Archean	A-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	even-grained/even textured/ equigranular	e
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-gme-YNA**

Contact relationships

In the Errabiddy Shear Zone, medium-grained equigranular biotite monzogranite forms veins and thin dykes up to about 1 m wide, which typically trend 070–080°, parallel or subparallel to the layering in the Archean granitic gneisses (A-mgnl-YNA, A-mgnw-YNA). However, some biotite monzogranite dykes intrude the granitic gneisses at a high angle to layering. On GOULD, the granite contains inclusions of leucocratic granitic gneiss (A-mgnl-YNA). In both the Errabiddy Shear Zone and in the Narryer Terrane on northeastern GOULD, medium-grained equigranular biotite monzogranite is intruded by veins and sheets of variably metamorphosed and deformed coarse-grained granite and pegmatite (P_-MO-mgp).

Geochronology

A-gme-YNA	*Maximum*	*Minimum*
Age (Ma)	2608 ± 3	2608 ± 3
Age	Neoarchean	Neoarchean
Source	Isotopic	Isotopic
References	Nelson, 1998	Nelson, 1998

A dyke of equigranular biotite monzogranite, which intruded mesocratic granitic gneiss (A-mgnw-YNA) and mesocratic porphyritic biotite monzogranite (A-gmp-YNA) about 1 km north-northwest of Bilja Well, on southwestern ERRABIDDY was sampled for SHRIMP U–Pb zircon geochronology and yielded an igneous crystallization age of 2608 ± 3 Ma (Nelson, 1998).

References

Nelson, DR 1998, 142907: biotite monzogranite dyke, Bilja Well; Geochronology Record 332: Geological Survey of Western Australia, 4p.

Unnamed unit (A-gmpw-YNA)

Legend narrative

Mesocratic, medium-grained, very strongly porphyritic biotite monzogranite; ranges from massive to gneissic; metamorphosed

Rank	Member
Parent	Unnamed unit (A-gmp-YNA)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Overlying units	A-gme-YNA
Underlying units	A-mgnl-YNA, A-mgnw-YNA, A-mwa-YNA

Summary

Mesocratic porphyritic biotite monzogranite is only recognized in the Narryer Terrane in the southwestern corner of ERRABIIDY and in the southeastern corner of LANDOR. In the Yarlarweelor Gneiss Complex, mesocratic porphyritic biotite monzogranite is gneissic and cannot be separated from older components of the reworked mesocratic granitic gneiss (AP_-mgnw-YNAY). A sample of the monzogranite has been dated using SHRIMP U–Pb zircon geochronology at 2630 ± 4 Ma.

Distribution

Mesocratic porphyritic biotite monzogranite forms several small plugs, the largest of which, located 6 km east-southeast of Billycan Bore on LANDOR (at Zone 50, MGA 498740E 7181340N), is about 1 km^2 in area. The plugs contain up to 50% inclusions of banded leucocratic and mesocratic granitic gneiss (A-mgnw-YNA, A-mgnl-YNA) and amphibolite (A-mwa-YNA). Veins of mesocratic porphyritic biotite monzogranite are also widespread in the granitic gneisses west of Errabiddy Homestead. In these areas, individual east- to east-northeasterly trending shear zones that constitute the Errabiddy Shear Zone, may preserve a transition from mesocratic porphyritic biotite monzogranite to porphyritic mesocratic granitic gneiss. Mesocratic porphyritic biotite monzogranite is probably present in the Yarlarweelor Gneiss Complex, but is now part of the Paleoproterozoic gneissic fabric.

Lithology

Mesocratic porphyritic biotite monzogranite consists of round phenocrysts of microcline, up to 5 cm in diameter, and smaller tabular plagioclase phenocrysts set in a dark-grey, fine- to medium-grained groundmass. The groundmass is composed of variably recrystallized quartz, andesine, microcline, and biotite, with accessory apatite, zircon, and allanite. Small crystals of partly hydrated allanite are ubiquitous. Andesine is partly replaced by sericite and clinozoisite. Magnetite is pseudomorphed by epidote. Microcline crystals commonly display deformation lamellae and ribbon and chequerboard microperthite textures.

Age code	Archean	A-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	porphyritic	p
2nd qualifier	megacrystic	w
Tectonic unit code	Narryer Terrane	-YNA
Rock code		**A-gmpw-YNA**

Contact relationships

Plugs and veins of mesocratic porphyritic biotite monzogranite intrude Archean leucocratic and mesocratic granitic gneiss (A-mgnl-YNA, A-mgnw-YNA) and amphibolite (A-mwa-YNA). Mesocratic porphyritic biotite monzogranite is intruded by veins and dykes of Neoarchean medium-grained, equigranular biotite granite (A-gme-YNA).

Geochronology

A-gmpw-YNA	*Maximum*	*Minimum*
Age (Ma)	2630 ± 4	2630 ± 4
Age	Neoarchean	Neoarchean
Source	Isotopic	Isotopic
References	Nelson, 1998a	Nelson, 1998a

A plug of mesocratic porphyritic biotite monzogranite east of Bilja Well on southwestern ERRABIIDY yielded an igneous crystallization age of 2630 ± 4 Ma (Nelson, 1998). This date is within uncertainty of the youngest zircon age component (2637 ± 3 Ma) in a sample of reworked mesocratic granitic gneiss (AP_-mgnw-YNA; GSWA 142853) from MARQUIS (Nelson, 1998b).

References

Nelson, DR 1998a, 142906: coarse porphyritic monzogranite, Beedarry Bore; Geochronology Record 331: Geological Survey of Western Australia, 4p.

Nelson, DR 1998b, 142853: granite gneiss, Jubilee Well rockhole; Geochronology Record 369: Geological Survey of Western Australia, 4p.

Unnamed unit (A-mg-YNAY)

Legend narrative

Undivided; foliated metagranite

Rank	Supersuite
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	CAPRICORN OROGEN, Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA

Summary

Foliated metagranite of the Yarlarweelor Gneiss Complex comprises only augen gneiss and foliated porphyritic metamonzogranite (A-mgmu-YNAY). This unit outcrops on ERRABIDDY.

Distribution

Foliated metagranite of the Yarlarweelor Gneiss Complex forms a series of sheets that intrude Archean and reworked leucocratic granitic gneisses on ERRABIDDY.

Lithology

The sole rock type is a foliated porphyritic metamonzogranite or augen gneiss with about 30–40% round phenocrysts of microcline in a medium-grained (2–3 mm) groundmass.

Age code	Archean	A-
Rock type	meta-igneous felsic intrusive	
Lithname	metagranitic rock	mg
Tectonic unit code	Yarlarweelor Gneiss Complex	-YNAY
Rock code		**A-mg-YNAY**

Contact relationships

Foliated metagranite intruded both Archean and reworked leucocratic granitic gneiss (A-mgnl-YNA, AP_-mgnl-YNAY), and is intruded by veins or dykes of medium-grained, equigranular biotite monzogranite (A-gme-YNA) and sheets and veins of medium- to very coarse-grained metagranite and pegmatite (P_-MO-mgmp).

Geochronology

A-mg-YNAY	*Maximum*	*Minimum*
Age (Ma)	2630	2608 ± 3
Age	Neoarchean	Neoarchean
Source	Inferred	Isotopic
References	–	Nelson, 1998

Details of the age of the foliated metagranite are contained in the description for the foliated porphyritic metamonzogranite and augen gneiss (A-mgmu-YNAY).

Reference

Nelson, DR 1998, 142907; biotite monzogranite dyke, Bilja Well; Geochronology record 332: Geological Survey of Western Australia, 4p.

WARRIGAL GNEISS
(A-_wa-mgmn)

Legend narrative

Foliated to gneissose, even-textured to sparsely porphyritic metamonzogranite; locally contains sheets and pods of amphibolite; cut by c. 1800 Ma pegmatite dykes. Deformation is Paleoproterozoic

Rank	Formation
Parent	Unnamed unit (A-mg-YNAY)
Tectonic units	Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA

Summary

The Warrigal Gneiss consists of late Archean granites that intruded the Narryer Terrane of the Yilgarn Craton, and were deformed and metamorphosed during the Paleoproterozoic Glenburgh and Capricorn Orogenies. The Warrigal Gneiss forms fault-bounded inliers within Paleoproterozoic rocks of the Camel Hills Metamorphics, and may have either formed basement to the sedimentary protoliths to the Camel Hills Metamorphics or was tectonically interleaved and later folded with them.

Distribution

The Warrigal Gneiss forms fault-bounded inliers within Paleoproterozoic rocks of the Camel Hills Metamorphics on LANDOR and ERONG.

Lithology

On LANDOR the Warrigal Gneiss consists of leucocratic and mesocratic, well-foliated to gneissic granite that is locally pegmatite banded. The relationships between different granite phases of the gneiss are complex, but in places dykes of both leucocratic and mesocratic granitic components intrude each other. The leucocratic component is biotite-bearing monzogranite. It is equigranular and medium grained, with a foliation defined by sparse biotite. The mesocratic component is also biotite-bearing monzogranite, which is pale grey, fine to medium grained, and equigranular, and locally porphyritic. Feldspar phenocrysts are up to 1 cm in diameter and commonly rounded. The Warrigal Gneiss has been described by Occhipinti et al. (2003).

Age code	Archean	A-
Stratigraphic code	WARRIGAL GNEISS	_wa-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	—	
2nd qualifier	gneissose	n
Rock code		**A-_wa-mgmn**
Additional lithologies	amphibolite derived from intrusive rock	

Contact relationships

Both the mesocratic and leucocratic components of the Warrigal Gneiss are cut by amphibolite, probably representing late Archean to early Paleoproterozoic dykes. All of the components of the gneiss were intruded by sheets and veins of medium- to very coarse-grained metagranite and pegmatite (P_-MO-mgmp).

Geochronology

A-_wa-mgmn	*Maximum*	*Minimum*
Age (Ma)	2758 ± 4	2585 ± 8
Age	Neoarchean	Neoarchean
Source	Isotopic	Isotopic
References	Nelson, 2001b	Nelson, 2000b

Four individual granitic components of the Warrigal Gneiss has been dated at three localities within the Errabiddy Shear Zone, yielding SHRIMP U–Pb zircon dates between c. 2758 and c. 2585 Ma (GSWA 139467, 139468, 168941, 168942; Nelson, 2000a,b, 2001a,b). Sample GSWA 139468 consists of a foliated porphyritic monzogranite or granodiorite, which yielded weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ dates of 2606 ± 4 Ma and 2585 ± 8 Ma. These two results were regarded by Nelson (2000b) as ages of crystallization of the two igneous components in the sample; the younger result is the youngest dated component in the Warrigal Gneiss. A monzogranite gneiss sampled about 3.5 km east-northeast of Old Camp Well indicated dates of 2669 ± 2 Ma, 2711 ± 13 Ma, and 2758 ± 4 Ma, and includes the oldest dated component in the Warrigal Gneiss (Nelson, 2001b).

References

Nelson, DR 2000a, 139467: pegmatite-banded monzogranitic gneiss, Black Duck Bore; Geochronology Record 428: Geological Survey of Western Australia, 4p.

Nelson, DR 2000b, 139468: foliated porphyritic biotite monzogranite, Black Duck Bore; Geochronology Record 429: Geological Survey of Western Australia, 4p.

Nelson, DR 2001a, 168941: biotite tonalite dyke, Old Camp Well; Geochronology Record 210: Geological Survey of Western Australia, 4p.

Nelson, DR 2001b, 168942: porphyritic biotite-muscovite monzogranite gneiss, Old Camp Well; Geochronology Record 211: Geological Survey of Western Australia, 4p.

Occhipinti, SA, Sheppard, S, Tyler, IM, Sircombe, KN, Reddy, S, Hollingsworth, D, Martin, DMcB and Thorne, AM 2003, Proterozoic geology of the Capricorn Orogen, Western Australia — a field guide: Geological Survey of Western Australia, Record 2003/16, 64p.

HALFWAY GNEISS
(AP_-_ha-mgn)

Legend narrative

Interlayered leucocratic and mesocratic granitic gneiss, pale-grey granitic gneiss and foliated metagranite, and gneissic to foliated porphyritic metagranodiorite

Rank	Formation
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DA-g, P_-MOdu-ggp, P_-MOsc-gm, P_-MOru-mgm, P_-MO-gmeb, P_-MO-gmp, P_-MO-gp, P_-MO-gmvl, P_-MO-mgnl, P_-MO-mgn, P_-MO-mgmz, P_-MO-xmg-m, P_-DUda-mgmu, P_-DU-mgm, P_-DU-mgmb, P_-DU-mgmt (intrusive and faulted); P_-MGm-mls, P_-MGm-mtsf, P_-MGm-mtq, P_-MG-mk, P_-MG-mkk, P_-mog-GAG, P_-mus-GAG, P_-mwa-GAG, P_-LS-mlsg, P_-LS-mhs, P_-LS-xmh-mw, P_-PO-mkq, P_-POb-mlpc, P_-POb-mlsm, P_-POb-mqef, P_-POb-mtef, P_-POb-mxq, P_-POs-mtqs, P_-MEy-st, (faulted); P_-MGm-mtsf, P_-MEy-st (unconformable)

Summary

Banded granitic gneiss of the Halfway Gneiss consists of several interlayered rock types heterogeneously deformed and metamorphosed to at least amphibolite facies. Despite the metamorphism, original igneous components can be recognized in areas of low strain. Igneous crystallization ages for the granitic protoliths range between 2660 and 2430 Ma.

The Halfway Gneiss comprises interlayered leucocratic granitic gneiss and foliated leucocratic granite, mesocratic granitic gneiss, pale-grey granitic gneiss, gneissic to foliated porphyritic granodiorite, foliated granite, and pegmatite. There are no sharp boundaries between the various rock types as they are interleaved at both mesoscopic and megascopic scales. Two mappable units are recognized within the Halfway Gneiss: leucocratic granitic gneiss and foliated granite (AP_-_ha-mgnl), and mesocratic granitic gneiss (AP_-_ha-mgnw).

Derivation of name

The Halfway Gneiss is named after Halfway Bore on northwestern GLENBURGH (Zone 50, MGA 414500E, 7231240N).

Distribution

The Halfway Gneiss (AP_-_ha-mgn, AP_-_ha-mgnl, and AP_-_ha-mgnw) comprises much of the basement to the Glenburgh Terrane on the northern parts of GLENBURGH, LANDOR, and DAURIE CREEK and the southern and central parts of LOCKIER, YINNETHARRA, PINK HILLS, and CANDOLLE.

Undivided Halfway Gneiss (AP_-_ha-mgn) forms a 50 km long, 25 km wide belt that straddles the southern parts of LOCKIER and YINNETHARRA and northern parts of DAURIE CREEK and GLENBURGH, forming the core of a regional-scale (25 km wavelength) tight to isoclinal, steep southeast-plunging fold. Two outcrops lie on the northern side of the Ti Tree Shear Zone. One is a 14 km-long outcrop on northern PINK HILLS and the other is an isolated inlier on southern CANDOLLE.

Mesocratic gneiss (AP_-_ha-mgnw) forms significant components to the Halfway Gneiss, where it forms numerous disparate, outcrop-scale irregular shaped bodies. However, the mesocratic gneiss does form more coherent, discretely mappable units. On GLENBURGH and DAURIE CREEK, mesocratic gneiss forms an elongate 1 km wide, 8 km long body along the southern margin of the leucocratic gneiss. Farther north on LOCKIER and YINNETHARRA mesocratic gneiss forms a 5 km wide, 50 km long southeast-trending belt that defines the northern limb of the regional-scale fold. On the southwestern corner of YINNETHARRA and southern part of PINK HILLS the unit forms an irregular shaped outcrop some 13 km^2. To the west, the mesocratic unit is found on both sides of the Ti Tree Shear Zone. On the southern side, the mesocratic gneiss forms a 5 km-wide outcrop around the Injinu Hills (PINK HILLS). On the northern side of the Ti Tree Shear Zone on PINK HILLS and CANDOLLE the mesocratic gneiss forms a significant 25 km by 15 km outcrop that is intercalated with massive quartzite of the Moogie Metamorphics and is intruded by various granitic bodies of the Moorarie Supersuite. On CANDOLLE the Mesocratic gneiss forms rafts of elongate material within these younger granitic bodies.

The leucocratic gneiss is present throughout all parts of the Halfway Gneiss, but generally forms disparate outcrop-scale units. Continuous 'mappable' outcrops of leucocratic gneiss are found on GLENBURGH and DAURIE CREEK,where it forms a 6 km-wide, east-west trending linear belt that defines the southern limb of the regional-scale isoclinal fold. The same unit is folded around the southeast trending regional-scale fold hinge where it transects YINNETHARRA and LOCKIER as a northwest-southeast trending belt some 7 km wide.

Lithology

The Halfway Gneiss comprises interlayered leucocratic granitic gneiss and foliated leucocratic granite, mesocratic granitic gneiss, pale grey granitic gneiss and foliated granite, gneissic to foliated porphyritic granodiorite, and pegmatite. There are no sharp boundaries between the various rock types as they are interleaved at both mesoscopic and megascopic scales. Contacts between the various rock types are typically tectonic, although in places igneous intrusive relationships between individual granitic protoliths are preserved. Two mappable units are recognized within the Halfway Gneiss: leucocratic granitic gneiss and foliated granite (AP_-_ha-mgnl), and mesocratic granitic gneiss (AP_-_ha-mgnw). Mapped boundaries of the leucocratic and mesocratic gneisses define areas of dominance of one gneiss type over the others. In areas where neither mesocratic nor leucocratic gneiss dominate, the gneiss is mapped as undivided Halfway Gneiss (AP_-_ha-mgn); however, within AP_-_ha-mgn there are discrete units of pale-grey granitic gneiss that are not present within either the leucocratic or mesocratic portions. The leucocratic and mesocratic components of the Halfway Gneiss are described in the relevant rock units (AP_-_ha-mgnl and AP_-_ha-mgnw).

Pale-grey granitic gneiss and foliated granite is abundant south and southeast of Dunnawah Well, and consists of plagioclase, quartz, biotite, K-feldspar, and epidote, with accessory zircon and titanite. Biotite constitutes about 10% of the rocks. Zircon is commonly euhedral and zoned. The rock is typically fine- to medium-grained, and weakly to moderately pegmatite banded. In lower strain domains, it consists of medium-grained, equigranular or weakly porphyritic biotite metagranodiorite and quartz-rich leucocratic metatonalite, and can be difficult to distinguish from medium-grained biotite(–muscovite) granite (P_-MO-gmeb) of the Moorarie Supersuite. The gneissic layering is defined by biotite- or epidote-rich layers, alternating with quartz- and feldspar-rich layers. Plagioclase often forms large porphyroclasts (up to 7 mm in diameter) enclosed by mica or quartz. In a few layers, quartz grains are flattened and display undulose extinction, whereas in other layers quartz grains are largely polygonal, exhibiting triple junctions. Biotite, commonly with zircon inclusions, defines the foliation and a mineral lineation, and may be completely pseudomorphed by pale-green chlorite. Fine-grained sericite and epidote variably replace plagioclase and K-feldspar.

Age code	Archean–Proterozoic	AP_-
Stratigraphic code	HALFWAY GNEISS	_ha-
Rock type	meta-igneous felsic intrusive	mg
Lithname	granitic gneiss	n
Rock code		**AP_-_ha-mgn**

Contact relationships

The Halfway Gneiss is tectonically interleaved with calc-silicate gneiss, amphibolite, actinolite schist, tremolite schist, and pelitic schist of the Moogie Metamorphics. The original relationship between these supracrustal rocks and the Halfway Gneiss is unknown, although the ages of detrital zircon from several psammitic and pelitic schists and quartzites from the Mumba Psammite (Johnson et al., 2010) indicate that they were derived from the Halfway Gneiss by erosion sometime after c. 2250 Ma. A rare series of outcrops on the southern part of Yinnetharra (e.g. SPJYIN000220; Zone 50, MGA 412464E 7240270N) demonstrate that psammitic schists of the Moogie Metamorphics (P_-MGm-mtsf) have near-horizontal bedding planes which are sub-parallel to the schist contact with the underlying mesocratic gneiss, possibly representing a paleo-unconformity. The relationships with the structurally overlying Leake Spring Metamorphics are unclear, everywhere being in apparent faulted contact. Low-grade metasandstone and metaconglomerate of the Mount James Subgroup (Biddenew Formation) are mainly in faulted contact with the Halfway Gneiss but presumably these metasedimentary rocks were originally unconformable on the gneiss as reflected by the large 2500–2450 Ma detrital zircon components in the uppermost marine psammites of the Spring Camp Formation (e.g. GSWA 185953 and 185954). Surprisingly, the lowermost Mount James Subgroup metaconglomerates do not contain clasts derived from the Halfway Gneiss, nor the underlying Glenburgh Terrane. Based on regional scale map patterns along the southern margin of Pink Hills and northernmost part of Landor, the lowermost unit of the Mesoproterozoic Edmund Group, the Yilgatherra Formation, must unconformably overlie the Halfway Gneiss.

The Halfway Gneiss is extensively intruded by sheets and dykes of the Dumbie Granodiorite (P_-MOdu-ggp), plutons, dykes, and veins of the Scrubber Granite (P_-MOsc-gm), and numerous plutons from both the Moorarie and Durlacher Supersuites. The age of c. 2005 Ma (Nelson, 2001a) obtained from the youngest phase of the Halfway Gneiss indicates that leucocratic igneous material from the Dalgaringa Supersuite forms a volumetrically minor part of the gneiss.

Geochronology

AP_-_ha-mgn	*Maximum*	*Minimum*
Age (Ma)	2663 ± 7	2429 ± 4
Age	Neoarchean	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2000a	Wingate et al., 2009

Seven samples of the Halfway Gneiss have been dated using SHRIMP U–Pb zircon methods; six of these were dated by GSWA, and the remaining sample was dated by Kinny et al. (2004). Three of the dated samples were from undivided Halfway Gneiss (AP_-_ha-mgn; GSWA 164309, GSWA 168950, NP21), two of leucocratic gneiss (AP_-_ha-mgnl; GSWA 188955, GSWA 168947) and two of mesocratic gneiss (AP_-_ha-mgnw; GSWA 142988, GSWA 188973). Four of the samples indicated Neoarchean crystallization ages for the precursor granites, two yielded early Paleoproterozoic ages, and the remaining sample has a crystallization age indistinguishable from those of granitic rocks of the Paleoproterozoic Dalgaringa Supersuite.

A pale-grey augen gneiss (AP_-_ha-mgn) derived from biotite granodiorite was collected about 1 km southeast of Middle Well (Zone 50, MGA 413616E 7225303N) on northern Glenburgh. This sample yielded a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 2544 ± 5 Ma, interpreted as the crystallization age of the granodiorite precursor, and an older weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 2563 ± 8 Ma, interpreted as representing xenocrysts (Nelson, 2000b). A sample (Zone 50, MGA 360390E 7165760N) of pegmatite-banded tonalitic gneiss (AP_-_ha-mgn) from the Carrandibby Inlier on Carrandibby yielded a complex array of concordant to slightly discordant analyses, with the discordance pattern consistent with several episodes of radiogenic Pb redistribution, including an episode at c. 1900 Ma (Nelson, 2001b). Six analyses provide a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 2515 ± 5 Ma and is interpreted to reflect crystallization age of the gneiss; older dates are interpreted to be of xenocrystic zircons, and younger dates to reflect ancient Pb loss, most likely at c. 1900 Ma (Nelson, 2001b). A sample (NP21) from the same gneiss unit (AP_-_ha-mgn) was also dated at 2508 ± 5 Ma by Kinny et al. (2004). However, one analysis of a low-Th/U zircon overgrowth indicated a date of c. 2390 Ma, suggesting that this gneiss was metamorphosed at this time.

A sample of medium-grained leucocratic gneiss (AP_-_ha-mgnl; Zone 50, MGA 428780E 7244930N) was collected about 350 m south of a disused beryl mine on southeast YINNETHARRA. The gneiss yielded many zircons, most of which contained high common-Pb contents. Several age components were dated between c. 2835 and c. 2340 Ma. Seven of these analyses yielded a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 2528 ± 10 Ma, and two indicated dates of c. 2350 Ma (Kirkland et al., 2009). It is possible that the c. 2530 Ma date represents crystallization of the monzogranitic precursor to the gneiss, whereas the younger dates represent younger age components of the gneiss such as thin leucocratic veins. However, the gneiss protoliths could be as young as c. 2350 Ma.

In addition to the Neoarchean ages determined for the Halfway Gneiss, Nelson (2001a) dated a leucocratic granitic gneiss (AP_-_ha-mgnl) derived from biotite monzogranite on DAURIE CREEK (Zone 50, MGA 381950E 7230840N). The igneous crystallization age of the precursor granite to the gneiss was defined as 2006 ± 6 Ma (Nelson, 2001a). This result suggests that the Halfway Gneiss contains some elements of the Dalgaringa Supersuite.

Nelson (2000a) also dated the tonalitic component of a mesocratic, banded granitic gneiss (AP_-_ha-mgnw) immediately west of Dunnawah Well on northwestern GLENBURGH. This sample contains several concordant zircon age components, at 2550 ± 7 Ma, 2663 ± 7 Ma, 2709 ± 10 Ma, and c. 3300 Ma or older. Nelson (2000a) suggested that the 2663 ± 7 Ma date represents igneous crystallization of the tonalite precursor, and the 2550 ± 7 Ma date corresponds to thin pegmatite veins in the sample. Occhipinti and Sheppard (2001) preferred the interpretation that the youngest date at 2550 ± 7 reflects the igneous crystallization of the precursor tonalite. However, follow-up work on this sample failed to identify any more zircons of c. 2550 Ma age; all additional analysed grains were c. 2660 Ma or older, indicating that the original interpretation of Nelson (2000a) may be correct.

A single sample of mesocratic gneiss was dated from the Limejuice zone on central, southern PINK HILLS (GSWA 188973). This granodioritic gneiss yielded numerous zircons of magmatic origin, the majority of which yielded a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 2429 ± 4 Ma, interpreted as the crystallization age of the gneiss protolith (Wingate et al., in prep.).

References

Kirkland, CL et al., 2009, 185955: Leucogranite gneiss, 500 m south of old Beryl mine YINNETHARRA.

Nelson, DR 2000a, 142988: biotite tonalite, Dunnawah Bore; Geochronology Record 291: Geological Survey of Western Australia.

Nelson, DR 2000b, 164309: foliated porphyritic biotite granodiorite, Middle Well; Geochronology Record 217: Geological Survey of Western Australia, 5p.

Nelson, DR 2001a, 168947: biotite-muscovite monzogranite gneiss, Weedarrah Homestead; Geochronology Record 185: Geological Survey of Western Australia, 4p.

Nelson, DR 2001b, 168950: pegmatite-banded biotite tonalite gneiss, Yanderra Well; Geochronology Record 188: Geological Survey of Western Australia, 4p.

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HALFWAY GNEISS; subunit (AP_-_ha-mgnl)

Legend narrative

Leucocratic granitic gneiss and foliated leucocratic metagranite; derived from biotite monzogranite and granodiorite

Rank	Member
Parent	HALFWAY GNEISS (AP_-_ha-mgn)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DA-g, P_-MOdu-ggp, P_-MOsc-gm, P_-MOru-mgm, P_-MO-gmeb, P_-MO-gmp, P_-MO-gp, P_-DUda-mgmu, P_-DU-mgmt (intrusive and faulted); P_-MGm-mls, P_-MGm-mtsf, P_-MG-mkq, P_-MG-mkk, P_-mus-GAG, P_-mwa-GAG, P_-LS-mlsg, P_-LS-mhs, P_-LS-xmh-mw, P_-POb-mqef, P_-POs-mtqs (faulted); P_-MGm-mtsf (unconformable)

Summary

Medium grained leucocratic granitic gneiss forms a series of linear belts along the southern and northern margins of the known outcrops of Halfway Gneiss on GLENBURGH and DAURIE CREEK, and YINNETHARRA, PINK HILLS, and LOCKIER respectively. There are no sharp boundaries between the leucocratic, undivided (AP_-_ha-mgn) and mesocratic (AP_-_ha-mgnw) portions as they are interleaved at both mesoscopic and megascopic scales. The leucocratic gneiss is generally very homogenous locally showing weak to moderate pegmatite-banding and flaser textured gneissic fabrics defined by discontinuous layers of biotite. On southern YINNETHARRA, a medium-grained, pegmatite-banded, leucocratic biotite metamonzogranite was dated at c. 2530 Ma and contained a younger component at c. 2350 Ma; interpreted to represent the age of the pegmatite intrusions. On DAURIE CREEK, a banded leucocratic gneiss gave an age of c. 2005 Ma suggesting that the present-day southern margin of the Halfway Gneiss contains intrusions of the Dalgaringa Supersuite.

Distribution

Leucocratic granitic gneiss is present along the southern and northern margins of the Halfway Gneiss. On the southern margin the gneiss forms an east–west trending belt that dissects GLENBURGH and DAURIE CREEK. The unit is folded around a southeast trending regional-scale fold hinge where it transects PINK HILLS, YINNETHARRA, and LOCKIER as a northwest-southeast trending belt some 7 km wide. On southeastern YINNETHARRA this belt of leucocratic granitic gneiss bifurcates with one branch extending 20 km eastward across to the northern side of the Chalba Shear Zone, immediately south of Mount James and northeast of Daly Bore.

Lithology

Leucocratic granitic gneiss is medium grained, with thin discontinuous layers of biotite giving it a flaser texture and defining the foliation or gneissic layering. The gneiss ranges from weakly to moderately pegmatite banded. Lower strain domains of the gneiss consist of foliated, coarse-grained porphyritic biotite metagranite, and minor foliated fine- to medium-grained, equigranular metagranite and may contain metre- to decimetre-scale inclusions or strips of recrystallized quartzite and calc-silicate rock. Precursors to the gneiss range in composition from granodiorite to monzogranite. The porphyritic granite contains about 10–30% round and squat, 1–3 cm-long, tabular phenocrysts of microperthite, in a groundmass of plagioclase, quartz, microperthite, and a few percent biotite, with or without muscovite. The rocks commonly contain micrographic and myrmekitic textures.

Age code	Archean–Proterozoic	AP_-
Stratigraphic code	HALFWAY GNEISS	_ha-
Rock type	meta-igneous felsic intrusive	mg
Lithname	granitic gneiss	n
1st qualifier	—	
2nd qualifier	leucocratic	l
Rock code		**AP_-_ha-mgnl**

Contact relationships

Leucocratic granitic gneiss is tectonically interleaved with undivided Halfway Gneiss (AP_-_ha-mgn) and mesocratic granitic gneiss (AP_-_ha-mgnw), as well as a range of rock types belonging to the Moogie Metamorphics and younger meta-igneous rocks of the Moorarie and Durlacher Supersuites. The 2006 ± 6 Ma age determined for a foliated leucocratic metagranite, implies that at least some of the leucocratic granitic gneiss (originally part of the Dalgaringa Supersuite) must have intruded the Halfway Gneiss, but original field relationships have been obliterated by multiple tectonic and metamorphic events.

Geochronology

AP_-_ha-mgnl	*Maximum*	*Minimum*
Age (Ma)	2528 ± 10	2528 ± 10
Age	Neoarchean	Neoarchean
Source	Isotopic	Isotopic
References	Wingate et al., 2010	Wingate et al., 2010

In addition to Neoarchean ages determined for the undivided Halfway Gneiss (AP_-_ha-mgn) and the mesocratic component (AP_-_ha-mgnw), Nelson (2001) dated a leucocratic granitic gneiss (AP_-_ha-mgnl) derived from biotite monzogranite on DAURIE CREEK (Zone 50, MGA 381950E 7230840N). The igneous crystallization age of the precursor granite to the gneiss was defined as 2006 ± 6 Ma (Nelson, 2001). This result suggests that the Halfway Gneiss contains some elements of the Dalgaringa Supersuite. Another sample, from a broad swath of leucocratic foliated granites and gneisses in the Chalba Shear Zone on YINNETHARRA, yielded numerous concordant dates between c. 2820 and c. 2340 Ma. The largest group (7 analyses) indicated a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 2528 ± 10 Ma possibly representing the age of crystallization of the monzogranite protolith (Wingate et al., 2010). However, a younger group provided a date of c. 2350 Ma and represents either a younger component (such as thin pegmatite or granitic veins) to the gneiss or possibly the age of crystallization of the gneiss protolith. No zircons with dates as young as c. 2000 Ma were identified, suggesting that the Halfway Gneiss is mainly c. 2660–2430 Ma in age, and that the younger dates, such as the 2006 Ma result of Nelson (2001), may only occur along the southern margin of the gneiss where it is in (presumably intrusive) contact with the younger Dalgaringa Supersuite.

References

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Nelson, DR 2001, 168947: biotite-muscovite monzogranite gneiss, Weedarrah Homestead; Geochronology Record 185: Geological Survey of Western Australia, 4p.

HALFWAY GNEISS; subunit (AP_-_ha-mgnw)

Legend narrative

Mesocratic granitic gneiss; derived from variably porphyritic tonalite

Rank	Member
Parent	HALFWAY GNEISS (AP_-_ha-mgn)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MOdu-ggp, P_-MOsc-gm, P_-MOru-mgm, P_-MO-gmeb, P_-MO-gmvl, P_-MO-gp, P_-MO-xmg-m, P_-DUda-mgmu, P_-DU-mgm, P_-DU-mgmb, P_-MW-od (intrusive and faulted); P_-MGm-mls, P_-MGm-mtsf, P_-MGm-mtq, P_-MG-mkq, P_-LS-mhs, P_-PO-mkq, P_-POb-mlpc, P_-POb-mlsm, P_-POb-mqef, P_-POb-mtef, P_-POb-mxq, P_-POs-mtqs, P_-MEy-st, (faulted); P_-MGm-mtsf, P_-MEy-st (unconformable)

Summary

Medium grained, pegmatite banded mesocratic gneiss forms a series of irregular bodies interleaved and interfolded with undivided and leucocratic portions of the Halfway Gneiss on GLENBURGH, DAURIE CREEK, LANDOR, LOCKIER, YINNETHARRA, PINK HILLS, and CANDOLLE. The gneiss is comprised of variably deformed porphyritic metatonalite with subordinate porphyritic metagranodiorite. In low strain zones the equigranular tonalitic gneiss protolith contains up to 30% ovoid, squat, and occasionally amoeboid plagioclase phenocrysts that under increasing strain progressively become flattened and elongate to form discontinuous leucocratic gneissic fabrics. Field relationships suggest that the pegmatitic portions of the gneiss were intruded during several magmatic episodes. A metatonalitic portion of the gneiss on GLENBURGH, immediately west of Dunnawah Bore, yielded a crystallization age of c. 2660 Ma, whereas a granodioritic gneiss east of Mt James Homestead on PINK HILLS, yielded a crystallization age of c. 2430 Ma. Similar to other portions of the Halfway Gneiss, the mesocratic gneiss is tectonically interleaved with various units of the Moogie Metamorphics, although the sediments may have originally been deposited unconformably on the gneiss. The gneiss is intruded by various metagranitic rocks of the Moorarie and Durlacher Supersuites.

Distribution

Mesocratic gneiss is a significant component of the Halfway Gneiss which comprises the basement of the Glenburgh Terrane. The mesocratic gneiss outcrops as numerous irregular shaped bodies. On GLENBURGH and DAURIE CREEK, mesocratic gneiss forms an elongate 1 km wide, 8 km long body along the southern margin of the leucocratic gneiss. Farther north on LOCKIER and YINNETHARRA mesocratic gneiss forms a 5 km wide, 50 km long southeast-trending belt that defines the northern limb of the regional-scale fold. On the southwestern corner of YINNETHARRA and southern part of PINK HILLS the unit forms an irregular shaped outcrop some 13 km^2. To the west, the mesocratic unit is found on both sides of the Ti Tree Shear Zone. On the southern side, the mesocratic gneiss forms a 5 km-wide outcrop around the Injinu Hills (PINK HILLS). On the northern side of the Ti Tree Shear Zone on PINK HILLS and CANDOLLE the mesocratic gneiss forms a significant 25 km by 15 km outcrop that is intercalated with massive quartzite of the Moogie Metamorphics and is intruded by various granitic bodies of the Moorarie Supersuite. On CANDOLLE the Mesocratic gneiss forms rafts of elongate material within these younger granitic bodies.

Lithology

Mesocratic granitic gneiss is a fine- or medium-grained, pegmatite-banded, dark-grey rock. Lower strain domains of the gneiss consist of foliated, fine-grained, weakly porphyritic metatonalite and medium-grained, strongly porphyritic metatonalite. Pegmatite banding is variable across the outcrops, with pegmatites of various generations comprising 5–30% of the gneiss. On southern YINNETHARRA and central PINK HILLS, pegmatite banded metagranodiorite is locally more prevalent than the metatonalite. Within the low strain areas, the fine-grained metatonalites typically contain about 10% round plagioclase phenocrysts a few millimetres in diameter, whereas the medium-grained units contain up to 30% round, squat, or occasionally amoeboid plagioclase phenocrysts, about 5–20 mm in diameter. The groundmass consists of plagioclase, quartz, and biotite (15–20% of the rock), with accessory apatite and zircon. Some amoeboid textures are present, implying metamorphism at medium-to high-grade. Quartz and plagioclase commonly define a grain-flattening fabric. In the metagranodiorite parts of the gneiss, similar textures and mineral phases are present, except that K-feldspar becomes more prominent in the matrix and can locally comprise up to 20% of the phenocrysts.

Age code	Archean–Proterozoic	AP_-
Stratigraphic code	HALFWAY GNEISS	_ha-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	n
1st qualifier	—	
2nd qualifier	mesocratic	w
Rock code		**AP_-_ha-mgnw**

Contact relationships

Mesocratic gneiss is tectonically interleaved and folded with leucocratic (AP_-_ha-mgnl) and undivided (AP_-_ha-mgn) Halfway Gneiss at both mesoscopic and megascopic scales so that the boundaries are commonly hard to define. Similar to the other Halfway Gneiss units, the mesocratic component is interleaved and folded with various units of the Moogie Metamorphics, especially the Mumba Psammite. On the southern part of YINNETHARRA (e.g. SPJYIN000220; Zone 50, MGA 412464E 7240270N) psammitic schists of the Mumba Psammite (P_-MGm-mtsf) have near-horizontal bedding planes which are sub-parallel to the schist–mesocratic-gneiss contact, possibly representing a paleo-unconformity. The relationships with the structurally overlying Leake Spring Metamorphics (specifically P_-LS-mhs) are unclear, everywhere being in apparent faulted contact. In an arcuate outcrop between Mount James and Mount Gascoyne, low-grade metasandstone and metaconglomerate of the Mount James Subgroup (Biddenew Formation) are partly in faulted contact, but in the main are presumably in unconformable contact with the underlying mesocratic gneiss. Interestingly, the basal conglomerate (P_-POb-mxq) contains only a near unimodal composition of clasts (quartz vein clasts) and does not contain any clasts of Halfway Gneiss. Detrital zircon components in the uppermost marine psammites of the Spring Camp Formation (e.g. GSWA 185953 and 185954), collected 5 km to the west of Mount James, suggest that these sediments were locally sourced, in part from the underlying mesocratic gneiss as reflected by the large 2500–2450 Ma-aged components. Based on regional scale map patterns along the southern margin of Pink Hills and northernmost part of Landor, the lowermost unit of the Mesoproterozoic Edmund Group, the Yilgatherra Formation (P_-MEy-st), must unconformably overlie the gneiss, although this contact is unexposed.

The mesocratic gneiss is extensively intruded by sheets and dykes of the Dumbie Granodiorite (P_-MOdu-ggp), plutons, dykes, and veins of the Scrubber Granite (P_-MOsc-gm), and numerous plutons from both the Moorarie and Durlacher Supersuites. It is also crosscut by numerous metre-wide dolerite dykes of the c. 755 Mundine Well Dolerite suite.

Geochronology

AP_-_ha-mgnw	*Maximum*	*Minimum*
Age (Ma)	2663 ± 7	2429 ± 4
Age	Neoarchean	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2000	Wingate et al., in prep.

Two samples of mesocratic gneiss were sampled for SHRIMP U–Pb zircon geochronology. A sample of mesocratic gneiss (AP_-_ha-mgnw) was collected immediately west of Dunnawah Well, on northwestern Glenburgh. As with the undivided (AP_-_ha-mgn) and leucocratic (AP_-_ha-mgnl) portions of the Halfway Gneiss, the sample of mesocratic gneiss provided Neoarchean crystallization ages for its precursor granite. Although the rocks around this sample were mapped as undivided gneiss (AP_-_ha-mgn), Nelson (2000) dated the mesocratic, tonalitic component of the gneiss. This sample contains several concordant zircon age components, at 2550 ± 7 Ma, 2663 ± 7 Ma, 2709 ± 10 Ma, and c. 3300 Ma or older. Nelson (2000) suggested that the 2663 ± 7 Ma date represents the igneous crystallization age of the tonalite precursor, and the 2550 ± 7 Ma date corresponds to the age of thin pegmatite veins in the sample. Occhipinti and Sheppard (2001) preferred the interpretation that the youngest date of 2550 ± 7 reflects the igneous crystallization age of the precursor tonalite. However, follow-up work on this sample failed to identify any additional zircons of c. 2550 Ma age; all analysed grains were c. 2660 Ma or older, indicating that the original interpretation of Nelson (2000) may be correct.

A single sample of mesocratic gneiss was dated from the Limejuice Zone on the central parts of southern Pink Hills. This granodioritic gneiss yielded numerous zircons, which yielded a date of 2429 ± 4 Ma, interpreted as the crystallization age of the gneiss protolith (Wingate et al., in prep.). A single low-Th/U zircon rim yielded a concordant date of 1838 ± 7 Ma, interpreted as the age of a metamorphic overprint of unknown metamorphic grade.

References

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Moogie Metamorphics
(P_-MG-xmh-mk)

Legend narrative

Psammitic and pelitic schist; calc-silicate rock; minor quartzite, marble, amphibolites, and ultramafic schist

Rank	Group
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	Dalgaringa Supersuite, Moorarie Supersuite, Durlacher Supersuite, Thirty Three Supersuite, Mundine Well Dolerite Suite (intrusive); Pooranoo Metamorphics, Mount Augustus Sandstone, Edmund Group (unconformable)
Underlying units	Halfway Gneiss (unconformable and fault)

Summary

The Moogie Metamorphics is a package of mainly psammitic schists (Mumba Psammite: P_-MGm-mtsf), which contains discontinuous layers of pelitic schist (P_-MGm-mls) and quartzite (P_-MGm-mtq), although discrete packages of pelite and quartzite are common. These units are intercalated with minor calc-silicate gneiss (P_-MG-mk), marble (P_-MG-mkk), amphibolite (P_-MG-mwa-GAG), actinolite-tremolite schist (P_-MG-mus-GAG) and metagabbro (P_-MG-mog-GAG). The units occur within the Paradise, Mooloo, and Mutherbukin Zones at the southern end of the Gascoyne Province as three linear belts intercalated and interfolded with basement gneisses of the Halfway Gneiss. The precursor sediments were deposited sometime between 2240 Ma and 2125 Ma, possibly as a result of uplift during the Ophthalmian Orogeny to the north, and were sourced directly from the underlying Halfway Gneiss.

Distribution

The Moogie Metamorphics are distributed within the Paradise, Mooloo, and Mutherbukin zones as three main west–east to northwest–southeast trending belts comprising mainly schistose rocks of the Mumba Psammite. The southerly belt forms a 30 km long series of outcrops on DAURIE CREEK and GLENBURGH which is centred on and around Mount Dalgety. The central belt is roughly 40 km long and straddles the southern parts of LOCKIER, YINNETHARRA and the northern parts of DAURIE CREEK and GLENBURGH, whereas the northern belt forms a discontinuous train of outcrops some 150 km long on the northern parts of LOCKIER, YINNETHARRA, and central and southern parts of PINK HILLS and CANDOLLE. Intermittent, decimetre-scale outcrops of calc-silicate gneiss, amphibolite, metagabbro, marble, and ultramafic schist are found within and between these schist belts where they are interleaved and folded with gneissic rocks of the Halfway Gneiss and deformed meta-igneous rocks of the Moorarie Supersuite.

Derivation of name

Metasedimentary rocks of the Moogie Metamorphics were previously included within the Morrissey Metamorphic Suite (Williams et al., 1983b; Williams, 1986), the name given for a suite of metamorphosed and deformed Proterozoic sedimentary rocks thought to outcrop throughout the Gascoyne Province (Williams et al., 1983a). The suite was considered to be equivalent, in part, to sedimentary rocks of the Wyloo Group to the north, and sedimentary rocks of the Yerrida and Bryah Groups (Pirajno et al., 1998) to the east. However, it is now clear that all the metasedimentary rocks throughout the Gascoyne Province were not deposited in the same sedimentary basin nor are the same age. The Moogie Metamorphics on GLENBURGH, DAURIE CREEK, LOCKIER, YINNETHARRA, PINKS HILLS, and CANDOLLE are separated from the Morrissey Metamorphic Suite, as defined on the GLENBURGH1:100 000 sheet (Occhipinti and Sheppard., 2001), by large areas of granitic gneiss, supracrustal metasedimentary and mafic meta-igneous rocks, and large fault structures.

The Moogie Metamorphics were named after Moogie Well in the western part of GLENBURGH.

Lithology

The Moogie Metamorphics are comprised mainly from a series of psammitic schists known as the Mumba Psammite. This unit not only contains abundant psammitic schist (P_-MGm-mtsf) but also pelitic schist (P_-MGm-mls) and quartzite (P_-MGm-mtq). Minor lithologies within the Moogie Metamorphics are calc-silicate gneiss (P_-MG-mkq) and associated marble (P_-MG-mkk).

The Mumba Psammite is dominated by medium- to coarse-grained feldspathic psammitic schist but discrete belts of pelitic schist and massive recrystallized quartzite are common. Most of the lithologies have been metamorphosed at medium- to high-grade during the 2005–1950 Ma Glenburgh Orogeny with the pelitic lithologies undergoing melting and migmatization. However, all of the peak metamorphic assemblages, including key metamorphic porphyroblasts like garnet and sillimanite, have been retrogressed during subsequent deformation and metamorphism.

Calc-silicate gneiss (P_-MG-mkq) and associated marble (P_-MG-mkk) are minor, but widespread rock types within the Paradise, Mooloo, and Limejuice Zones. The units commonly have a fine-scale compositional layering defined by alternations of amphibole- or diopside-rich and quartz-rich layers.

Age code	Proterozoic	P_-
Stratigraphic code	Moogie Metamorphics	MG-
Mixed or xenolith-bearing	Mixed	x
Rock type 1	metasedimentary siliciclastic: psammite and pelite; interlayered	
Lithname 1	psammite and pelite; interlayered	mh
Rock type 2	metasedimentary carbonate	
Lithname 2	metacarbonate	-mk
Rock code		**P_-MG-xmh-mk**
Additional lithologies	marble, calc-silicate, gneiss	

Contact relationships

The Mumba Psammite forms three sub-parallel east–west, northwest–southeast-trending belts, each of which is some 3–10 km wide and with strike lengths of over 50 km. The contacts with other rock units are rarely exposed. It is interpreted that most contacts with the underlying Halfway Gneiss are tectonic, although in rare low-strain pockets on the southern part of Yinnetharra (SPHYIN000220) the Mumba Psammite is observed to rest unconformably on the Halfway Gneiss. This interpretation is supported by a detrital zircon geochronological study which indicates that the Mumba Psammite was sourced directly by the erosion of the Halfway Gneiss (Johnson et al., 2010). On southern Yinnetharra the psammitic schists are intruded by numerous sub-parallel sheets of leucocratic metamonzogranite to pegmatite (P_-MO-gmvl) of the Moorarie Supersuite, and on Pinks Hills the psammitic schists are in tectonic contact with numerous rocks of the Moorarie Supersuite, Durlacher Supersuite, and Edmund Group.

The minor lithologies generally form disparate infolds within the Mumba Psammite or, more commonly, as folded imbricates within the Halfway Gneiss. In the northern part of Glenburgh and on southern and central Yinnetharra, lenses of calc-silicate gneiss and marble appear to be faulted against the Halfway Gneiss and contain a moderate to well-developed gneissic layering that is folded with the Halfway Gneiss. On Glenburgh, in the vicinity of Hectors Bore and Middle Well, the calc-silicate gneiss and marble are locally intruded by granites of the Moorarie Supersuite. In the southeastern part of Glenburgh, several rafts of calc-silicate gneiss are present in foliated and gneissic granite of the Nardoo Granite.

Contacts between the amphibolites (P_-mwa-GAG) and foliated to gneissic granites of the Dalgaringa Supersuite and Halfway Gneiss are commonly tectonic and parallel to the foliation or compositional banding in the granitic rocks. Locally, a few mafic layers are discordant at a low angle to the foliation or layering in the granites, indicating that at least a few of the amphibolites were mafic dykes. These relationships are interpreted to indicate that rocks of the Moogie Metamorphics were intruded by the amphibolitesand the 2005–1975 Ma Dalgaringa Supersuite — an interpretation that is supported by the detrital and metamorphic zircon age constraints on the timing of deposition of this metasedimentary package.

Geochronology

P_-MG-xmh-mk	*Maximum*	*Minimum*
Age (Ma)	2240 ± 8	2125 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Wingate et al., 2010a	Johnson et al., 2010

Detrital zircon and metamorphic zircon and monazite from eight samples of the Mumba Psammite have been dated using SHRIMP U–Pb methods. The psammitic schists were collected from the Paradise, Mooloo, and Mutherbukin Zones. Samples GSWA 183275, 184160, 184161, and 187403 (Kirkland et al., 2009a,b; Wingate et al., 2010a,b), and NP20 (Kinny et al., 2004), were collected for detrital zircon geochronology and samples GSWA 164333, 164369, and 168713 (Johnson et al., 2010) were collected for in situ monazite dating.

The detrital zircon age spectra from all samples are similar, with abundant dates in the 2800–2300 Ma range, together with minor older and slightly younger age components. The youngest detrital zircons in all samples are similar in age, with the youngest grain present in GSWA 184160 dated at 2240 ± 8 Ma. The next three youngest grains from two other samples (GSWA 187403 and NP20) provide a more robust maximum age of deposition of c. 2280 Ma. Additionally, sample GSWA 164369 contains partially recrystallized monazite with cores of probable metamorphic origin and discrete metamorphic zircon grains dated at c. 2125 Ma. This date is taken to represent the age of metamorphism of the psammitic schist during a currently unknown tectonic event. This also provides a minimum age for deposition of the protolith.

Abundant metamorphic zircon rims and monazite are present within all dated samples. The range of dates for this metamorphic event are mainly constrained between 1965 and 1950 Ma and represent the age of high-grade metamorphism and migmatization that affected most of the Moogie Metamorphics during the D_{2g} event of the collision-related Glenburgh Orogeny. In addition, younger metamorphic rims with ages of c. 1770 and c. 1790 Ma (samples GSWA 187403 and 184160, respectively) are interpreted to date low- to medium-grade overprinting during the intracontinental Capricorn Orogeny, presumably during the D_{2n} event. No samples of the minor lithologies (calc-silicate rock or marble) have been dated directly, although their field relationships suggest that they are an integral part of the Moogie Metamorphics and have similar depositional ages and settings.

Based on the ages of both detrital zircons and metamorphic events, this package is interpreted to have been deposited between 2240 and 2125 Ma, possibly as a result of uplift during the Ophthalmian Orogeny (Johnson et al., 2010), and was affected by high-grade metamorphism at 1965–1950 Ma during the Glenburgh Orogeny, and subsequent low-grade overprinting during the intracontinental Capricorn Orogeny at c. 1780 Ma (Johnson et al., 2010).

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MUMBA PSAMMITE
(P_-MGm-mtsf)

Legend narrative

Quartzofeldspathic psammitic schist commonly with chloritoid; local minor pelitic schist and quartzite

Rank	Formation
Parent	Moogie Metamorphics (P_-MG-xmh-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	AP_-_ha-mgn, AP_-_ha-mgnl, AP_-_ha-mgnw, P_-MGm-mtq, P_-MGm-mls, P_-MO-mgnl, P_-LS-mhs, P_-MO-xmg-m (faulted); P_-MOsc-gm, P_-MOdu-ggp, P_-MO-gmvl, P_-MO-gp (intrusive)
Underlying units	P_-MGm-mtq, P_-MGm-mls (conformable); AP_-_ha-mgnw (unconformable)

Summary

The Mumba Psammite (P_-MGm-mtsf, P_-MGm-mls, and P_-MGm-mtq) is a series of psammitic and pelitic schists and quartzites that form three main east–west to northwest–southeast trending belts within the Paradise, Mooloo, Mutherbukin, and Limejuice Zones. The schists and quartzites are variably tectonically interleaved and folded with basement gneisses of the Halfway Gneiss. The southerly belt is dominated by pelitic schist and retrogressed pelitic diatexite (P_-MGm-mls) with subordinate psammitic schist and quartzite. The central belt is dominated by quartzofeldspathic psammitic schist (P_-MGm-mtsf) with subordinate pelitic schist and quartzite, whereas the northern belt is dominated by massive recrystallized quartzite (P_-MGm-mtq) with subordinate quartzofeldspathic psammitic schist. The quartzofeldspathic psammitic schist member (P_-MGm-mtsf) comprises quartz–sericite–feldspar–albite–chloritoid(–chlorite) schist and chloritoid–chlorite–sericite–quartz–feldspar–albite (–garnet) schist although a few transitional rock types are present. Compositional layering representative of bedding is locally preserved, especially on southern Yinnetharra, where the schists appear to be unconformable upon the Halfway Gneiss. Detrital zircon dating indicates that this unit was deposited sometime after c. 2240 Ma but before the growth of metamorphic zircon and monazite during a metamorphic event of unknown grade at c. 2125 Ma. The Mumba Psammite was deposited possibly as a result of uplift during the Ophthalmian Orogeny to the north, and was sourced directly from the underlying Halfway Gneiss. Subsequent low grade metamorphism, presumably during the Capricorn Orogeny, overprinted the schists, downgrading and pseudomorphing high-grade minerals with lower grade equivalents.

Distribution

The Mumba Psammite (P_-MGm-mtsf, P_-MGm-mls, and P_-MGm-mtq) is distributed within the Paradise, Mooloo, Mutherbukin and Limejuice Zones as three main west–east to northwest–southeast trending belts that are variably tectonically interleaved and folded with basement gneisses of the Halfway Gneiss. The southern belt forms a 30 km long series of outcrops on Daurie Creek and Glenburgh which is centred on and around Mount Dalgety, and comprises mainly pelitic schist and retrogressed pelitic diatexite (P_-MGm-mls) with minor psammitic schist (P_-MGm-mtsf) and quartzite (P_-MGm-mtq). The central belt is roughly 40 km long and straddles the southern parts of Lockier, Yinnetharra, and the northern parts of Daurie Creek and Glenburgh, and is composed mainly of chloritoid-bearing psammitic schists and quartzofeldspathic psammitic schists with minor pelitic schist, retrogressed pelitic diatexite, and quartzite. The northern belt, which is truncated by the Ti Tree Shear Zone, forms a discontinuous train of outcrops some 150 km long on the northern parts of Lockier, Yinnetharra, and central and southern parts of Pink Hills and Candolle; apart from the most southerly outcrops of psammitic schist on Pink Hills, the belt comprises predominantly massive recrystallized quartzite with very minor interbeds of psammitic schist. Thin discontinuous strips of psammitic and pelitic schist and quartzite also lie within the Chalba Shear Zone, where they are tectonically interleaved with leucocratic gneisses of the Halfway Gneiss. The Mumba Psammite forms rocky strike ridges and hills up to 500 m high; the highest ridges are defined by outcrops of quartzite. The Mumba Psammite is characterized by rugged deep-red weathering air-photo patterns.

Derivation of name

The name Mumba Pelite was first defined by Occhipinti and Sheppard (2001) for a belt of metapelitic rocks which also included minor psammitic schist and quartzite on the Glenburgh 1:100 000 sheet. This belt of rock also continues onto Daurie Creek. Subsequent mapping on Yinnetharra, Lockier, Pink Hills, and Candolle has revealed that these siliciclastic rocks form three sub parallel belts with psammitic schist forming the major and dominant lithology; hence the original name of Mumba Pelite has been altered to Mumba Psammite in order to better reflect the dominant rock type in the unit.

Lithology

Psammitic schist and chloritoid-bearing psammitic schist are most abundant north of the Dalgety Fault within the central belt of the Mumba Psammite, but also forms centimetre- to metre-thick interbeds within pelitic schists in the southern belt and within quartzites of the northern belt. There are two main rock types: quartz–sericite–feldspar–albite–chloritoid(–chlorite) schist and chloritoid–chlorite–sericite–quartz–feldspar–albite (–garnet) schist, although a few transitional rock types are present. In outcrop, both rock types commonly show a millimetre- or centimetre-scale compositional layering that contains a subparallel fabric, which is folded by the regional F1n folds of the Capricorn Orogeny. Quartz–sericite–feldspar–albite–chloritoid(–chlorite) schist is pale green when fresh or red–brown when weathered. Chloritoid comprises about 10–15% of these rocks, commonly forming 'clots' or 'clusters', or small (<1.5 mm long) dark-green to black chloritoid porphyroblasts. The chloritoid is commonly aligned in the foliation, but also forms randomly oriented porphyroblasts that overprint the foliation, which is most often defined by sericite and chlorite. Locally, chloritoid porphyroblasts are enclosed by the foliation. Chloritoid–chlorite–sericite–quartz–feldspar–albite(–garnet) schists are dark green on fresh surfaces, with a reddish brown exterior. The rocks commonly have a 'knobbly' appearance due to knots of fine-grained sericite up to 1 c. in diameter, which are enclosed by the foliation. A few of the sericite knots contain relict orthoclase. Chloritoid comprises 30% or more of these rocks, forming randomly oriented porphyroblasts that overprint the foliation, which is commonly defined by chlorite and sericite. Garnet is rare, forming colourless xenoblastic crystals in a few samples. Accessory minerals comprise rutile and apatite. In both rock types feldspar shows various degrees of alteration; being replaced by sericite. All of these rocks are interbedded with pelitic units that locally preserve diatexite textures indicating that migmatization and melting was a function of composition because the psammitic rocks would have experienced similar high-temperature conditions but did not melt.

Age code	Proterozoic	P_-
Stratigraphic code	Moogie Metamorphics, Mumba Psammite	MGm-
Rock type	metasedimentary siliciclastic: psammite	mt
Lithname	psammitic schist	s
1st qualifier	–	
2nd qualifier	felsic/feldspathic; K-metasomatized	f
Rock code		**P_-MGm-mtsf**
Additional lithologies	quartzite, pelitic schist, pelitic migmatite	

Contact relationships

Quartzofeldspathic schist and chloritoid-bearing schist (P_-MGm-mtsf) are most prominent within the central belt that straddles northern Glenburgh and southern Lockier and Yinnetharra, but also occurs as a significant southwest-northeast trending unit within the northern belt on central Pink Hills. These rocks nearly always form tight to isoclinal upright infolds within basement gneisses of the Halfway Gneiss (AP_-_ha-mgn, AP_-_ha-mgnl, and AP_-_ha-mgnw) cross-cutting the gross-scale lithological variation in this gneissic basement. Thin strips and lenses are also folded and tectonically interleaved with the leucocratic Halfway Gneiss (AP_-_ha-mgnl) in the Chalba Shear Zone. However, on the southern part of Yinnetharra at SPJYIN000284 near-horizontal bedding suggests that the psammitic schist sits unconformably on mesocratic Halfway Gneiss (AP_-_ha-mgnw). Within the southern and northern belts, quartzofeldspathic psammitic schist is interbedded on the cm-scale with the pelitic schist and quartzite members of the Mumba Psammite. The psammitic schists are intruded by various granitic sheets and stocks of the Moorarie Supersuite including the Scrubber Granite (P_-MOsc-gm), Dumbie Granodiorite (P_-MOdu-ggp), and Rubberoid Granite (P_-MOru-mgm). On southern Yinnetharra the psammitic schists are intruded by metre- to decametre-scale sheets of medium-grained to pegmatitic leucocratic metamonzogranite (P_-MO-gmvl). On Pink Hills, thin strips of quartzite lie within the Ti Tree Shear Zone and are in tectonic contact with various metagranitic and metasedimentary units including P_-MO-mgnl, P_-LS-mhs, and P_-MO-xmg-m. South of Clever Mary Hills, quartzites are in faulted contact with low- to medium-grade Edmund Group rocks including P_-MEk-s. The southwest-northeast trending belts of psammitic schists contain a thin unit, up to 100 m-wide, of medium grained recrystallized quartzite (P_-MGm-mtq) that forms an eastward-thinning extension of the main quartzite units of the Clever Mary Hills.

Geochronology

P_-MGm-mtsf	*Maximum*	*Minimum*
Age (Ma)	2240 ± 8	2125 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Wingate et al., 2010a	Johnson et al., 2010

Detrital zircon and metamorphic zircon and monazite from eight samples of the Mumba Psammite have been dated using SHRIMP U–Pb geochronology. Representative samples were collected from the Paradise, Mooloo, and Mutherbukin Zones although only samples GSWA 183275, 184160, and 164333 (central and northern zones) are psammitic schists belonging to the P_-MGm-mtsf member of the Mumba Psammite. The geochronological information obtained from the other samples will be described in detail under their relevant lithological units. Samples GSWA 183275 and 184160 were collected for detrital zircon dating and sample GSWA 164333 was selected for in situ monazite dating.

Samples GSWA 183275 (51 analyses) and GSWA 184160 (64 analyses) both yielded abundant detrital zircons with $^{207}Pb^*/^{206}Pb^*$ dates of 3163–2240 Ma, and included significant age components at c. 3000 Ma, c. 2700 Ma, c. 2500 Ma and 2380–2300 Ma. The youngest detrital zircons in GSWA 183275 (Wingate et al., 2010b) are represented by a group of four analyses that indicate a weighted mean $^{207}Pb^*/^{206}Pb^*$ date of 2306 ± 12 Ma. There were no metamorphic zircon overgrowths present in this sample.

The youngest detrital zircon core in GSWA 184160 (Wingate et al., 2010a) indicated a $^{207}Pb^*/^{206}Pb^*$ date of 2240 ± 8 Ma. A more conservative estimate of the maximum depositional age is provided by the next youngest 26 analyses, which indicate a weighted mean $^{207}Pb^*/^{206}Pb^*$ date of 2485 ± 3 Ma. This sample also contained abundant zircon overgrowths interpreted to be of metamorphic origin based on their textural characteristics, uranium contents, and Th/U ratios. Of 13 zircon rims dated, seven analyses yielded a weighted mean $^{207}Pb^*/^{206}Pb^*$ date of 1928 ± 7 Ma, and six analyses yielded $^{207}Pb^*/^{206}Pb^*$ dates of 1880–1795 Ma. The older date is interpreted as the age of high-grade metamorphism during the D_{2g} event of the Glenburgh Orogeny, which is dated elsewhere between 1965–1950 Ma (Johnson et al., 2010). This result also provides a minimum age for deposition of the protolith of the psammitic schist. The younger dates of 1880–1795 Ma are interpreted to reflect loss of radiogenic Pb, possibly at about 1800 Ma.

Sample GSWA 164333, a chloritoid psammitic schist from the central belt of Mumba Psammite rocks, contained abundant monazite within chloritoid porphyroblasts (pseudomorphing garnet) and within the matrix. The monazite grains were variably altered around their margins to mixtures of Fe-oxide minerals and REE-minerals. The least altered grains yielded a concordant $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1947 ± 6 Ma, and those representing increasing degrees of alteration indicated $^{207}Pb^{*}/^{206}Pb^{*}$ dates ranging from c. 1950 to c. 1840 Ma. The c. 1950 Ma result is interpreted as the age of high-grade metamorphism that affected the psammitic schist (porphyroblasts of garnet grew during this event) whereas the younger dates are interpreted to indicate recrystallization and Pb-loss from monazite during low-grade overprinting (pseudomorphing of garnet with chloritoid) some time after c. 1840 Ma. The age of high-grade metamorphism at c. 1950 Ma is consistent with results from other samples dated here and from other units of the Mumba Psammite.

The best constraint for the minimum depositional age for the whole Mumba Psammite package is taken from sample GSWA 164369 (P_-MGm-mls) that contains metamorphic zircon and monazite that grew during an event at c. 2125 Ma, implying that the sediment was deposited by this time.

References

Johnson, SP, Sheppard, S, Rasmussen, B, Wingate, MTD, Kirkland, CL, Muhling, JR, Fletcher, IR and Belousova, E 2010, The Glenburgh Orogeny as a record of continent–continent collision: Geological Survey of Western Australia Record 2010/5, 54p.

Occhipinti, SA and Sheppard, S 2001, Geology of the Glenburgh 1:100 000 sheet: Geological Survey of Western Australia, 1:100 000 Geological Series Explanatory Notes, 37p.

Wingate, MTD, Bodorkos, S, Kirkland, CL, Johnson, SP and Sheppard, S 2010a, 184160: psammitic schist, Weedarrah Homestead; Geochronology Record 863: Geological Survey of Western Australia, 5p.

Wingate, MTD, Kirkland, CL, Bodorkos, S, Sheppard, S and Johnson, SP 2010b, 183275: psammitic schist, Mount Dalgety; Geochronology Record 836: Geological Survey of Western Australia, 5p.

MUMBA PSAMMITE; subunit (P_-MGm-mtq)

Legend narrative

Metamorphosed quartz sandstone, granule metaconglomerate and quartzite gneiss, locally micaceous; minor psammitic schist; locally with relict cross-bedding

Rank	Member
Parent	MUMBA PSAMMITE (P_-MGm-mtsf)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-mgnl, P_-DU-mgms (intrusive and faulted); P_-MGm-mtsf, P_-MGm-mls, AP_-_ha-mgnw, P_-LS-mhs, P_-MEk-s, P_-MEl-s, P_-MEv- kd, P_-MO-mgn, and P_-MO-mgnl (faulted)
Underlying units	P_-MGm-mtsf, P_-MGm-mls (conformable); AP_-_ha-mgnw (unconformable)

Summary

Quartzite gneiss and metamorphosed quartz sandstone (P_-MGm-mtq) form a discontinuous train of outcrops some 150 km long on the northern parts of LOCKIER, YINNETHARRA, and central and southeastern parts of PINK HILLS forming the spine of both the Clever Mary Hills and Injinu Hills on PINK HILLS. These quartzites are folded and imbricated with basement gneisses of the Halfway Gneiss. However, on central GLENBURGH and southern YINNETHARRA meta-quartz sandstone, feldspathic metasandstone, and minor feldspathic granule metaconglomerate typically form layers less than 20 cm thick within the dominant psammitic and pelitic lithologies of the Mumba Psammite. The quartzite gneiss and granule metaconglomerate appear to be locally internally bedded, and cross-bedding and graded bedding are locally well preserved. The predominant quartzite gneiss is medium-grained, recrystallized with a sugary granular texture and comprises over 95% quartz with the remaining 5% consisting of heavy mineral components such as opaque minerals, tourmaline, and zircon. Other very minor accessory phases include sericite and muscovite. Both dated samples were deposited in a similar time frame sometime between c. 2275 Ma and c. 1935 Ma. One sample from the Paradise Zone was deformed and metamorphosed at 1965–1950 Ma during the Glenburgh Orogeny, whereas the sample from the northern belt in the Mutherbukin Zone, only shows evidence for a metamorphic overprint during the Capricorn Orogeny.

Distribution

Quartzite gneiss and metamorphosed quartz sandstone form a discontinuous train of outcrops some 150 km long on the northern parts of LOCKIER, YINNETHARRA, and central and southeastern parts of PINK HILLS. Major 100–200 m-thick, massive bedded units form the spine of both the Clever Mary Hills and Injinu Hills on PINK HILLS. Thin discontinuous strips of quartzite are also found in the Chalba Shear Zone where they are tectonically interleaved with leucocratic gneisses of the Halfway Gneiss. On central GLENBURGH and southern YINNETHARRA meta-quartz sandstone, feldspathic metasandstone, and minor feldspathic granule metaconglomerate typically form layers less than 20 cm thick within the dominant psammitic and pelitic lithologies of the Mumba Psammite, but locally become the predominant rock type; such as immediately north of Moogie Well. Fine- to medium-grained, recrystallized quartzite also forms the spine of the Koolyin Hills in the Carrandibby Inlier on CARRANDIBBY, a sample of which (NP20) was dated by Kinny et al (2004).

Lithology

The quartzite gneiss and granule metaconglomerate appear to be locally internally bedded, and cross-bedding and graded bedding are preserved in places (e.g. SPJPKH000783). The quartzite gneiss, especially those units outcropping in the Clever Mary Hills and Injinu Hills, is medium-grained, recrystallized with a sugary granular texture, and comprises over 95% quartz. They locally preserve a weak bedding-parallel cleavage defined by minor heavy mineral components such as opaque minerals, tourmaline, and zircon (e.g. SPJPKH000783). Other minor mineral phases include sericite and muscovite usually after feldspar and chlorite. On northwestern YINNETHARRA tourmaline-rich quartzites crop out as a series of 30–50 m-thick, 5 m-high ridges (PGBYIN000079). The units are coarse grained containing an interlocking sugary texture with randomly oriented cm-long tourmaline sporadically growing parallel to fracture-joint sets.

Age code	Proterozoic	P_-
Stratigraphic code	Moogie Metamorphics, MUMBA PSAMMITE	MGm-
Rock type	metasedimentary siliciclastic: psammite	mt
Lithname	quartzite	q
Rock code		**P_MGm-mtq**
Additional litholpogies	psammitic schist	

Contact relationships

Quartzite gneiss and meta-quartz sandstone are predominant in the northern belt that stretches from central PINK HILLS through northern YINNETHARRA onto northern LOCKIER. Outcrops within and immediately to the south of the Clever Mary Hills are folded and in tectonic contact with mesocratic gneisses of the Halfway Gneiss (AP_-_ha-mgnw). Along the southern margin, the quartzites are in faulted contact with low- to medium grade metasedimentary rocks of the Leake Spring Metamorphics and Edmund Group including P_-LS-mhs, P_-MEk-s, P_-MEl-s, and P_-MEv-kd. In the Injinu Hills the quartzite is tectonically interleaved with metagranitic gneisses of the Halfway Gneiss and Moorarie Supersuite (AP_-_ha-mgnw, P_-MO-mgn and P_-MO-mgnl). On northern YINNETHARRA, tourmaline-bearing quartzites form mega-scale folded inclusions within deformed and metamorphosed metagranitic lithologies of the Durlacher Supersuite including P_-DU-mgnl and P_-DU-mgms.

Geochronology

P_MGm-mtq	*Maximum*	*Minimum*
Age (Ma)	2273 ± 10	2125
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	inferred
References	Kinny et al., 2004	Johnson et al., 2010

Detrital and metamorphic zircons from two samples of quartzite were dated by SHRIMP. Sample GSWA 187403 (Wingate et al., 2009), is a recrystallized tourmaline-bearing orthoquartzite from the northern belt of Mumba Psammite (Mutherbukin Zone) and the other sample, NP20 (Kinny et al., 2004) is a fine-grained recrystallized quartzite from the Koolyin Hills of the Carrandibby Inlier (Paradise Zone). Both samples yielded abundant detrital zircons, and most of them are overgrown by thin rims of moderate- to high-U, structureless zircon interpreted as metamorphic in origin (Kinny et al., 2004; Wingate et al., 2010; Johnson et al., 2010). Detrital zircons from the two samples yielded $^{207}Pb^{*}/^{206}Pb^{*}$ dates of 3212–2270 Ma, and include significant age components at c. 3000 Ma, c. 2850 Ma, c. 2730 Ma, 2580–2500 Ma, and 2290–2270 Ma.

The youngest detrital zircon in GSWA 187403 yielded a $^{207}Pb^{*}/^{206}Pb^{*}$ date of 2286 ± 13 Ma (1σ), providing a maximum age for deposition of the sandstone protolith. A more conservative estimate is provided by the next two youngest analyses, which indicated a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 2327 ± 14 Ma. Four high-U, low-Th/U metamorphic zircon rims yielded a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1772 ± 6 Ma, interpreted to reflect a period of metamorphism that affected the quartzite. This result is within uncertainty of the date for the youngest low-Th/U rim in sample GSWA 184160 (1788 ± 12 Ma), a psammitic schist from the central belt of Mumba Psammite. The two dates reflect a strong Capricorn Orogeny metamorphic overprint in the central and northern belts (Johnson et al., 2010). It is noteworthy that sample GSWA 187403 does not appear to record any effects of the earlier Glenburgh Orogeny.

The youngest detrital component in NP20 is provided by two zircons that yielded $^{207}Pb^{*}/^{206}Pb^{*}$ dates of 2290 and 2270 Ma (Kinny et al., 2004). Three analyses of low-Th/U metamorphic rims yielded an imprecise weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1934 ± 43 Ma. This result is within uncertainty of Glenburgh Orogeny metamorphic ages obtained from the other Mumba Psammite samples, and indicates that parts of the Paradise Zone were also affected by the D_{2g} event.

The two samples were deposited during the same interval as the other Mumba Psammite members. Although these samples did not include any metamorphic zircon or monazite dated at 2125 ± 5 Ma (Johnson et al., 2010), they are considered to be a coherent part of the Mumba Psammite and as such conform to the same depositional age constraints.

References

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MUMBA PSAMMITE; subunit (P_-MGm-mls)

Legend narrative

Pelitic schist commonly with chloritoid; locally with relict garnet porphyroblasts

Rank	Member
Parent	MUMBA PSAMMITE (P_-MGm-mtsf)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	Dalgaringa Supersuite (possibly intrusive); P_-MO-gmeb, P_-MO-gp (intrusive); P_-POb-mxq, P_-POs-mtqs (unconformable)
Underlying units	P_-MGm-mtsf, P_-MGm-mtq (conformable); AP_-_ha-mgnl, AP_-_ha-mgnw (unconformable and faulted)

Summary

Pelitic schist with minor interbedded psammitic schist and quartzite outcrops mainly within the Paradise and Mooloo Zones as a near continuous belt some 30 km long transecting DAURIE CREEK and GLENBURGH. Contacts with the surrounding rocks units are rare, being covered mainly by extensive alluvial and colluvial deposits. This unit is probably intruded by the granite protoliths of the 2005–1970 Ma Dalgaringa Supersuite, and would have originally sat unconformably upon the Halfway Gneiss basement. The unit is extensively intruded by stocks, veins, and dykes of Moorarie Supersuite granites. The schist consists mainly of quartz–sericite(–chlorite–biotite) schist and chloritoid-bearing schist with locally well developed compositional layering reflecting original bedding. Detrital zircon studies suggest that this package was deposited sometime between c. 2370 Ma and c. 2125 Ma. In some low-strain zones the presence of retrogressed pelitic diatexite textures indicates that these lithologies were subject to high-grade metamorphism resulting in extensive migmatization. Metamorphic zircon and monazite and recrystallization of pre-existing monazite indicate that this high-grade event occurred between c. 1965 Ma and c. 1950 Ma, coincident with the D_{2g} event of the Glenburgh Orogeny.

Distribution

Pelitic schist with minor psammitic schist (P_-MGm-mtsf) and quartzite gneiss (P_-MGm-mtq) outcrops mainly within the Paradise and Mooloo Zones as a near continuous belt some 30 km long on DAURIE CREEK and GLENBURGH, centred on and around Mount Dalgety. The Dalgety Fault on GLENBURGH (Occhipinti and Sheppard 2001) was interpreted to define the southern limit of the Mumba Psammite, but pelitic schists of the Mumba Psammite outcrop extensively on either side of this fault on DAURIE CREEK. The southerly contact with the Dalgaringa Supersuite is covered by extensive alluvial and colluvial deposits. Thin discontinuous units of pelitic schist also form thin cm- to m-scale interbeds within more dominant psammitic schist in a central belt of siliciclastic rocks that straddle the southern parts of LOCKIER, YINNETHARRA, and the northern parts of DAURIE CREEK and GLENBURGH and also as discontinuous strips and lenses that are tectonically interleaved with the Halfway Gneiss in the Chalba Shear Zone.

Lithology

Pelitic schist is the predominant rock type in the southern belt of the Mumba Psammite and consists mainly of quartz–sericite(–chlorite–biotite) schist and chloritoid-bearing schist. Compositional layering within the schist is commonly well developed and appears to represent bedding. For the most part the compositional layering is only 2–10 mm thick, although local graded bedding into more quartz-rich parts is up to 10 cm thick. The pelite also has a well-developed bedding-parallel foliation. Primary compositional layering is typically indicated by the presence of more or less chloritoid in the S_{1g} foliation, which is subparallel to bedding. On DAURIE CREEK (e.g. Zone 50, MGA 394260E 7217900N), magnetite-bearing pelitic schists become more abundant. Bedding is largely defined by variable amounts of magnetite in the layering and large porphyroblasts of magnetite up to 1 c. in diameter are present in a few layers; chloritoid is less abundant in these rocks. Locally, the pelitic schist contains abundant garnet porphyroblasts, although these are commonly pseudomorphed by chloritoid(–chlorite–quartz). On the southwestern slopes of Mount Dalgety on DAURIE CREEK (SPJDAU000005) texturally preserved pelitic diatexite provides evidence that these rocks were metamorphosed at high temperature. These rocks contain euhedral 5–10 cm diameter porphyroblasts of former garnet pseudomorphed by chloritoid. These porphyroblasts are concentrated in 1–10 cm-thick, biotite-rich restitic layers which are now composed of radially arranged chloritoid set within a matrix of biotite–sericite–chlorite–quartz and which are wrapped by discontinuous leucosomes of quartz–feldspar–sillimanite (now sericite). The relict garnet porphyroblasts contain coarse quartz and biotite inclusion trails that are continuous with the external S_{2g} fabric. Relict diatexite textures are locally preserved in pelitic and semi-pelitic lithologies within both the southern and central belts of the Mumba Psammite indicating that high-grade metamorphism and migmatization associated with the Glenburgh Orogeny occurred throughout the region and was not just a local phenomenon.

Age code	Proterozoic	P_-
Stratigraphic code	Moogie Metamorphics, MUMBA PSAMMITE	MGm-
Rock type	metasedimentary siliciclastic: pelite	ml
Lithname	pelitic schist	s
Rock code		**P_MGm-mls**
Additional lithologies	quartzite, psammitic schist	

Contact relationships

Pelitic schists of the Mumba Psammite are found mainly within the southern belt that straddles GLENBURGH and DAURIE CREEK. On GLENBURGH and DAURIE CREEK, the pelitic schists are separated from Dalgaringa Supersuite gniesses by alluvial and colluvial deposits and it is not clear whether the Dalgaringa granite protoliths were originally intrusive into the Mumba Psammite. However, dolomitic marble (P_-MG-mkk) and calc-silicate gneiss (P_-MG-mk) of the Moogie Metamorphics are found as xenoliths within the Dalgaringa Supersuite (e.g. SAO4021), and considering the depositional age range of the Mumba Psammite (2240–2150 Ma), it is considered likely that the Dalgaringa Supersuite protoliths were also intrusive into the Mumba Psammite. The northern margin of the pelitic schist belt on GLENBURGH and DAURIE CREEK is intruded by sheets and stocks, including veins and dykes of medium-grained even-textured monzogranite (P_-MO-gmeb) and leucocratic granite (P_-MO-gp) of the Moorarie Supersuite. On DAURIE CREEK at site SAO4078 and site SAO3934, pelitic schists are folded and tectonically interleaved with leucocratic and mesocratic gneisses of the Halfway Gneiss (AP_-_ha-mgnl and AP_-_ha-mngw). The pelitic schists are unconformably overlain by metaconglomerate (P_-POb-mxq) and metamorphosed quartz sandstone (P_-POs-mtqs) of the Mount James Sub-Group at Mount Dalgety on DAURIE CREEK.

Geochronology

P_MGm-mls	*Maximum*	*Minimum*
Age (Ma)	2369 ± 8	2125 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Kirkland et al., 2009	Johnson et al., 2010

Three samples of pelitic schist and retrogressed pelitic diatexite from the Mooloo Zone were collected for geochronology. One sample, GSWA 184161, a retrogressed pelitic diatexite from Mount Dalgety on DAURIE CREEK was sampled for detrital and metamorphic zircon analysis, whereas samples GSWA 164369 and GSWA 168713 (both from the Mooloo Zone on DAURIE CREEK), a garnet–sericite schist and magnetite schist, respectively, were collected for in situ monazite dating.

Sample GSWA 184161 (Kirkland et al., 2009) contained abundant detrital zircons, most of which were overgrown by low-Th/U metamorphic zircon rims. Detrital zircon cores indicated $^{207}Pb^*/^{206}Pb^*$ dates of 2843–2396 Ma. The youngest detrital zircon in this sample yielded a concordant date of 2369 ± 8 Ma (1σ) providing a maximum age for deposition of the sedimentary protolith. However, a more conservative estimate is based on the next two youngest analyses which indicate a concordant date of 2487 ± 12 Ma. Fifteen analyses of zircon rims indicated a date of 1952 ± 4 Ma, interpreted as the age of high-grade metamorphism and migmatization that affected this rock.

The two rocks (GSWA 164369 and 168713) sampled for in situ monazite dating (Johnson et al., 2010) contained abundant, but texturally complex, monazite grains. Most of the monazite is intensely altered, and yielded a variety of concordant to discordant $^{207}Pb^*/^{206}Pb^*$ dates (Johnson et al., 2010). Monazite that grew during peak metamorphism in sample GSWA 164369 provided a concordant weighted mean $^{207}Pb^*/^{206}Pb^*$ date of 1958 ± 6 Ma (MSWD = 0.82) and those within sample GSWA 168713 yielded a concordant weighted mean $^{207}Pb^*/^{206}Pb^*$ date of 1966 ± 4 Ma (MSWD = 1.12). In addition sample GSWA 164369 also yielded numerous grains with older ages at c. 2125 Ma which were interpreted as the age of an earlier period of metamorphism experienced by the sample (Johnson et al., 2010).

Detrital zircon data from sample GSWA 184161 (Kirkland et al., 2009) and the presence of metamorphic monazite within sample GSWA 164369, suggest that the package of pelitic schists (P_-MGm-mls) was deposited between 2369 and 2125 Ma. All three samples were metamorphosed at middle to upper amphibolite facies conditions, as evidenced by growth of metamorphic zircon and monazite and recrystallization of pre-existing monazite. Both monazite and zircon provide dates of 1966–1952 Ma, which are consistent with results obtained from other high-grade samples of Mumba Psammite, and are correlated with the D_{2g} event of the collision-related Glenburgh Orogeny. In addition, sample GSWA 164369 contained metamorphic zircon and monazite that grew during an event at c. 2125 Ma, although the metamorphic grade and tectonic significance of this event is currently unknown.

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Moogie Metamorphics; subunit (P_-MG-mkq)

Legend narrative

Calc-silicate gneiss; pargasite- or diopside-bearing quartz–plagioclase–epidote(–titanite) rock; tremolite–diopside(–garnet) calc-silicate rock with minor marble

Rank	Formation
Parent	Moogie Metamorphics (P_-MG-xmh-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MGm-mtsf, P_-MG-mkk (conformable); P_-DA-xmgt-mgg, P_-DAna-mgt, P_-MO-gmeb, P_-MOru-mgm (intrusive)
Underlying units	P_-MGm-mtsf, P_-MG-mkk (conformable); AP_-_ha-mgn, AP_-_ha-mgnl, AP_-_ha-mgnw, P_-MGm-mtsf, P_-MGm-mls, P_-DA-xmgt-mgg, P_-DAna-mgt, P_-MOdu-ggp, P_-MOsc-gm, P_-MOru-mgm (fault)

Summary

Calc-silicate gneiss (P_-MG-mkq) and associated marble (P_-MG-mkk) are minor, but widespread rock types within the Paradise, Mooloo, and Limejuice Zones, forming narrow lenses; most commonly interleaved with the Halfway Gneiss and Mumba Psammite but also as fault bounded xenoliths within foliated and gneissic granites of the Dalgaringa and Moorarie Supersuites. The units commonly have a fine-scale compositional layering defined by alternations of amphibole- or diopside-rich and quartz-rich layers. These units are interpreted to have been deposited at the same time as the Mumba Psammite as locally the two are interbedded.

Distribution

Calc-silicate gneiss (P_-MG-mkq) and associated marble (P_-MG-mkk) are minor, but widespread rock types within the Paradise and Mooloo Zones on Glenburgh, Daurie Creek, Lockier, and Yinnetharra and in the Limejuice Zone on Pink Hills and Candolle. The rocks form narrow lenses, mostly commonly interleaved with the Halfway Gneiss and Mumba Psammite, but also as xenoliths within foliated and gneissic granites of the Dalgaringa and Moorarie supersuites. Most calc-silicate layers are between 50 and 200 m wide and 0.3 to 2 km long, appear dark brown on aerial photographs, and outcrop as low, rocky strike ridges. The calc-silicate layers are near evenly distributed throughout the region and do not form linear belts. On Candolle, calc-silicate gneiss interfolded with Halfway Gneiss forms a 4 km-long xenolith within the Rubberoid Granite (P_-MOru-mgm) of the Moorarie Supersuite.

Lithology

Calc-silicate gneiss is composed of fine- to medium-grained amphibole- or diopside-rich gneiss but nearly always includes subordinate medium-grained massive marble (P_-MG-mkk). The amphibole and diopside gneisses are green on a fresh surface, but weather to a reddish-brown exterior. They are typically compositionally layered, with alternations of amphibole- or diopside-rich and quartz-rich layers, up to several centimetres thick. At some localities (e.g. SPJGAS001111) the compositionally layered calc-silicate has been brecciated to form a jigsaw texture, and intruded by coarse grained leucocratic (quartz–feldspar) veins. This veining is not evident in the surrounding country rocks, and where present appears to be closely related in time to the formation/deposition of the calc-silicate. Medium-grained anorthosite is a very minor component of the calc-silicate gneiss.

In the southern part of Glenburgh, the amphibole- and diopside-rich gneisses are composed of weakly pleochroic pargasite or diopside, with quartz, subordinate plagioclase, and minor amounts of titanite. A few samples contain epidote rather than plagioclase. Most of the rocks display amoeboid and polygonal granoblastic textures. In the northern part of Glenburgh, southern and central Yinnetharra, Pink Hills, and Candolle, equivalent rocks contain coarse-grained clinopyroxene–actinolite–plagioclase gneiss and less abundant diopside–plagioclase–titanite gneiss. In the clinopyroxene–actinolite–plagioclase gneiss, clinopyroxene forms coarse crystals partly intergrown with and replaced by pale green actinolite, which has grown within S_1 layering. Plagioclase constitutes no more than 10% of the rocks. Titanite is abundant and associated with pleochroic haloes in actinolite. The protolith appears to be a clinopyroxene-rich ultramafic rock. Diopside–plagioclase–titanite gneiss is fine- to medium-grained, and typically contains fine-scale banding (2–15 mm). The rocks have a polygonal granoblastic texture with compositional layering reflecting different proportions of diopside and titanite versus plagioclase. Diopside is very pale green and non-pleochroic (probably diopside–hedenbergite). Titanite constitutes about 2–3% of the rocks.

Age code	Proterozoic	P_-
Stratigraphic code	Moogie Metamorphics	MG-
Rock type	metasedimentary carbonate	mk
Lithname	calc-silicate rock	q
Rock code		**P_-MG-mkq**

Contact relationships

In the northern part of Glenburgh, and southern and central Yinnetharra, lenses of calc-silicate gneiss and marble appear to be faulted against the Halfway Gneiss (AP_-_ha-mgn, AP_-_ha-mgnl, and AP_-_ha-mgnw) and contain a moderate- to well-developed gneissic layering that is folded with the Halfway Gneiss. On southwestern Yinnetharra, calc-silicate rocks appear to be interlayered with the Mumba Psammite (P_-MGm-mtsf) (e.g. SPJYIN000058 and SPJYIN000048) suggesting they are part of the stratigraphic sequence. The calc-silicate gneiss and marble (P_-MG-mkk) are locally intruded by granite of the Moorarie Supersuite; for example about 5 km southwest of Hectors Bore (Zone 50, MGA 419600E 7223250N; where veins of monzogranite cut calc-silicate rock), and 2.5 km south of Middle Well (Zone 50, MGA

413400E 7223700N; where leucocratic coarse-grained granite and pegmatite cut marble). In the southeastern part of GLENBURGH, several rafts of calc-silicate gneiss are present in foliated and gneissic granite of the Nardoo Granite (P_-DAna-mgt). Most layers of calc-silicate and quartzite gneiss are less than 3 m wide and up to a few hundred metres long. Calc-silicate and quartzite gneiss layers, up to about 100 m thick and nearly 1 km long, outcrop southeast and east of Ghnyndad Bore (Zone 50, MGA 433600E 7189300N and 436800E 7190800N respectively). Contacts between the calc-silicate and quartzite gneiss, and foliated to gneissic granites of the Dalgaringa Supersuite are either not exposed or tectonic. Calc-silicate and quartzite gneiss is intruded by the Nardoo Granite and leucocratic biotite granite and pegmatite, which may belong to the 1820–1775 Ma Moorarie Supersuite. On CANDOLLE, calc-silicate gneiss interfolded with Halfway Gneiss forms a 4 km-long xenolith within the Rubberoid Granite (P_-MOru-mgm) of the Moorarie Supersuite.

Geochronology

P_-MG-mkq	*Maximum*	*Minimum*
Age (Ma)	2240	2125
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., 2010	Johnson et al., 2010

No samples of calc-silicate gneiss have been dated directly. However, these rocks are interlayered with and, presumably, were interbedded with, extensive psammitic and pelitic schist of the Mumba Psammite. Eight samples of psammitic schist from GLENBURGH, DAURIE CREEK, and YINNETHARRAhave provided a maximum depositional age based on the youngest detrital zircons of 2240 ± 8 Ma and a minimum depositional age of 2125 ± 5 Ma based on the dates obtained from metamorphic monazite and zircon in one of the samples (Johnson et al., 2010). These dates are also inferred to represent maximum and minimum depositional ages for the calc-silicate rocks. All rocks of the Moogie Metamorphics were metamorphosed during the D_{2g} event of the Glenburgh Orogeny, precisely dated between 1965 and 1950 Ma by metamorphic zircon and monazite within the psammitic schists (Johnson et al., 2010). The calc-silicate rocks also form xenoliths within foliated and gneissic granites of the Dalgaringa Supersuite (P_-DA-xmgt-mgg) providing a minimum age constraint of 2002 ± 3 Ma (Nelson, 1999).

References

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Moogie Metamorphics; subunit (P_-MG-mkk)

Legend narrative

Marble; dolomite(–quartz) and dolomite–calcite–forsterite–clinohumite–serpentine rock; locally contains garnet

Rank	Formation
Parent	Moogie Metamorphics (P_-MG-xmh-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MGm-mtsf, P_-MG-mkq (conformable); P_-DA-xmgt-mgg, P_-DAna-mgt, P_-MO-gmeb, P_-MO-gp (intrusive)
Underlying units	P_-MGm-mtsf, P_-MG-mkq (conformable); AP_-_ha-mgn, AP_-_ha-mgnl, AP_-_ha-mgnw, P_-MGm-mtsf, P_-MGm-mls, P_-DA-xmgt-mgg, P_-DAna-mgt, P_-MOdu-ggp, P_-MOsc-gm (fault)

Summary

Marble (P_-MG-mkk) and associated calc-silicate gneiss (P_-MG-mkq) are minor, but widespread, rock types within the Paradise and Mooloo Zones that form narrow lenses; mostly commonly interleaved with the Halfway Gneiss and Mumba Psammite, but also as fault bounded xenoliths within foliated and gneissic granites of the Dalgaringa and Moorarie supersuites. The marble generally has a polygonal texture and is mainly composed of dolomite with or without quartz. These units are interpreted to have been deposited at the same time as the Mumba Psammite as the two are locally interbedded.

Distribution

Marble (P_-MG-mkk) and associated calc-silicate gneiss (P_-MG-mkq) are minor, but widespread, rock types on in the Paradise and Mooloo Zones on GLENBURGH, LOCKIER, and YINNETHARRA. The rocks form narrow lenses, most commonly interbedded with calc-silicate gneiss (P_-MG-mkq) which forms the major part of the outcrop. Marble is also interleaved with the Halfway Gneiss and foliated and gneissic granites of the Dalgaringa and Moorarie supersuites. Most marble layers are between 50 and 200 m wide and 0.3 to 2 km long. Layers of marble may have a white or dark-grey pattern on aerial photographs, and outcrop as low, blocky, rugged hills within the granitic gneiss.

Lithology

The marbles are white or cream on fresh surfaces, but weather to a pale- or dark-grey exterior. The marbles have a polygonal texture and are mainly composed of dolomite, with or without quartz. There are rare amoeboid granoblastic rocks composed of calcite, dolomite, garnet, forsterite, clinohumite, serpentine, and accessory opaque minerals. Forsterite forms cores of pale-yellow to orange–yellow clinohumite. Serpentine also partly replaces forsterite. Domains of coarser grained calcite–dolomite–forsterite are probably relicts from a higher grade metamorphic event. In some areas in the northern part of GLENBURGH, abundant magnesium-rich chlorite replaces biotite within the marble.

Age code	Proterozoic	P_-
Stratigraphic code	Moogie Metamorphics	MG-
Rock type	metasedimentary carbonate	mk
Lithname	marble	k
Rock code		**P_-MG-mkk**

Contact relationships

In the northern part of GLENBURGH and on southwestern YINNETHARRA the marble forms narrow lenses, mostly commonly interbedded with calc-silicate gneiss (P_-MG-mkq) which dominates the outcrop. Contacts between the calc-silicate and marble are generally graded but some sharp contacts are locally present. These calc-silicate marble units are coarsely interbedded with psammitic schists of the Mumba Psammite; for example at SPJYIN000058 and SPJYIN000048. Lenses of marble also appear to be faulted against the Halfway Gneiss and contain a moderate- to well-developed gneissic layering that is folded with the Halfway Gneiss. The marble and calc-silicate gneiss are locally intruded by granite of the Moorarie Supersuite; for example about 5 km southwest of Hectors Bore (Zone 50, MGA 419600E 7223250N; where veins of monzogranite cut calc-silicate rock), and 2.5 km south of Middle Well (Zone 50, MGA 413400E 7223700N; where leucocratic coarse-grained granite and pegmatite cut marble). At the latter locality the marble forms a lens about 100 m long, and is one of a series of lenses or pods of marble in this zone. East of Hectors Bore, the marble outcrop is difficult to differentiate from massive dolostone near the base of the Paleoproterozoic to Mesoproterozoic Irregully Formation (Edmund Group).

Geochronology

P_-MG-mkk	*Maximum*	*Minimum*
Age (Ma)	2240	2125
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., 2010	Johnson et al., 2010

No marble units have been dated directly. However, these rocks are interlayered with and, presumably, were interbedded with extensive psammitic and pelitic schist of the Mumba Psammite. Eight samples of psammitic schist from GLENBURGH, DAURIE CREEK, and YINNETHARRA have provided a maximum depositional age of 2240 ± 8 Ma, based on the youngest detrital zircon, and a minimum depositional age of 2125 ± 5 Ma based on the dates obtained from metamorphic monazite and zircon in one of the samples (Johnson et al., 2010). These dates are also inferred to represent the maximum and minimum depositional ages for the calc-silicate rocks. All of the metamorphic rocks of the Moogie Metamorphics were metamorphosed during the D_{2g} event of the Glenburgh Orogeny, precisely dated between 1965 and 1950 Ma by metamorphic zircon and monazite within the psammitic schists (Johnson et al., 2010). These calc-silicate rocks also form xenoliths within foliated and gneissic granites of the Dalgaringa Supersuite (P_-DA-xmgt-mgg) providing a minimum age constraint of 2002 ± 3 Ma (Nelson, 1999).

References

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Dalgaringa Supersuite (P_-DA-mg)

Legend narrative

Metagranite and granitic gneiss

Rank	Supersuite
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	Bertibubba Supersuite, Moorarie Supersuite (intrusive); Pooranoo Metamorphics (unconformable)
Underlying units	Halfway Gneiss and Moogie Metamorphics (faulted and intrusive)

Summary

The Dalgaringa Supersuite consists of massive, foliated, and gneissic granites dated at 2005–1970 Ma (Sheppard et al., 1999). On Glenburgh the supersuite comprises two episodes of magmatism, separated by a deformation and high-grade regional metamorphic event. The two magmatic episodes are represented by 2005–1985 Ma foliated to gneissic, metamorphosed quartz-diorite, as well as metatonalite, metagranodiorite, and metamonzogranite, and c. 1975 Ma metatonalite and metagranodiorite of the Nardoo Granite. Between these two magmatic episodes, and after the deformation and regional metamorphism, sheets of foliated leucocratic metamonzogranite intruded the early foliated to gneissic granites. Foliated and gneissic granites range from strongly deformed and completely recrystallized foliated and gneissic granite in zones of high strain, to statically recrystallized granites with preserved intrusive relationships in areas of low strain. All the rocks have been metamorphosed at medium to high grade, even where evidence of substantial strain is lacking.

In zones of moderate to high strain the rocks are pegmatite banded and strongly resemble Archean mesocratic granitic gneiss in the Narryer Terrane (Occhipinti et al., 1998; Sheppard and Swager, 1999). Williams et al. (1983) and Williams (1986) interpreted the foliated and gneissic granites as a migmatite produced during Proterozoic high-grade metamorphism and anatexis of Archean granites. However, SHRIMP U–Pb zircon dating of numerous samples from the Dalgaringa Supersuite indicates that all the rocks are Paleoproterozoic in age. The geochronology, geochemistry, and Nd isotopic compositions of the supersuite were discussed by Sheppard et al. (2004).

Distribution

Metagranites of the Dalgaringa Supersuite are an integral component of the Glenburgh Terrane, which is exposed in the Mooloo and Paradise Zones at the southern end of the Gascoyne Province. Metagranites of the supersuite outcrop mainly in the Paradise Zone along the southern edge of the province and its continuation to the west, the Carrandibby Inlier. The Dalgaringa Supersuite outcrops over much of the southern part of Glenburgh, and to the east, in the southwestern corner of Landor. The supersuite may also underlie Cenozoic units of the Macadam Plains in the eastern half of Landor. Geochronological studies indicate that rocks of the supersuite are a component of the Halfway Gneiss in the Mooloo Zone on northern Glenburgh.

Lithology

The Dalgaringa Supersuite comprises 2005–1985 Ma foliated to gneissic granites, and c. 1975 Ma metatonalite and metagranodiorite of the Nardoo Granite. The foliated to gneissic granites are divided into a number of units that are composites of different rock types. In outcrop the individual rock types comprise sheets, dykes, and veins, and cannot themselves be represented as separate units on maps. The boundaries between the mapped units are typically gradational, and mark changes in the abundance of one or more main rock types. The boundaries are commonly parallel to the regional tectonic fabric. The foliated to gneissic granites comprise five main rock types:

- fine- to medium-grained, mesocratic, metamorphosed quartz-diorite, metatonalite, and metadiorite (collectively referred to as 'tonalite');
- fine- to medium-grained, pale-grey biotite metamonzogranite and leucocratic metatonalite ('fine-grained granite');
- medium-grained, variably porphyritic metatonalite and metagranodiorite ('mafic granodiorite');
- medium-grained, leucocratic biotite metamonzogranite and metagranodiorite ('felsic granodiorite'); and
- coarse-grained, leucocratic, biotite metagranite and metapegmatite (P_-DA-mgp; 'pegmatite').

Veins and sheets of coarse-grained, leucocratic, biotite metagranite and metapegmatite (P_-DA-mgp) consistently intrude the other four rock types. All these rock types, including the metapegmatite, are extensively intruded by medium-grained leucocratic metamonzogranite (P_-DA-mgml). All rock types in the Dalgaringa Supersuite, including the c. 1975 Ma Nardoo Granite, commonly have a blotchy appearance due to the presence of clots (0.5 – 2 cm in diameter) of fine-grained biotite after garnet.

Age code	Proterozoic	P_-
Stratigraphic code	Dalgaringa Supersuite	DA-
Rock type	meta-igneous felsic intrusive	
Lithname	metagranitic rock	mg
Rock code		**P_-DA-mg**
Additional lithologies	metatonalite, metadiorite, pegmatite, metamonzogranite	

Contact relationships

The Dalgaringa Supersuite forms the bulk of the Glenburgh Terrane in the Paradise Zone, and is probably also widespread in the Mooloo Zone to the north, where it is tectonically interleaved with Archean to Paleoproterozoic granitic rocks as part of the Halfway Gneiss. The Dalgaringa Supersuite presumably intruded the protoliths to the Halfway Gneiss, but there is little evidence preserved of an intrusive relationship. In the

Paradise Well area, strips and lenses of metasedimentary rock outcrop within the Dalgaringa Supersuite (P_-mli-GAG). The Dalgaringa Supersuite is younger than the Moogie Metamorphics, and probably intruded the metamorphic rocks. The Dalgaringa Supersuite is intruded by various granites of the Moorarie Supersuite, as well as dykes of the Bertibubba Supersuite in the Paradise Zone.

Geochronology

P_-DA-mg	*Maximum*	*Minimum*
Age (Ma)	2002 ± 5	1974 ± 4
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1999a	Nelson, 1999b

About 14 granitic rocks from the Dalgaringa Supersuite sampled for SHRIMP U–Pb zircon geochronology yielded crystallization ages ranging between 2002 ± 3 Ma and 1974 ± 4 Ma. The supersuite comprises foliated and gneissic granites with igneous crystallization ages between 2002 ± 3 Ma and 1987 ± 4 Ma, and foliated tonalites of the Nardoo Granite dated at 1977 ± 4 Ma and 1974 ± 4 Ma. The Nardoo Granite contains inclusions of folded, foliated, and gneissic granites, indicating an episode of tectonism between the two pulses of granitic magmatism. Most granitic rocks from the Dalgaringa Supersuite contain very few xenocrystic zircons, most of which are Paleoproterozoic in age, and similar to the crystallization ages obtained from the Halfway Gneiss protoliths (Johnson et al., 2010).

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NARDOO GRANITE
(P_-DAna-mgt)

Legend narrative

Foliated, medium-grained biotite metatonalite and metamorphosed quartz-diorite; equigranular or porphyritic; abundant small mafic clots

Rank	Formation
Parent	Dalgaringa Supersuite (P_-DA-mg)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DAna-mgtl, P_-BB-gtl, P_-MO-gp
Underlying units	P_-DA-xmgt-mgm, P_-DA-xmgt-mgg, P_-DA-xmgml-mgg

Summary

The Nardoo Granite is the largest exposed unit in the Dalgaringa Supersuite, comprising a large pluton on southeast Glenburgh and eastwards onto southern Landor. It comprises metamorphosed mesocratic and leucocratic tonalite, both of which are dated at c. 1975 Ma. The Nardoo Granite intrudes foliated and gneissic granites of the Dalgaringa Supersuite with igneous crystallization ages of 2005–1985 Ma.

Distribution

The Nardoo Granite forms an elliptical, east-northeasterly trending intrusion at least 45 km long and up to 20 km wide, the bulk of which is exposed on Glenburgh. The Nardoo Granite is also exposed in the southwestern corner of Landor to the east. Isolated outcrops of fresh granodiorite west of Dispute Bore in the eastern part of Landor are also interpreted as part of the Nardoo Granite. If this interpretation is correct, then the Nardoo Granite may be more than 75 km long and underlie an area of more than 1000 km^2.

The Nardoo Granite forms a gently undulating land surface with boulders, tors, and whalebacks, amongst locally derived sandy colluvial and sheetwash deposits. In the southeastern corner of Glenburgh, fresh granite is exposed beneath an old dissected land surface marked by ferruginous duricrust, saprolite, and weathered rock.

Derivation of name

The Nardoo Granite is named after Nardoo Well near the eastern edge of Glenburgh. The Nardoo Granite is equivalent to the gneissic biotite–hornblende granodiorite of the Dalgety Gneiss Dome of Williams (1986).

Lithology

The Nardoo Granite consists of two intrusive phases: medium-grained, equigranular or porphyritic, mesocratic biotite metatonalite and subordinate metamorphosed quartz-diorite (P_-DAna-mgt), and medium-grained, weakly porphyritic, leucocratic biotite metatonalite and minor metagranodiorite (P_-DAna-mgtl).

The two main intrusive phases of the Nardoo Granite correspond in part to the two-fold subdivision of the early stage gneissic granitoids southeast of Dalgety Downs Homestead outlined by Williams et al. (1983). Medium-grained mesocratic biotite metatonalite and subordinate metamorphosed quartz-diorite (P_-DAna-mgt) is the slightly more abundant of the two phases and predominates in the northern half of the intrusion. Medium-grained, weakly porphyritic, leucocratic biotite metatonalite (P_-DAna-mgtl) is the main rock type in the southern part of the intrusion.

The mesocratic metatonalite and metamorphosed quartz-diorite (P_-DAna-mgt) contains less than 5% tabular plagioclase phenocrysts, up to 1 cm long, in a medium-grained groundmass. In places, rust-brown prismatic crystals of altered allanite are visible in hand specimen. Numerous clots, 0.5 – 1.0 cm in diameter, of fine-grained biotite and chlorite are scattered throughout the rock. On weathered surfaces the metatonalite is commonly dark grey and contains small pits after mafic clots. Most samples of the mesocratic metatonalite and metamorphosed quartz-diorite are variably foliated and recrystallized. The rocks consist of plagioclase (andesine–oligoclase) and subordinate quartz and biotite, with accessory apatite, zircon, and allanite. Some samples contain a few percent microcline. Biotite is chocolate brown and constitutes about 20% of most rocks. Many biotite crystals have crystallographically oriented inclusions of acicular ?rutile. A few samples contain prominent euhedral zoned crystals of zircon, up to 400 µm long. Elliptical and lenticular inclusions of fine-grained metatonalite up to 1 m long are common in the medium-grained metatonalite. Angular slab-like inclusions of fine-grained metatonalite up to several metres long are locally present in the southeastern corner of the sheet area.

Age code	Proterozoic	P_
Stratigraphic code	Dalgaringa Supersuite, NARDOO GRANITE	DAna-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metatonalite	t
Rock code		**P_-DAna-mgt**

Contact relationships

The Nardoo Granite intrudes foliated and gneissic granite dated at 2005–1985 Ma, and interlayered amphibolite and calc-silicate gneiss, and contains several large rafts of foliated and gneissic granite up to 7 km long and 1 km wide. Inclusions of fine-grained, pegmatite-banded tonalite, fine-grained granite, and amphibolite are widespread in the Nardoo Granite. These inclusions, and the gneissic fabric within them, are commonly folded about an axial surface parallel to a penetrative foliation. These relationships indicate that the Nardoo Granite was intruded after deformation and high-grade metamorphism that occurred between c. 1985 and c. 1975 Ma. Therefore, the granite cannot have formed as a para-autochthonous diapir following partial melting of the enclosing foliated and gneissic granites as suggested by Williams (1986).

The Nardoo Granite is intruded by numerous dykes of coarse-grained leucocratic biotite granite (P_-MO-gmlp) southeast of Brockman Well on the western part of LANDOR, and by veins and dykes of coarse-grained granite and pegmatite (P_-MO-gp) on the southern part of GLENBURGH, between Dardoo Well and Salt Well and east-northeast of Parrot Bore. The Nardoo Granite is also intruded by numerous dolerite dykes; some of these probably belong to the c. 755 Ma Mundine Well Dolerite Suite (P_-MW-od), but others may belong to Mesoproterozoic (?1210 Ma) dyke suites.

Geochronology

P_-DAna-mgt	*Maximum*	*Minimum*
Age (Ma)	1977 ± 4	1974 ± 4
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1999a	Nelson, 1999b

A weakly foliated, metamorphosed, porphyritic, mesocratic tonalite to granodiorite about 4 km north of Dardoo Well was sampled for SHRIMP U–Pb zircon geochronology (GSWA 142932). Twenty-one concordant or slightly discordant zircons yielded a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1977 ± 4 Ma (Nelson, 1999a), interpreted as the time of igneous crystallization of the granodiorite. Two slightly discordant analyses indicated a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 2025 ± 11 Ma, and may represent xenocrystic zircons. The date of 1977 ± 4 Ma is indistinguishable from that of a sample of leucocratic tonalite (P_-DAna-mgtl; GSWA 142928) dated at 1974 ± 4 Ma (Nelson, 1999b).

References

Nelson, DR 1999a, 142932: biotite tonalite, Nardoo Bore; Geochronology Record 319: Geological Survey of Western Australia, 4p.

Nelson, DR 1999b, 142928: biotite tonalite, Nardoo Bore; Geochronology Record 315: Geological Survey of Western Australia, 4p.

Williams, SJ 1986, Geology of the Gascoyne Province, Western Australia: Geological Survey of Western Australia, Report 15, 85p.

Williams, SJ, Williams, IR and Hocking, RM 1983, Glenburgh, W.A.: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 25p.

NARDOO GRANITE; subunit (P_-DAna-mgtl)

Legend narrative

Foliated, medium-grained, weakly porphyritic, leucocratic biotite metatonalite and minor metagranodiorite

Rank	Member
Parent	NARDOO GRANITE (P_-DAna-mgt)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-BB-gtl, P_-MO-gp
Underlying units	P_-DAna-mgt, P_-DA-xmgt-mgm, P_-DA-xmgt-mgg, P_-DA-xmgml-mgg

Summary

Foliated medium-grained, weakly porphyritic, leucocratic biotite metatonalite is one of two main rock types that constitute the Nardoo Granite. The leucocratic phase is slightly less abundant than the foliated and mesocratic medium-grained biotite metatonalite and metamorphosed quartz-diorite (P_-DAna-mgt). The two rock types have indistinguishable SHRIMP U–Pb zircon ages of c. 1975 Ma.

Distribution

Medium-grained, weakly porphyritic leucocratic biotite metatonalite is the main rock type in the southern part of the Nardoo Granite along the southern edge of GLENBURGH.

Lithology

The leucocratic metatonalite typically contains 5–10% tabular plagioclase phenocrysts, up to 1 cm long, in a medium-grained groundmass. Relative to the mesocratic metatonalite, the leucocratic metatonalite has a slightly more felsic appearance, a paler weathering surface, and fewer mafic clots or inclusions of fine-grained metatonalite. Samples of the leucocratic phase are commonly less recrystallized than the mesocratic phase. The leucocratic metatonalite is composed of plagioclase, quartz, biotite, microperthite (up to about 8%), and accessory apatite, allanite, and zircon. Most samples contain a few percent microcline. A few plagioclase crystals preserve normal igneous zoning; cores of sodic andesine (An35) are zoned to rims of calcic oligoclase (An25). Chocolate-brown biotite forms about 10% of the rocks, with many crystals containing crystallographically oriented inclusions of acicular ?rutile. Biotite is typically the sole mafic mineral, although a few samples contain olive-green hornblende, which is possibly igneous in origin. The hornblende is rimmed by an optically continuous greenish-blue hornblende.

Age code	Proterozoic	P_-
Stratigraphic code	Dalgaringa Supersuite, NARDOO GRANITE	DAna-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metatonalite	t
1st qualifier	–	
2nd qualifier	leucocratic	l
Rock code		**P_-DAna-mgtl**
Additional ithologies	metagranodiorite	

Contact relationships

Contacts between the leucocratic metatonalite and the mesocratic metatonalite phases of the Nardoo Granite are commonly sharp, but the two rock types grade into each other in places. In low-strain zones, irregular veins and dykes of leucocratic metatonalite consistently intrude the mesocratic metatonalite. Locally, the two phases are intermingled or tectonically interleaved at outcrop scale.

Geochronology

P_-DAna-mgtl	*Maximum*	*Minimum*
Age (Ma)	1974 ± 4	1974 ± 4
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1999	Nelson, 1999

A massive, medium- to coarse-grained biotite metatonalite about 4.5 km west-southwest of Nardoo Bore was sampled for SHRIMP U–Pb zircon geochronology (GSWA 142928). All twenty-two analysed zircons are concordant or slightly discordant, and yielded a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1974 ± 4 Ma (Nelson, 1999), interpreted as the age of igneous crystallization of the tonalite.

References

Nelson, DR 1999, 142928: biotite tonalite, Nardoo Bore; Geochronology Record 315: Geological Survey of Western Australia, 4p.

Dalgaringa Supersuite; subunit (P_-DA-xmgg-mwo)

Legend narrative

Foliated metagranodiorite and metamonzogranite sheets, with abundant layers of mafic granulite; minor pelite, including diatexite migmatite

Rank	Formation
Parent	Dalgaringa Supersuite (P_-DA-mg)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DA-mgp, P_-DAna-mgt, P_-DAna-mgtl (intrusive)
Underlying units	P_-DA-xmgt-mgm, P_-mli-GAG (xenoliths)

Summary

Foliated metagranodiorite and metamonzogranite, and mafic granulite and pelite form a distinctive association around Paradise Well on southwestern Glenburgh. The 'metagranodiorites' range from anhedral granular or polygonal-textured, metatonalite to K-poor metagranodiorite that comprise 70% of the rocks. The interleaved metamafic rocks may make up as much as 30% of the outcrop, are generally granoblastic, and contain both clinopyroxene and orthopyroxene with or without garnet. The unit also contains rafts of diatexite migmatite (P_-mli-GAG) up to 100 m long and 30 m wide.

Distribution

Metagranodiorite and metamonzogranite, and mafic granulite and pelite form a distinctive association around Paradise Well on southwestern Glenburgh. These rock types form an east-northeast trending belt at least 6 km long and up to 2 km wide. Mafic granulite layers may make up as much as 30% of the outcrop and give the unit a dark-brown colour on aerial photographs. This unit also contains lenses or rafts of diatexite migmatite (P_-mli-GAG), the largest of which (located about 0.5 km west-northwest of Paradise Well) is over 100 m long and 30 m wide, as well as pelitic granofels.

Lithology

Rocks referred to as 'mafic granodiorite' in the field consist of anhedral granular or polygonal-textured metatonalite, or K-poor metagranodiorite. Samples comprise a few percent relict igneous plagioclase phenocrysts in a matrix of fine-grained plagioclase, quartz, and biotite, with or without greenish-blue hornblende. Relict igneous plagioclase crystals display normal zoning, whereas finer grained plagioclase in the matrix is unzoned. Magnetite is a widespread minor mineral, and zircon, apatite, and allanite are the main accessory minerals. Mafic clots prominent in hand specimen are composed of fine-grained biotite(–magnetite–epidote).

Rocks called 'felsic granodiorite' in the field consist of anhedral granular or xenoblastic biotite metamonzogranite or K-rich metagranodiorite. The rocks are composed of microcline, plagioclase, quartz, and about 10% biotite. Most of the rocks are fine grained, but a few domains of medium- to coarse-grained microcline and plagioclase with rims of myrmekite are preserved. Xenoblastic porphyroblasts of garnet are preserved in a few samples, but most crystals are replaced by fine-grained, brownish-green biotite. Opaque minerals are uncommon, and mainly replaced by epidote and titanite. Zircon, apatite, and allanite are accessory minerals.

The lenses of diatexite around Paradise Well consist of medium-grained, siliceous leucosome (interpreted as melt) with layers or fragments of dark-grey, biotite(–garnet)-rich rock (restite). Where the proportion of leucosome is about 50%, restite forms semi-continuous layers, but at higher proportions of melt (up to 80%), restite forms equidimensional to lenticular fragments between 1 and 20 cm long. Pelitic granofels is a fine- to medium-grained rock, with porphyroblasts of almandine garnet about 1 c. in diameter.

Age code	Proterozoic	P_-
Stratigraphic code	Dalgaringa Supersuite	DA-
Mixed or xenolith-bearing	Mixed	x
Rock type 1	meta-igneous felsic intrusive	mg
Lithname 1	metagranodiorite	g
Rock type 2	meta-igneous mafic	-mw
Lithname 2	mafic granulite	o
Rock code		**P_-DA-xmgg-mwo**
Additional lithologies	metamonzogranite, metatonalite, pelitic migmatite	

Contact relationships

Sheets of medium-grained, variably porphyritic metatonalite and metagranodiorite ('mafic granodiorite'), and medium-grained, leucocratic biotite metamonzogranite and metagranodiorite ('felsic granodiorite') intrude or are tectonically interleaved with the mesocratic metatonalite and fine-grained metamonzogranite (P_-DA-xmgt-mgm). The metagranodiorite and metamonzogranite contain lenticular and angular inclusions of foliated metatonalite. Larger inclusions of tonalite, up to 1 m long, typically have a blocky shape.

Geochronology

P_-DA-xmgg-mwo	*Maximum*	*Minimum*
Age (Ma)	2002	1997
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 1999	Wingate et al., 2010

No samples of the foliated metagranodiorite and metamonzogranite with associated mafic granulite and pelitic migmatite have been dated directly. However, a sample (GSWA 142925) of metamonzogranite from P_-DA-xmgg-mggl taken about 300 m south of Challenger Well on eastern Glenburgh has an igneous crystallization age of 2002 ± 3 Ma (Nelson, 1999). The unit of foliated metagranodiorite and metamonzogranite with mafic granulite and pelitic migmatite is, in common with all other foliated and gneissic granite units of the Dalgaringa Supersuite, intruded by the c. 1975 Ma Nardoo Granite. A sample of pelitic diatexite migmatite (P_-mli-GAG; GSWA 185942) was sampled for U–Pb SHRIMP zircon geochronology. The sample contained numerous detrital zircons that yielded $^{207}Pb^{*}/^{206}Pb^{*}$ dates of 3222–2115 Ma. However, abundant high-U, low-Th/U structureless zircon overgrowths interpreted as having grown during the granulite facies event (Johnson et al., 2010) yield a concordia age of 1997 ± 10 Ma, providing a younger limit for crystallization of the meta-igneous rocks with which they are intercalated.

References

Johnson, SP, Sheppard, S, Rasmussen, B, Wingate, MTD, Kirkland, CL, Muhling, JR, Fletcher, IR and Belousova, E 2010, The Glenburgh Orogeny as a record of continent–continent collision: Geological Survey of Western Australia, Record 2010/5, 54p.

Nelson, DR 1999, 142925: biotite monzogranite, Challenger Well; Geochronology Record 312: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, C, Johnson, SP and Sheppard S 2010, 185942: pelitic diatexite, Paradise Well; Geochronology Record 861: Geological Survey of Western Australia, 5p.

Dalgaringa Supersuite; subunit (P_-DA-xmgt-mgg)

Legend narrative

Interlayered, medium-grained metatonalite and metagranodiorite, leucocratic biotite metamonzogranite and metagranodiorite; subordinate fine-grained metatonalite and metamonzogranite; gneissic to weakly foliated

Rank	Formation
Parent	Dalgaringa Supersuite (P_-DA-mg)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DA-mgp, P_-DAna-mgt, P_-DAna-mgtl (intrusive)
Underlying units	P_-DA-mgtw, P_MO-ggev

Summary

The metatonalite, metagranodiorite, and metamonzogranite that constitute much of this unit resemble the mafic and felsic phases of the Nardoo Granite, such that they cannot always be confidently distinguished from each other. However, geochronology demonstrates that the oldest phases of metatonalite, metagranodiorite, and metamonzogranite are about 20–25 Ma older (c. 2005 Ma) than the Nardoo Granite (1970–1975 Ma).

Distribution

The largest unit of the foliated and gneissic granites is dominated by foliated medium-grained metatonalite and metagranodiorite, and foliated, leucocratic biotite metamonzogranite and metagranodiorite. The unit forms two parallel arcuate belts, each 5 km or more wide, on southern GLENBURGH and on the eastern edge of DAURIE CREEK to the west. Exposure is good, and typically consists of boulders and pavements on low hills and rises. Tors and small whalebacks are common in low-strain zones.

Lithology

Foliated, medium-grained metatonalite and metagranodiorite, and foliated, leucocratic biotite metamonzogranite and metagranodiorite are the main rock types, but this unit also contains subordinate fine-grained metatonalite and metagranite.

Metatonalite or K-poor metagranodiorite have anhedral or polygonal textures, and comprise a few percent relict igneous plagioclase phenocrysts in a matrix of fine-grained plagioclase, quartz, and biotite, with or without greenish-blue hornblende. Relict igneous plagioclase crystals display normal zoning, whereas finer grained plagioclase in the matrix is unzoned. Magnetite is a widespread minor mineral, and zircon, apatite, and allanite are the main accessory minerals. Mafic clots prominent in hand specimen are composed of fine-grained biotite(–magnetite–epidote).

Biotite metamonzogranite or K-rich metagranodiorite display anhedral granular or xenoblastic textures. The rocks are composed of microcline, plagioclase, quartz, and about 10% biotite. Most of the rocks are fine grained, but a few domains of medium- to coarse-grained microcline and plagioclase with rims of myrmekite are preserved. Xenoblastic porphyroblasts of garnet are preserved in a few samples, but most crystals are replaced by fine-grained, brownish-green biotite. Opaque minerals are uncommon, and mainly replaced by epidote and titanite. Zircon, apatite, and allanite are accessory minerals.

Fine-grained metatonalite has textures that range from anhedral granular in massive rocks through to amoeboid and granoblastic in compositionally layered rocks. Green hornblende, with optically continuous rims of sodic hornblende, is present in many samples. Fine-grained metagranite consists of either biotite monzogranite or leucocratic biotite tonalite, but the two rock types are not readily distinguished in the field. The rocks range from massive and statically recrystallized through to strongly foliated or gneissic and finely pegmatite banded.

Age code	Proterozoic	P_-
Stratigraphic code	Dalgaringa Supersuite	DA-
Mixed or xenolith-bearing	Mixed	x
Rock type 1	meta-igneous felsic intrusive	mg
Lithname 1	metatonalite	t
Rock type 2	meta-igneous felsic intrusive	-mg
Lithname 2	metagranodiorite	g
Rock code		**P_-DA-xmgt-mgg**

Contact relationships

Sheets of medium-grained, variably porphyritic metatonalite and metagranodiorite, and medium-grained, leucocratic biotite metamonzogranite and metagranodiorite intrude or are tectonically interleaved with the mesocratic metatonalite and fine-grained metamonzogranite (P_-DA-xmgt-mgm). The metagranodiorite and metamonzogranite contain lenticular and angular inclusions of foliated metatonalite. Larger inclusions of metatonalite, up to 1 m long, typically have a blocky shape.

Although the leucocratic biotite metamonzogranite to metagranodiorite is the oldest dated rock type in the Dalgaringa Supersuite, yielding igneous crystallization ages of 2002 ± 3 Ma (GSWA 142925: Nelson, 1999a) and 2000 ± 8 Ma (GSWA 168951: Nelson, 2001), it consistently intrudes fine- and medium-grained mesocratic metatonalite. A sample of fine-grained metatonalite (GSWA 142933) south of Meerawana Well on GLENBURGH has an igneous crystallization age of 1989 ± 3 Ma. These field relationships and ages imply that there were probably repeated episodes or cycles of tonalitic, granodioritic, and monzogranitic magmatism during assembly of the 2005–1985 Ma foliated and gneissic granites of the Dalgaringa Supersuite.

Geochronology

P_-DA-xmgt-mgg	*Maximum*	*Minimum*
Age (Ma)	2002 ± 3	1977
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Inferred
References	Nelson, 1999a	Nelson, 1999b

Foliated metamonzogranite (GSWA 142925) 300 m south of Challenger Well on eastern GLENBURGH was sampled for SHRIMP U–Pb zircon geochronology, and yielded a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 2002 ± 3 Ma (Nelson, 1999a), interpreted as the time of igneous crystallization of the monzogranite protolith. The unit of foliated metagranodiorite and metamonzogranite with mafic granulite and pelitic migmatite is, in common with all other foliated and gneissic granite units of the Dalgaringa Supersuite, intruded by the c. 1975 Ma Nardoo Granite (Nelson, 1999b).

References

Nelson, DR 1999a, 142925: biotite monzogranite, Challenger Well; Geochronology Record 312: Geological Survey of Western Australia, 4p.

Nelson, DR 1999b, 142932: biotite tonalite, Nardoo Bore; Geochronology Record 319: Geological Survey of Western Australia, 4p.

Nelson, DR 2001, 168951: foliated biotite–muscovite monzogranite, Salt Well; Geochronology Record 189: Geological Survey of Western Australia, 4p.

Dalgaringa Supersuite; subunit (P_-DA-xmgml-mgg)

Legend narrative

Interlayered, medium-grained, leucocratic biotite metamonzogranite and metagranodiorite; commonly with clots of biotite after garnet

Rank	Formation
Parent	Dalgaringa Supersuite (P_-DA-mg)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DAna-mgt, P_-DAna-mgtl (intrusive)
Underlying units	P_-DA-mgtw

Age code	Proterozoic	P_-
Stratigraphic code	Dalgaringa Supersuite	DA-
Mixed or xenolith-bearing	Mixed	x
Rock type 1	meta-igneous felsic intrusive	mg
Lithname 1	metamonzogranite	m
1st qualifier	–	
2nd qualifier	leucocratic	l
Rock type 2	meta-igneous felsic intrusive	-mg
Lithname 2	metagranodiorite	g
Rock code		**P_-DA-xmgml-mgg**

Summary

Interlayered, medium-grained, leucocratic biotite metamonzogranite and metagranodiorite is a widespread and abundant rock unit of the 2005–1985 Ma foliated and gneissic granites in the Dalgaringa Supersuite. It is the oldest dated unit in the supersuite at c. 2005 Ma, but the rock types that constitute this unit appear to have been intruded repeatedly over about 20 Ma. This unit is closely related to interlayered, medium-grained metatonalite and metagranodiorite, leucocratic biotite metamonzogranite and metagranodiorite (P_-DA-xmgt-mgg), differing mainly in the abundance of the leucocratic phases.

Distribution

Medium-grained, leucocratic biotite metamonzogranite and metagranodiorite are extensively exposed as sheets up to several hundred metres thick around Hadlam Well and Challenger Well on eastern GLENBURGH. Elsewhere, on southern GLENBURGH, it typically forms lenses within the other larger units. Exposure is very good, consisting of small rocky hills and ridges covered in boulders and tors. This unit is commonly distinguishable on aerial photographs when it is enclosed in units dominated by fine-grained mesocratic metatonalite and fine-grained metagranite.

Lithology

Metamonzogranite and metagranodiorite are composed of microcline, plagioclase, quartz, and about 10% biotite. Most of the rocks are fine grained, but a few domains of medium- to coarse-grained microcline and plagioclase with rims of myrmekite are preserved. Xenoblastic porphyroblasts of garnet are preserved in a few samples, but most crystals are replaced by fine-grained, brownish-green biotite. Opaque minerals are uncommon, and mainly replaced by epidote and titanite. Zircon, apatite, and allanite are accessory minerals.

Contact relationships

Medium-grained, leucocratic biotite metamonzogranite and metagranodiorite form sheets that intrude, or are tectonically interleaved with, mesocratic metatonalite and fine-grained metagranite. The metamonzogranite and metagranodiorite intrude and contain lenticular and angular inclusions of foliated tonalite. Larger inclusions of metatonalite, up to 1 m long, typically have a blocky shape.

Although the leucocratic biotite metamonzogranite to metagranodiorite is the oldest dated rock type in the Dalgaringa Supersuite, yielding igneous crystallization ages of 2002 ± 5 Ma (GSWA 168951: Nelson, 2001) and 2000 ± 8 Ma (GSWA 142925: Nelson, 1999), it consistently intrudes fine- and medium-grained mesocratic metatonalites. A sample of fine-grained metatonalite (GSWA 142933) south of Meerawana Well on GLENBURGH has an igneous crystallization age of 1989 ± 3 Ma. These field relationships and ages imply that there were probably repeated episodes or cycles of tonalitic, granodioritic, and monzogranitic magmatism during assembly of the 2005–1985 Ma foliated and gneissic granites of the Dalgaringa Supersuite.

Geochronology

P_-DA-xmgml-mgg	*Maximum*	*Minimum*
Age (Ma)	2002	1977
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 1999a	Nelson, 1999b

Medium-grained, leucocratic biotite metamonzogranite and metagranodiorite have not been dated directly. However, a sample (GSWA 142925) of lithologically identical metamonzogranite (P_-DA-xmgg-mggl) taken about 300 m south of Challenger Well on eastern GLENBURGH, has an igneous crystallization age of 2002 ± 3 Ma (Nelson, 1999). Medium-grained leucocratic biotite metamonzogranite and metagranodiorite are, in common with all other foliated and gneissic granite units of the Dalgaringa Supersuite, intruded by the c. 1975 Ma Nardoo Granite.

References

Nelson, DR 1999a, 142925: biotite monzogranite, Challenger Well; Geochronology Record 312: Geological Survey of Western Australia, 4p.

Nelson, DR 1999b, 142932: biotite tonalite, Nardoo Bore; Geochronology Record 319: Geological Survey of Western Australia, 4p.

Nelson, DR 2001, 168951: foliated biotite-muscovite monzogranite, Salt Well; Geochronology Record 189: Geological Survey of Western Australia, 4p.

Dalgaringa Supersuite; subunit (P_-DA-xmgt-mgm)

Legend narrative

Interlayered, fine-grained mesocratic metatonalite and fine-grained, pale grey, biotite metamonzogranite and leucocratic metatonalite; commonly with clots of biotite after garnet

Rank	Formation
Parent	Dalgaringa Supersuite (P_-DA-mg)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DA-mgtw, P_-DA-mgml, P_-DA-mgp

Summary

Interlayered, fine-grained mesocratic metatonalite and fine-grained, pale grey, biotite metamonzogranite and leucocratic metatonalite is both a widespread and voluminous unit of the 2005–1985 Ma foliated and gneissic granites of the Dalgaringa Supersuite. A dated sample each of metatonalite and biotite metamonzogranite from this unit yielded indistinguishable igneous crystallization ages of c. 2000 Ma.

Distribution

Interlayered, fine-grained mesocratic metatonalite and fine-grained, pale grey, biotite metamonzogranite and leucocratic metatonalite form a 20 km-long northeasterly trending belt, up to several kilometres wide, extending from southeast of Paradise Well to northeast of Carradarra Well on southern GLENBURGH. The unit also forms a large screen in the Nardoo Granite, several kilometres long and nearly 1 km wide, north of Salt Well. Medium-grained metagranodiorite, metamonzogranite, and metatonalite are subordinate or minor rock types in this unit. Sheets and veins of coarse-grained, leucocratic metamorphosed pegmatite and leucocratic granite (P_-DA-mgp) extensively intrude the unit. Exposure mainly consists of weathered boulders and pavements on low rises and hills.

Lithology

Weathered surfaces on the metatonalite are typically dark grey and pitted. Fine-grained metadiorite and metamorphosed quartz-diorite are distinguished from amphibolite by the absence of quartz in the latter. Metamorphosed quartz-diorite, metatonalite, and metadiorite have textures that range from anhedral granular in massive samples through to amoeboid and granoblastic in compositionally layered rocks. The rocks are composed of plagioclase, biotite, and quartz, and minor amounts of magnetite and ilmenite. Green hornblende, with optically continuous rims of sodic hornblende, is present in many samples. Quartz typically constitutes about 10–20% of the rocks, and thus most rocks are quartz diorite in composition. Most plagioclase crystals consist of unzoned andesine, but a few relict coarser plagioclase crystals display normal and oscillatory zoning. One sample (GSWA 142933) has a granoblastic to amoeboid texture and is composed of andesine, clinopyroxene, biotite, and quartz. Accessory minerals in most samples consist of apatite, zircon, and metamict and altered allanite.

Fine-grained metamonzogranite and leucocratic metatonalite are pale grey and contain biotite crystals disseminated through the groundmass and as clots. Preferential weathering of biotite clots in these rocks typically gives them a strongly pitted appearance. Fine-grained biotite metamonzogranite and leucocratic biotite metatonalite are not readily distinguished in the field. The rocks range from massive and statically recrystallized through to strongly foliated or gneissic and finely pegmatite banded. Metamonzogranite consists of quartz, microcline, oligoclase and a few percent biotite. Leucocratic metatonalite consists of oligoclase–andesine, quartz, and a few percent biotite.

Age code	Proterozoic	P_-
Stratigraphic code	Dalgaringa Supersuite	DA-
Mixed or xenolith-bearing	Mixed	x
Rock type 1	meta-igneous felsic intrusive	mg
Lithname 1	metatonalite	t
Rock type 2	meta-igneous felsic intrusive	-mg
Lithname 2	metamonzogranite	m
Rock code		**P_-DA-xmgt-mgm**

Contact relationships

Fine-grained mesocratic metatonalite is consistently intruded by all the other foliated and gneissic granites. Contacts between the metatonalite and amphibolite layers are typically tectonic, but in places amphibolite intrudes the granitic rocks; therefore, at least some of the amphibolites were mafic dykes. Fine-grained, pale-grey metamonzogranite and leucocratic metatonalite is commonly interlayered with the mesocratic metatonalite. In areas of low strain, preserved igneous relationships show that the fine-grained metamonzogranite intruded the metatonalite. Locally, preserved net-vein textures imply that there is little age difference between the two rock types.

Geochronology

P_-DA-xmgt-mgm	*Maximum*	*Minimum*
Age (Ma)	2002 ± 2	1999 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1999a	Nelson, 1999b

Two rocks from the interlayered, fine-grained mesocratic metatonalite and fine-grained, pale grey, biotite metamonzogranite and leucocratic metatonalite (P_-DA-xmgt-mgm) unit were sampled for SHRIMP U–Pb zircon geochronology. The two sample sites are less than 50 m apart, and are located about 5 km northwest of Mulunka Well on southeastern GLENBURGH. Fine-grained, mesocratic metatonalite (GSWA 142926; Zone 50, MGA 443430E 7200110N) was sampled from a low-strain zone, where the metatonalite is net-veined by a fine- to medium-grained, pale grey metamonzogranite to metagranodiorite, of which sample GSWA 142927 (Zone 50, MGA 443460E 7200070N) is representative.

The metatonalite sample yielded a date of 2002 ± 2 Ma, interpreted as the time of igneous crystallization of the tonalite (Nelson, 1999a). The weakly foliated metamonzogranite to metagranodiorite yielded a date of 1999 ± 5 Ma, interpreted as the age of igneous crystallization of the igneous precursor (Nelson, 1999b). Six variably discordant analyses of five zircons in this sample indicated older ages, and are interpreted to represent xenocrystic zircons.

References

Nelson, DR 1999a, 142926: foliated biotite tonalite, Mulunka Well; Geochronology Record 313: Geological Survey of Western Australia, 4p.

Nelson, DR 1999b, 142927: foliated biotite-oligoclase granodiorite, Mulunka Well; Geochronology Record 314: Geological Survey of Western Australia, 4p.

Dalgaringa Supersuite; subunit (P_-DA-mgtw)

Legend narrative

Fine-grained mesocratic metatonalite; minor fine-grained metamonzogranite and leucocratic metatonalite, medium-grained metatonalite and metagranodiorite, and leucocratic metamonzogranite and metagranodiorite

Rank	Formation
Parent	Dalgaringa Supersuite (P_-DA-mg)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DA-mgtw, P_-DA-mgml, P_-DA-mgp

Summary

Fine-grained mesocratic metatonalite is both a widespread and abundant component of the 2005–1985 Ma foliated and gneissic granites of the Dalgaringa Supersuite. Field relationships and SHRIMP U–Pb zircon dating indicate that the metatonalite was intruded over an interval of at least 15 Ma (>2002 ± 3 Ma to 1989 ± 3 Ma).

Distribution

Fine-grained mesocratic metatonalite forms strips or lenses a few hundred metres wide and up to 3 km long on Glenburgh. The unit also outcrops as pods or lenses in other foliated and gneissic granites in the Carrandibby Inlier on Carrandibby. Fine-grained metamonzogranite and leucocratic metatonalite is only a minor component of this unit, and this distinguishes it from the unit of interlayered, fine-grained mesocratic metatonalite and fine-grained, pale grey, biotite metamonzogranite and leucocratic metatonalite (P_-DA-xmgt-mgm). Medium-grained metatonalite and metagranodiorite, and leucocratic metamonzogranite and metagranodiorite are typically minor components. In the southern part of Glenburgh, this unit is common between Meerawana Well and Ghnyndad Bore.

Lithology

Fine-grained mesocratic metatonalite commonly has a strongly banded appearance owing to the presence of abundant veins and sheets of metamorphosed pegmatite and leucocratic biotite granite. Rocks mapped as metatonalite also include fine-grained metadiorite and metamorphosed quartz-diorite, which are distinguished from amphibolite by the absence of quartz in the latter. Metamorphosed quartz-diorite, metatonalite, and metadiorite have textures that range from anhedral granular in massive samples through to amoeboid and granoblastic in compositionally layered rocks. The rocks are composed of plagioclase, biotite, and quartz, and minor amounts of magnetite and ilmenite. Green hornblende, with optically continuous rims of sodic hornblende, is present in many samples. Quartz typically constitutes about 10–20% of the rocks, and thus many rocks are metamorphosed quartz diorite. Most plagioclase crystals consist of unzoned andesine, but a few relict coarser plagioclase crystals display normal and oscillatory zoning. One of the dated samples (GSWA 142933) has a granoblastic to amoeboid texture and is composed of andesine, clinopyroxene, biotite, and quartz. Accessory minerals in most samples consist of apatite, zircon, and metamict and altered allanite.

Age code	Proterozoic	P_-
Stratigraphic code	Dalgaringa Supersuite	DA-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metatonalite	t
1st qualifier	—	
2nd qualifier	mesocratic	w
Rock code		**P_-DA-mgtw**
Additional lithologies	metagranodiorite, metamonzogranite	

Contact relationships

Fine-grained mesocratic metatonalite is consistently intruded by all the other foliated and gneissic granites, including medium-grained, leucocratic biotite metamonzogranite and metagranodiorite dated at 2002 ± 3 and 2000 ± 8 Ma (see P_-DA-xmgml-mgg). Nevertheless, a sample of fine-grained mesocratic metatonalite has yielded an age of 1989 ± 3 Ma, indicating that there are multiple episodes of emplacement of the various rock types comprising the foliated and gneissic granites. Along with these rocks, the mesocratic metatonalite is intruded by the c. 1975 Ma Nardoo Granite.

Geochronology

P_-DA-mgtw	*Maximum*	*Minimum*
Age (Ma)	2002	1989 ± 3
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Isotopic
References	Nelson, 1999a	Nelson, 1999b

A high-grade metadiorite (GSWA 142933) about 350 m south of Meerawana Well (Zone 50, MGA 421290E 7189830N) was sampled for SHRIMP U–Pb zircon geochronology. Thirty analyses of 30 zircons were obtained from the sample. Twenty-seven concordant analyses indicated a date of 1989 ± 3 Ma, interpreted as the igneous crystallization age of the dioritic protolith (Nelson, 1999b). The date of 2005 ± 3 Ma indicated by two additional concordant analyses may represent xenocrystic zircons (Nelson, 1999b).

References

Nelson, DR 1999a, 142925: biotite monzogranite, Challenger Well; Geochronology Record 312: Geological Survey of Western Australia, 4p.

Nelson, DR 1999b, 142933: biotite–hypersthene–clinopyroxene–andesine mafic granulite, Meerawana Bore; Geochronology Record 320: Geological Survey of Western Australia, 4p.

Dalgaringa Supersuite; subunit (P_-DA-mgml)

Legend narrative

Medium-grained, leucocratic biotite metamonzogranite; foliated; commonly with clots of biotite after garnet

Rank	Formation
Parent	Dalgaringa Supersuite (P_-DA-mg)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DAna-mgt, P_-DAna-mgtl (intrusive); Lyons Group (CP-LY-sepg; unconformable)
Underlying units	P_-DA-mgtw, P_-DA-xmgt-mgm (intrusive)

Summary

Foliated, leucocratic biotite metamonzogranite of the Dalgaringa Supersuite is restricted to the southwest corner of GLENBURGH. It may have been a much more extensive unit than is presently exposed, as it is unconformably overlain by Carboniferous to Permian sedimentary rocks of the Lyons Group to the west. Foliated, leucocratic biotite metamonzogranite has been dated at 1987 ± 4 Ma.

Distribution

Foliated, leucocratic biotite metamonzogranite is extensively exposed in the southwestern corner of GLENBURGH. West of the Deadman Fault, it forms a pluton at least 35 km^2 in area, containing numerous rafts and screens of interlayered fine-grained mesocratic metatonalite and fine-grained metamonzogranite and leucocratic metatonalite (P_-DA-xmgt-mgm). East of the Deadman Fault and south of Geeranoo Creek in the southernmost part of GLENBURGH, leucocratic biotite monzogranite forms sheets that extensively intrude interlayered fine-grained mesocratic metatonalite and fine-grained metamonzogranite and leucocratic metatonalite (P_-DA-xmgt-mgm). The pluton and sheets commonly form low rocky hills. Exposure is good, but commonly weathered, as this area is just below an old land surface marked by ferruginous duricrust. Several sheets up to 200 m thick are also present between Meerawana Well and Carradarra Well.

Lithology

Foliated, leucocratic biotite metamonzogranite is a reasonably homogeneous, medium grained and equigranular rock. Much of the unit has a blotchy texture due to the presence of clots, up to 5 cm in diameter, of fine-grained biotite after garnet.

Age code	Proterozoic	P_-
Stratigraphic code	Dalgaringa Supersuite	DA-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	—	
2nd qualifier	leucocratic	l
Rock code		**P_-DA-mgml**

Contact relationships

Foliated, leucocratic biotite metamonzogranite extensively intrudes fine-grained mesocratic metatonalite (P_-DA-mgtw), and interlayered fine-grained mesocratic metatonalite and fine-grained metamonzogranite and leucocratic metatonalite (P_-DA-xmgt-mgm). West of the Deadman Fault on southern GLENBURGH, rafts interlayered fine-grained mesocratic metatonalite and fine-grained metamonzogranite and leucocratic metatonalite are mostly less than 2 km long, although one very large strip is more than 4 km long and up to 500 m wide. East of the Deadman Fault and south of Geeranoo Creek in the southernmost part of GLENBURGH, leucocratic biotite monzogranite forms sheets that extensively intrude interlayered fine-grained mesocratic metatonalite and fine-grained metamonzogranite and leucocratic metatonalite (P_-DA-xmgt-mgm). Inclusions of these latter rocks typically have a foliation or gneissic layering, which is truncated by veins of the foliated leucocratic biotite metamonzogranite; this relationship indicates that intrusion of the foliated leucocratic metamonzogranite followed an episode of deformation and metamorphism. Foliated, leucocratic biotite metamonzogranite is unconformably overlain by Carboniferous to Permian sedimentary rocks of the Lyons Group.

Geochronology

P_-DA-mgml	*Maximum*	*Minimum*
Age (Ma)	1987 ± 4	1987 ± 4
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1999a	Nelson, 1999a

A sample (GSWA 142923) of pale pink, foliated, leucocratic biotite metamonzogranite was collected from a low pavement about 100 m west of the Carnarvon–Mullewa Road, and about 5 km south-southwest of Glenburgh Homestead. The sample yielded a weighted mean ^{207}Pb*/^{206}Pb* date of 1987 ± 4 Ma, interpreted as the igneous crystallization age of the precursor monzogranite (Nelson, 1999a). This result is similar to the age of 1989 ± 3 Ma for metadiorite sample GSWA 142933 (Nelson, 1999b), although field relationships imply an episode of deformation and metamorphism between emplacement of the two rocks.

References

Nelson, DR 1999a, 142923: foliated biotite monzogranite, Glenburgh Homestead; Geochronology Record 343: Geological Survey of Western Australia, 4p.

Nelson, DR 1999b, 142933: biotite-hypersthene-clinopyroxene-andesine mafic granulite, Meerawana Bore; Geochronology Record 320: Geological Survey of Western Australia, 4p.

Dalgaringa Supersuite; subunit (P_-DA-mgp)

Legend narrative

Coarse-grained, leucocratic metapegmatite and metagranite, commonly with clots of biotite after garnet

Rank	Formation
Parent	Dalgaringa Supersuite (P_-DA-mg)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DAna-mgt, P_-DAna-mgtl
Underlying units	P_-DA-mgtw, P_-DA-xmgt-mgm, P_-DA-xmgml-mgg, P_-DA-xmgt-mgg, P_-DA-xmgg-wo

Summary

Coarse-grained, leucocratic metamorphosed pegmatite and leucocratic granite comprise sheets and veins that intrude all the foliated and gneissic granites of the Dalgaringa Supersuite across southern GLENBURGH and on CARRANDIBBY. One of the pegmatites has been dated at 1994 ± 2 Ma.

Distribution

Sheets and veins of metamorphosed pegmatite and granite are ubiquitous in the 2005–1985 Ma foliated and gneissic granites of the Dalgaringa Supersuite. Where abundant, they give the rocks a gneissic appearance. Individual pegmatite sheets are up to 4 m thick. Williams (1986) interpreted the sheets and veins of pegmatite as leucosome veins within ‘migmatites’.

Lithology

The metamorphosed pegmatite and leucocratic granite sheets are moderately to strongly recrystallized, and mainly consist of subsolvus pegmatite and monzogranite. Recrystallized hypersolvus pegmatite (plagioclase bearing) and leucocratic metatonalite are minor rock types. Subsolvus pegmatite and monzogranite are composed of microcline (or microperthite) and quartz, subordinate plagioclase, and minor amounts of biotite and garnet. Garnet is commonly replaced by a brownish-green biotite. Myrmekitic textures are widespread.

Age code	Proterozoic	P_-
Stratigraphic code	Dalgaringa Supersuite	DA-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metapegmatite	p
Rock code		**P_-DA-mgp**
Additional lithologies	metagranitic rock	

Contact relationships

Sheets and veins of metamorphosed pegmatite and leucocratic granite intrude all the foliated and gneissic granites of the Dalgaringa Supersuite.

Geochronology

P_-DA-mgp	*Maximum*	*Minimum*
Age (Ma)	1994 ± 2	1994 ± 2
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1999	Nelson, 1999

A sheet of metamorphosed, coarse-grained, leucocratic, biotite pegmatite about 3 km south (Zone 50, MGA 428800E 7192730N) of Fred Well was sampled for SHRIMP U–Pb zircon geochronology. The pegmatite intrudes interlayered metamorphosed fine- to medium-grained, mesocratic quartz diorite, tonalite, and diorite, and fine- to medium-grained, pale-grey biotite metamonzogranite (P_-DA-xmgt-mgm). The sample yielded a date of 1994 ± 2 Ma, interpreted as the age of igneous crystallization of the pegmatite, whereas several analyses indicating younger dates are interpreted to have lost radiogenic Pb during ancient disturbance events (Nelson, 1999).

References

Nelson, DR 1999, 142930: coarse leucocratic pegmatite, Fred Well; Geochronology Record 317: Geological Survey of Western Australia, 4p.

Williams, SJ 1986, Geology of the Gascoyne Province, Western Australia: Geological Survey of Western Australia, Report 15, 85p.

Dalgaringa Supersuite; subunit (P_-DA-moa) formerly P_-MG-mwa

Legend narrative

Amphibolite; locally mafic granulite

Rank	Formation
Parent	Dalgaringa Supersuite (P_-DA-mg)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DAna-mgt (intrusive)
Underlying units	P_-DA-xmgt-mgg (intrusive)

Summary

Amphibolite and granulite form a minor part of the Dalgaringa Supersuite outcropping as thin lenses and strips within the Paradise Zone on southern GLENBURGH and DAURIE CREEK. These mafic rocks are extensively interleaved with gneisses of the Dalgaringa Supersuite and are interpreted to represent former mafic dykes that accompanied intermediate to felsic magmatism between 2005 Ma and 1985 Ma. They were metamorphosed and deformed during the D_{1g} event of the Glenburgh Orogeny.

Distribution

Lenses and strips of fine- and medium-grained amphibolite form a minor part of the Dalgaringa Supersuite outcropping within the Paradise Zone on southern GLENBURGH and DAURIE CREEK. The amphibolites are extensively interleaved with foliated and gneissic granites of the Dalgaringa Supersuite. They are particularly abundant in a wide, northeasterly trending belt between Paradise Well and Carradarra Well, north of Meerawana Well and 2 km west of Watson Bore. Higher grade equivalents of the amphibolites are associated with mafic granulite and pelite between Paradise Well and Condamine Well. The amphibolite and mafic granulite form low rubbly hills that have a dark-brown colour on aerial photographs. In most areas the amphibolites constitute up to a few percent of the outcrop. Most of the amphibolite layers are less than 2 m wide and can be traced along strike for about 50 m. About 2 km west of Watson Bore, numerous layers of amphibolite outcrop in a zone about 2 to 3 km long and 2 km wide. These amphibolites may be repeated by isoclinal folding or faulting subparallel to the regional foliation, but this cannot be established due to the rubbly nature of the outcrop. The mafic granulites are tightly or isoclinally folded around Paradise Well, and layers are repeated throughout the area. Locally, the mafic rocks contain wine-red garnet porphyroblasts, up to 2 cm in diameter, enclosed by a layer-parallel foliation.

Lithology

Most of the amphibolites are fine- to medium-grained and equigranular, with a weak compositional banding. They have a polygonal texture and are composed of olive-green or brown hornblende, and plagioclase (labradorite or andesine), with minor quartz and ilmenite or titanite. Clinopyroxene is typically absent, but constitutes up to 15% of the rock in a few samples. Clinopyroxene forms cores to olive-green hornblende; rare samples contain clinopyroxene oikocrysts with blebby inclusions of plagioclase and quartz, and narrow rims of hornblende. A small number of samples consist of quartz amphibolite; these rocks contain about 15% quartz, and the plagioclase is andesine in composition. The quartz amphibolites were probably derived from metamorphism of a diorite or quartz diorite protolith.

Mafic gneisses between Paradise Well and Condamine Well, in the southwestern part of GLENBURGH, contain assemblages of: hypersthene, clinopyroxene, and plagioclase (labradorite–bytownite) with minor amounts of brown hornblende, quartz, and ilmenite; or plagioclase, clinopyroxene, and hypersthene, with minor amounts of garnet. These assemblages are indicative of metamorphism to granulite facies.

The amphibolites and quartz amphibolites are, in part, retrogressed to greenish-blue hornblende or actinolite, sodic plagioclase, and epidote. The degree of overprinting by this lower grade assemblage varies from weak to moderate. The lower grade assemblage is common in the eastern part of GLENBURGH between Dalgety Brook and the Dalgety Downs – Landor road. The granulites have not been significantly retrogressed during subsequent deformation and metamorphism (e.g. the Capricorn Orogeny).

Age code	Proterozoic	P_-
Stratigraphic code	Dalgaringa Supersuite	DA-
Rock type	meta-igneous mafic intrusive	mo
Lithname	amphibolite	a
Rock code		**P_-DA-moa**

Contact relationships

Lenses and strips of fine- and medium-grained amphibolite are extensively interleaved with the 2005–1970 Ma foliated and gneissic granites of the Dalgaringa Supersuite. Contacts between the amphibolites and foliated to gneissic granites of the Dalgaringa Supersuite are commonly tectonic and parallel to the foliation or compositional banding in the granitic rocks. Locally, a few mafic layers are discordant at a low angle to the foliation or layering in the granites, indicating that at least a few of the amphibolites were mafic dykes. It is possible that in the Dalgaringa Supersuite, the amphibolites formed xenoliths in granite and were subsequently deformed with the granite to form the gneisses. However, most of the amphibolites have a weak compositional banding parallel to the foliation or gneissic layering in the surrounding granitic rocks. The amphibolites and their compositional banding are folded along with the granitic rocks. The amphibolites are intruded by sheets and veins of leucocratic biotite granite and pegmatite, and by the Nardoo Granite (P_-DAna-mgt).

Geochronology

P_-DA-moa	*Maximum*	*Minimum*
Age (Ma)	2002	1977
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson 1999a	Nelson 1999b

The amphibolites have not been dated directly. The maximum age of this unit is unconstrained but field relationships indicate that they are probably intrusive into, and form an integral part of the Dalgaringa Supersuite, the oldest intrusion dated at 2002 ± 5 Ma (Nelson, 1999a). The amphibolites are intruded by the Nardoo Granite (P_-DAna-mgt) the oldest phase of which is dated at 1977 ± 7 Ma (Nelson 1999b), thus providing a minimum age for the protoliths to the amphibolites.

References

Nelson, DR 1999a, 142925: biotite monzogranite, Challenger Well; Geochronology Record 312: Geological Survey of Western Australia, 4p.

Nelson, DR 1999b, 142932: biotite tonalite, Nardoo Bore; Geochronology Record 319: Geological Survey of Western Australia, 4p.

Unassigned Proterozoic unit (P_-mi-GAG)

Legend narrative

Metamorphosed banded iron-formation

Rank	Group
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Glenburgh Terrane, Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA

Summary

Metamorphosed banded iron-formation is a very minor unit in the Paradise and Mooloo Zones in the southern part of the Gascoyne Province. The age of the unit is very poorly constrained, and it has not been assigned to a metasedimentary package.

Distribution

Metamorphosed banded iron-formation outcrops at several localities on GLENBURGH. In the southeastern part of the sheet area several layers of very weathered, metamorphosed banded iron-formation form prominent narrow ridges about 2.5 km north and 3 km northeast of Paradise Well. The layers are up to 10 m thick and can be traced along strike for between 0.4 and 1.5 km. The northern half of GLENBURGH has rare small lenses (2–3 m wide and less than 20 m long) of metamorphosed banded iron-formation.

Lithology

Metamorphosed banded iron-formation comprises iron oxide (after magnetite) and quartz.

Age code	Proterozoic	P_-
Rock type	metasedimentary other chemical: meta-iron formation	
Lithname	meta-iron formation	mi
Tectonic code	Gascoyne Province, Glenburgh Terrane	-GAG
Rock code		**P_-mi-GAG**

Contact relationships

Contact relationships of the metamorphosed banded iron-formation with enclosing units are not exposed.

Geochronology

P_-mi-GAG	*Maximum*	*Minimum*
Age (Ma)	–	–
Age	Archean	Paleoproterozoic
Source	Inferred	Inferred

Metamorphosed banded iron-formation has not been dated directly and, in the absence of reliable contact relationships with surrounding units, the age of the iron formation is poorly constrained. The metamorphosed banded iron-formation appears to be tectonically interleaved with the Dalgaringa Supersuite, and is overprinted by the Glenburgh Orogeny, indicating a minimum age of c. 1965 Ma.

Unassigned Proterozoic unit (P_-mli-GAG)

Legend narrative

Migmatitic pelitic gneiss (diatexite migmatite)

Rank	Subgroup
Parent	Unassigned Proterozoic unit (P_-ml-GAG)
Tectonic units	Glenburgh Terrane, Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DA-xmgg-mwo (intrusive or fault)
Metamorphic facies	granulite facies: cordierite – K-feldspar zone

Summary

Migmatitic pelitic gneiss forms rare, 5–10 m wide, discontinuous strips up to 100 m long, intercalated with intermediate to felsic gneisses of the Dalgaringa Supersuite in the Paradise Zone around Paradise Well on Glenburgh. The pelitic gneiss is migmatized and consists of diatexite as schollen migmatite with a mesosome of dark biotite-rich restite. The diatexite leucosomes contain an assemblage of cordierite–sillimanite–hercynitic-spinel–biotite–quartz–corundum and the mesosome/restite contains garnet–sillimanite–gahnitic-spinel–plagioclase–biotite–quartz, assemblages indicative of high-temperature, moderate- to high-pressure metamorphism. Results from U–Pb SHRIMP zircon geochronology indicate that the pelitic protolith was deposited sometime after c. 2080 Ma and metamorphosed at high grade during the D_{1g} event of the Glenburgh Orogeny at c. 2000 Ma, coincident with the intrusion of voluminous intermediate to felsic arc-related rocks.

Distribution

Migmatitic pelitic gneiss forms rare, 5–10 m wide, discontinuous strips up to 100 m long, intercalated with intermediate to felsic gneisses of the Dalgaringa Supersuite in the Paradise Zone around Paradise Well on Glenburgh. The largest is located about 0.5 km west-northwest of Paradise Well and is 100 m long and 30 m wide.

Lithology

Migmatitic pelitic gneiss forms rare, 5–10 m wide, discontinuous strips or lenses within intermediate to felsic gneisses of the Dalgaringa Supersuite. An example of diatexite that has been dated using U–Pb SHRIMP zircon geochronology is located at SPJGLE000002 (Zone 50, MGA 413802E 7191863N). The pelitic gneiss is migmatized and consists of diatexite as schollen migmatite with a mesosome of dark biotite-rich restite. It is a coarse-grained granoblastic rock with mm- to cm-scale discontinuous leucocratic melt segregations that parallel the regional S_{1g} gneissic fabrics. The diatexite leucosomes contain an assemblage of cordierite–sillimanite–hercynitic-spinel – biotite–quartz–corundum. The cordierite forms 1–5 mm-diameter porphyroblasts with the core regions intergrown with abundant fibrolite mats. The outer 0.25 – 1 mm part of the porphyroblasts are free of sillimanite, but are partially mantled by coarse-grained (0.5 – 2 mm diameter) euhedral sillimanite blades. The cores of these sillimanite blades are replaced with hercynitic spinel, which in turn are locally pseudomorphed by corundum. Tabular biotite blades are intergrown within the cordierite–sillimanite coronas and appear to be in textural equilibrium with these phases; however, in the matrix, which comprises quartz–cordierite–biotite, the biotite blades are not in textural equilibrium, being mantled by fringes of fibrolite and cordierite. The mesosome/restite contains an assemblage of garnet–sillimanite–gahnitic-spinel–plagioclase–biotite–quartz. Garnet is observed within 10–20 mm-thick biotite-rich seams and forms 5–10 mm-diameter porphyroblasts that contain inclusions of both biotite and sillimanite. Outside of these seams, quartz and plagioclase are more prevalent with tabular biotite blades being mantled by fringes of fibrolite and cordierite and with the biotite exsolving small pockets of ilmenite. Discontinuous sillimanite-rich seams up to 10–15 mm wide are composed of euhedral sillimanite blades with minor biotite–quartz–plagioclase. The sillimanite cores are replaced by anhedral gahnitic spinel. The presence of almandine-garnet – corundum–spinel is interpreted to indicate metamorphism under high-temperature, moderate- to high-pressure conditions (Schulters and Bohlen 1988).

Age code	Proterozoic	P_-
Rock type	metasedimentary siliciclastic: pelite	ml
Lithname	pelitic migmatite	i
Tectonic code	Gascoyne Province, Glenburgh Terrane	-GAG
Rock code		**P_-mli-GAG**

Contact relationships

The diatexite only forms thin, discontinuous strips, trains, and inclusions within intermediate- to felsic-gneisses of the Dalgaringa Supersuite (P_-DA-xmgg-mwo). As the contacts are not exposed direct relationship between them and the surrounding gneiss is not known, but presumably the granitic precursors to the gneisses were intruded into the pelitic unit before deformation. Some of the boundaries could be tectonic in origin.

Geochronology

P_-mli-GAG	*Maximum*	*Minimum*
Age (Ma)	2083 ± 7	1997 ± 10
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Wingate et al., 2010	Wingate et al., 2010

A sample of pelitic diatexite (GSWA 185942) was collected for U–Pb SHRIMP zircon geochronology from the largest outcrop of diatexite, about 0.5 km west-northwest of Paradise Well. The sample yielded abundant subhedral to euhedral zircons, the majority of which consisted of zoned low-U detrital cores overgrown by high-U, low-Th/U metamorphic rims. Eighty-two analyses were obtained from 76 zircons, of which nine were obtained from high-U rims. Most analyses of zircon cores were concordant, and yielded $^{207}Pb^{*}/^{206}Pb^{*}$ dates of 3222–2083 Ma, including several age components. The two youngest analyses of detrital cores yielded a concordia age of 2083 ± 7 Ma, interpreted as a maximum age of deposition of the pelitic protolith. Seven analyses of zircon rims yielded a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1997 ± 10 Ma (MSWD = 3.3), interpreted as the age of high-grade metamorphism and migmatization.

Granites from the P_-DA-xmgg-mwo unit have not been dated directly but belong to a suite of intermediate and felsic rocks that are part of the Dalgaringa Supersuite, the older parts of which have been precisely dated between 2005 and 1985 Ma (Occhipinti et al 2004; Johnson et al, 2010), consistent with the geochronology of this sample. These ages suggest that metamorphism and migmatization in the pelitic strips occurred during the D_{1g} event of the Glenburgh Orogeny and was directly related to intrusion of the voluminous arc-related granites of the Dalgaringa Supersuite (Johnson et al., 2010).

References

Johnson, SP, Sheppard, S, Rasmussen, B, Wingate, MTD, Kirkland, CL, Muhling, JR, Fletcher, IR and Belousova, E 2010, The Glenburgh Orogeny as a record of continent–continent collision: Geological Survey of Western Australia, Record 2010/5, 54p.

Occhipinti, SA, Sheppard, S, Passchier, C, Tyler, IM and Nelson DR 2004, Paleoproterozoic crustal accretion and collision in the southern Capricorn Orogen: the Glenburgh Orogeny: Precambrian Research, v. 128, p. 237–255.

Schulters, JC and Bohlen, SR 1988, The stability of hercynite and hercynite–gahnite spinels in corundum- or quartz-bearing assemblages: Journal of Petrology, v. 30, p. 1017–1031.

Wingate, MTD, Kirkland, CL, Johnson, SP and Sheppard, S 2010, 185942: pelitic diatexite, Paradise Well; Geochronology Record 861: Geological Survey of Western Australia, 5p.

Unassigned Proterozoic unit
(P_-mwa-GAG)
formerly P_-MG-mwa

Legend narrative

Amphibolite

Rank	Subgroup
Parent	Unassigned Proterozoic unit (P_-mw-GAG)
Tectonic units	Glenburgh Terrane, Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmeb (intrusive)
Underlying units	AP_-_ha-mgn, AP_-_ha-mgnl, P_-MGm-mtsf, P_-MGm-mls (Intrusive; fault)

Summary

Fine- and medium-grained amphibolite outcrops as thin lenses and strips within both the Paradise and Mooloo Zones on northern GLENBURGH and DAURIE CREEK, and southwestern YINNETHARRA. These units are extensively interleaved with the Halfway Gneiss and form xenoliths within granites of the Moorarie Supersuite. They are interpreted to represent former mafic dykes that intruded the Halfway Gneiss basement and Moogie Metamorphics sometime after 2125 Ma and were subsequently metamorphosed and deformed during the D_{2g} event of the Glenburgh Orogeny at 1965 Ma.

Distribution

Lenses and strips of fine- and medium-grained amphibolite outcrop within both the Paradise and Mooloo Zones on northern GLENBURGH and DAURIE CREEK, and southwestern YINNETHARRA. The amphibolites are extensively interleaved with the Halfway Gneiss and the Mumba Psammite. Amphibolite also forms xenoliths within granites of the Moorarie Supersuite. Most of the amphibolite layers are less than 2 m wide and can be traced along strike for about 50 m. The amphibolites are most abundant in an east-southeast to east-trending corridor to the south of New Well along to Wilson Bore on northern GLENBURGH.

Lithology

Most of the amphibolites are fine- to medium-grained and equigranular, with a weak compositional banding. They have a polygonal texture and are composed of olive-green or brown hornblende, and plagioclase (labradorite or andesine), with minor quartz and ilmenite or titanite. The minerals within the amphibolites are commonly replaced by variable amounts of greenish-blue hornblende or actinolite, sodic plagioclase, and epidote.

Age code	Proterozoic	P_-
Rock type	meta-igneous mafic	mw
Lithname	amphibolite	a
Tectonic code	Gascoyne Province, Glenburgh Terrane	-GAG
Rock code		**P_-mwa-GAG**

Contact relationships

Lenses and strips of fine- and medium-grained amphibolite are extensively interleaved with the Halfway Gneiss and the Mumba Psammite. Amphibolite also forms xenoliths within granite of the Moorarie Supersuite. Contacts between the amphibolites and granitic gneisses of the Halfway Gneiss are commonly tectonic and parallel to the foliation or compositional banding in the granitic rocks. However, most of the amphibolites have a weak compositional banding parallel to the foliation or gneissic layering in the surrounding granitic rocks. The amphibolites and their compositional banding are folded along with the granitic rocks.

Geochronology

P_-mwa-GAG	*Maximum*	*Minimum*
Age (Ma)	2125	1965
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Johnson et al., 2010	Johnson et al., 2010

The amphibolites have not been dated directly. The maximum age of this unit is unconstrained but field relationships indicate that they are probably intrusive into the leucocratic (AP_-_ha-mgnl) and undivided parts of the Halfway Gneiss (AP_-_ha-mgn), the youngest component of which is dated at 2508 ± 5 Ma (Kinny et al., 2004). They are also probably intrusive into the psammitic schists of the Mumba Psammite, whose minimum depositional age is c. 2125 Ma (Johnson et al., 2010). Both the amphibolites, psammitic schists of the Mumba Psammite, and granitic gneisses of the Halfway Gneiss were deformed and metamorphosed during the collisional phase of the Glenburgh Orogeny D_{2g}, which is dated at 1965–1950 Ma (Johnson et al., 2010).

References

Johnson, SP, Sheppard, S, Rasmussen, B, Wingate, MTD, Kirkland, CL, Muhling, JR, Fletcher, IR and Belousova, E 2010, The Glenburgh Orogeny as a record of continent–continent collision: Geological Survey of Western Australia, Record 2010/5, 54p.

Kinny, PD, Nutman, AP and Occhipinti, SA 2004, Reconnaissance dating of events recorded in the southern part of the Capricorn Orogen: Precambrian Research, v. 128, p. 279–294.

Unassigned Proterozoic unit (P_-mog-GAG) formerly P_-MG-mog

Legend narrative

Plagioclase–actinolite–tremolite gneiss; after gabbro

Rank	Suite
Parent	Unassigned Proterozoic unit (P_-mo-GAG)
Tectonic units	Glenburgh Terrane, Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	P_-MGm-mtsf (fault)

Summary

Coarse-grained metagabbroic rocks outcrop only in the Paradise Zone in the northwestern corner of GLENBURGH and southeastern corner of LOCKIER. They are medium- to coarse-grained, equigranular, and consist of plagioclase and tremolite–actinolite, with accessory titanite. They are presumably in tectonic contact with the surrounding psammitic schists of the Mumba Psammite and gneisses of the Halfway Gneiss. They may be coeval with the amphibolites (P_-mwa-GAG).

Distribution

Coarse-grained metagabbroic rocks outcrop only in the Paradise Zone in the northwestern corner of GLENBURGH and southeastern corner of LOCKIER. These rocks form rubbly, hilly outcrops and appear to be largely undeformed. Within outcrops of equigranular granite of the Moorarie Supersuite, a few xenoliths of amphibolite (P_-mwa-GAG) form small knobbly hills and contain gabbroic textures; however, their aerial-photograph patterns are commonly indistinguishable from amphibolite in the same area, and they are not included in the gabbroic unit.

Lithology

The medium- to coarse-grained, ('ophitic-textured') mafic rocks comprises plagioclase and tremolite–actinolite, with accessory titanite. The felsic and mafic minerals appear to have had similar grain sizes of 2–5 mm.

Age code	Proterozoic	P_-
Rock type	meta-igneous mafic intrusive	mo
Lithname	metagabbro	g
Tectonic code	Gascoyne Province, Glenburgh Terrane	-GAG
Rock code		**P_-mog-GAG**

Contact relationships

Contacts between the metagabbroic rocks and surrounding lithologies are not exposed but these rocks are presumably in tectonic contact with psammitic schists of the Mumba Psammite. They may have originally been intrusive into the Mumba Psammite schists.

Geochronology

P_-mog-GAG	*Maximum*	*Minimum*
Age (Ma)	2125	1965
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Johnson et al., 2010	Johnson et al., 2010

The age of the metagabbroic rocks is not known, but if they are a coarser-grained equivalent of the amphibolites (P_-mwa-GAG) then similar age constraints would apply. Protoliths of the amphibolites were probably intruded into the leucocratic (AP_-_ha-mgnl) and undivided parts of the Halfway Gneiss (AP_-_ha-mgn), the youngest component of which is dated at 2508 ± 5 Ma (Kinny et al., 2004), and into the Moogie Metamorphics that were deposited sometime before c. 2515 Ma (Johnson et al., 2010), thus providing a maximum age for the meta-igneous rocks. The metagabbros and surrounding psammitic schists of the Mumba Psammite have been metamorphosed within the amphibolite facies during the D_{2g} phase of the Glenburgh Orogeny, dated at 1965–1950 Ma (Johnson et al., 2010).

References

Johnson, SP, Sheppard, S, Rasmussen, B, Wingate, MTD, Kirkland, CL, Muhling, JR, Fletcher, IR and Belousova, E 2010, The Glenburgh Orogeny as a record of continent–continent collision: Geological Survey of Western Australia, Record 2010/5, 54p.

Kinny, PD, Nutman, AP and Occhipinti, SA 2004, Reconnaissance dating of events recorded in the southern part of the Capricorn Orogen: Precambrian Research, v. 128, p. 279–294.

Unassigned Proterozoic unit (P_-mus-GAG) formerly P_-MG-mus

Legend narrative

Fine- to medium-grained actinolite(–clinozoisite–albite–titanite) and tremolite(–serpentine–talc–calcite) schist

Rank	Subgroup
Parent	Unassigned Proterozoic unit (P_-mu-GAG)
Tectonic units	Glenburgh Terrane, Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DA-xmgt-mgg, P_-MOdu-ggp (intrusive)
Underlying units	AP_-_ha-mgn, AP_-_ha-mgnl, P_-DA-xmgt-mgg (Fault)

Summary

Actinolite and tremolite schist after ultramafic rock form layers and lenses intercalated with gneisses of the Halfway Gneiss, Dalgaringa Supersuite, and Moorarie Supersuite, and outcrop mainly within a east-southeasterly belt within the Paradise Zone on the northern part of GLENBURGH. The schists comprise over 90% actinolite or tremolite with minor accessory phases including clinozoisite, talc, and titanite. The age of intrusion is loosely constrained between 2430 Ma and 2002 Ma.

Distribution

In the northwestern part of GLENBURGH, layers and lenses of actinolite schist and tremolite schist after ultramafic rock are common in an east-southeasterly trending belt extending from around Dunnawah Well to east of Geringee Bore. In the northeastern part of GLENBURGH, a few layers of ultramafic schist are present between Ti Tree Well and Puckford Bore. The layers range from about 10 m wide and 500 m long to about 50 m wide and more than 2 km long.

Lithology

Actinolite schists are dark green on fresh surfaces, whereas tremolite schists are pale green. Actinolite schists comprise 90% or more actinolite, with minor interstitial clinozoisite, albite, and titanite. Tremolite schists may be composed entirely of tremolite, or of tremolite, serpentine, talc, and minor calcite. Cores of green hornblende to tremolite are common in rocks composed solely of tremolite. The precursors to the schists were probably pyroxenite and olivine pyroxenite.

Age code	Proterozoic	P_-
Rock type	meta-igneous ultramafic volcanic or undivided	mu
Lithname	ultramafic schist, volcanic or undivided	s
Tectonic code	Gascoyne Province, Glenburgh Terrane	-GAG
Rock code		**P_-mus-GAG**

Contact relationships

Contacts between the schists and the enclosing granitic gneisses of the Halfway Gneiss and Dalgaringa Supersuite gneisses are tectonic. On central and southern GLENBURGH, actinolite schist also form 150–250 m-long inclusions within gneissic granites of the Dalgaringa Supersuite (P_-DA-xmgt-mgg) and granites of the Moorarie Supersuite, specifically the Dumbie Granodiorite (P_-MOdu-ggp).

Geochronology

P_-mus-GAG	*Maximum*	*Minimum*
Age (Ma)	2430	2002
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., in prep.	Nelson 1999

Actinolite schist and tremolite schist have not been dated directly. The maximum age of this unit is unconstrained. The rocks are in faulted contact with mesocratic and leucocratic gneisses of the Halfway Gneiss, but if they were originally intrusive, then the ultramafic igneous precursor must be younger than the age of 2430 ± 4 Ma (Wingate et al., in prep.) for the youngest sample of Halfway Gneiss. Actinolite schist and tremolite schist are intruded by several granites, the oldest of which, an interlayered succession of gneissic metatonalites and granodiorites of the Dalgaringa Supersuite (P_-DA-xmgt-mgg), is dated at 2002 ± 3 Ma (Nelson, 1999).

References

Nelson, DR 1999, 142925: biotite monzogranite, Challenger Well; Geochronology Record 312: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, Johnson, S and Sheppard, S in prep., 188973: granodiorite gneiss, Mount James Homestead: Geological Survey of Western Australia.

Camel Hills Metamorphics (P_-CH-xmd-mk)

Legend narrative

Pelite, calc-silicate rock, quartzite, metamorphosed banded iron-formation and amphibolite

Rank	Group
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	Bertibubba Supersuite, Moorarie Supersuite (intrusive); Pooranoo Metamorphics (unconformable); Dalgaringa Supersuite (faulted)
Underlying units	Warrigal Gneiss, Narryer Terrane (faulted)

Summary

Medium- to high-grade metasedimentary rocks of the Camel Hills Metamorphics outcrop in the Errabiddy Shear Zone between the Gascoyne Province and Narryer Terrane. The Camel Hills Metamorphics were deformed and metamorphosed during both the 2005–1950 Ma Glenburgh Orogeny and 1820–1770 Ma Capricorn Orogeny. The Camel Hills Metamorphics is subdivided into the Quartpot Pelite (P_-CHq-mln) and Petter Calc-silicate (P_-CHp-mk and P_-CHp-xmtq-mkq) and undivided units of metamorphosed banded iron formation (P_-CH-mi) and amphibolite (P_-CH-mwa). The Quartpot Pelite consists of pelitic diatexite and psammitic schist or gneiss interlayered with minor quartzite, calc-silicate gneiss, and amphibolite and the Petter Calc-silicate is comprised of calc-silicate schist or gneiss with minor quartzite. The calc-silicate rock (P_-CHp-mk) is commonly interlayered with the amphibolite (P_-CH-mwa). The Quartpot Pelite was sourced from a currently unexposed Paleoproterozoic Terrane with an age of 2095–2000 Ma, during the earliest event (D_{1g}) of the Glenburgh Orogeny. The Petter Calc-silicate was sourced directly from the Yilgarn Craton sometime between 2608 and 1944 Ma, and possibly deposited as a 'calc-rich' passive margin to the Yilgarn Craton.

Distribution

Medium- to high-grade metasedimentary rocks of the Camel Hills Metamorphics outcrop in the Errabiddy Shear Zone, on ERRABIDDY, LANDOR, YALBRA and ERONG. The fault bounded units generally have a strike length of more than 100 km, with cross-strike widths of a few km, although on ERRABIDDY the package of folded metasediments reaches 10 km or more.

Derivation of name

Metasedimentary rocks of the Camel Hills Metamorphics were previously included within the Morrissey Metamorphic Suite (Williams et al., 1983b; Williams, 1986), the name given for a suite of metamorphosed and deformed Proterozoic sedimentary rocks thought to outcrop throughout the Gascoyne Province (Williams et al., 1983a). The suite was considered to be equivalent, in part, to sedimentary rocks of the Wyloo Group to the north, and sedimentary rocks of the Yerrida and Bryah Groups (Pirajno et al., 1998) to the east. However, there is no certainty that all the metasedimentary rocks throughout the Gascoyne Province were deposited in the same sedimentary basin or are the same age. The Camel Hills Metamorphics on ERRABIDDY and LANDOR are separated from the Morrissey Metamorphic Suite, as defined on the MOUNT PHILLIPS 1:250 000 sheet (Williams et al., 1983a), by large areas of granitic gneiss, supracrustal metasedimentary and mafic meta-igneous rocks, and large fault structures.

The Camel Hills Metamorphics were named after the Camel Hills, a low range of hills on northern ERONG and southern LANDOR, which are underlain by the metamorphic rocks.

Lithology

The Camel Hills Metamorphics comprises the Quartpot Pelite and the Petter Calc-silicate, as well as undivided amphibolite and metamorphosed banded iron-formation. The Quartpot Pelite is dominated by pelitic schist and gneiss, much of it migmatitic, with minor amounts of interlayered quartzite, psammitic schist and gneiss, calc-silicate schist and gneiss, and amphibolite. The Petter Calc-silicate is composed of calc-silicate schist or gneiss (P_-CHp-mk) and interlayered quartzite (P_-CHp-xmtq-mkq), and minor pelitic schist or migmatitic pelitic gneiss and amphibolite.

Age code	Proterozoic	P_-
Stratigraphic code	Camel Hills Metamorphics	CH-
Mixed or xenolith-bearing	Mixed	x
Rock type 1	metasedimentary siliciclastic	
Lithname 1	metasiliciclastic rock; undivided	md
Rock type 2	metasedimentary carbonate	
Lithname 2	metacarbonate	-mk
Rock code		**P_-CH-xmd-mk**

Contact relationships

The Camel Hills Metamorphics are intruded by small plutons, dykes, and veins of metagranite belonging to both the 1960–1945 Ma Bertibubba Supersuite and the 1820–1775 Ma Moorarie Supersuite throughout the Errabiddy Shear Zone. On YALBRA, between Bungarra Bore and Coor-de-Wandy Hill to the west-southwest, the Camel Hills Metamorphics are overlain by low-grade metasedimentary rocks of the Mount James Subgroup of the Pooranoo Metamorphics. The Camel Hills Metamorphics are faulted against a number of units, including the Dalgaringa Supersuite in the Glenburgh Terrane, the Warrigal Gneiss, and various other Archean units of the Narryer Terrane.

Geochronology

P_-CH-xmd-mk	Maximum	Minimum
Age (Ma)	2001 ± 26	1955 ± 7
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Johnson et al., 2010	Nelson, 1999a

Several samples of metasedimentary rocks from the Camel Hills Metamorphics have been dated using SHRIMP U–Pb zircon methods. These include two samples of pelitic diatexite migmatite and a psammitic gneiss from the Quartpot Pelite, and one sample of calc-silicate gneiss from the Petter Calc-silicate.

All three samples from the Quartpot Pelite (GSWA 142905, 142910, 168944; Nelson, 1998, 1999a, 2001) are dominated by detrital zircons with $^{207}Pb^{*}/^{206}Pb^{*}$ dates in the range 2095–1985 Ma, and this age component is defined by >55% of the dated zircons (68 of 119 analyses). The samples also contain two distinct age components, at c. 2250 and c. 2175 Ma, and individual zircons as old as 2890 Ma (Johnson et al., 2010). Calculated zircon crystallinity suggests that the range of zircon dates between 2095 and 1985 Ma in all three samples reflects the true ages of the zircons and does not result from variable loss of radiogenic Pb (Johnson et al., 2010). Significant age components for the combined data from all three samples can be resolved at c. 2080, 2075, 2065, 2050, 2030, 2025, and 2000 Ma, and reflect derivation from a source or sources of different ages (Johnson et al., 2010). The youngest age component, at 2001 ± 26 Ma, is interpreted as a maximum age of deposition of the sedimentary protolith.

Two samples (GSWA 142905 and 142910) contain high-U, low Th/U structureless zircon rims that are interpreted to have grown during high grade D_{2g} metamorphism (Johnson et al., 2010). These rims yielded dates of 1952 ± 14 Ma (GSWA 142905) and 1955 ± 7 Ma (GSWA 142910) indicating that the Quartpot Pelite was deposited between c. 2000 and c. 1960 Ma, an age that overlaps with the earliest deformation and metamorphism associated with the Glenburgh Orogeny, i.e., D_{1g} (Johnson et al., 2010). Currently there are no known rocks in the Gascoyne Province with ages between 2080 and 2005 Ma and therefore the source of these abundant detrital zircons is unknown. However, it is possible that there are older, currently unexposed parts of the Dalgaringa arc (proto-Dalgaringa arc) that may have been uplifted and eroded during the D_{1g} event of the Glenburgh Orogeny to source the Quartpot Pelite.

The single sample of Petter Calc-silicate (GSWA 142908; Nelson, 1999b) contains an entirely different detrital zircon age spectrum to that of the Quartpot Pelite. This sample contains only Archean detritus, including the youngest detrital zircon component at c. 2610 Ma, suggesting that it was either deposited in the late Archean or that its detritus was sourced entirely from Archean rocks. The sample contains two minor age components, at 2660–2650 Ma and c. 2690 Ma and also contains a few individual zircons in the 3150–3030 Ma age range. A single metamorphic rim dated at c. 1945 Ma provides a younger limit for its deposition, setting wide time constraints between 2610 and 1945 Ma. A statistical comparison of the detrital zircon age modes within the Petter Calc-silicate sample with those of representative granitic samples along the northern part of the Yilgarn Craton, including the Yarlarweelor gneiss complex, provide a good correlation (Johnson et al., 2010), suggesting that the Petter Calc-silicate was sourced directly from the Yilgarn Craton. Although the Petter Calc-silicate is currently tectonically interleaved with the Quartpot Pelite, its detrital zircon components clearly indicate that the two formations were deposited in different, widely separated basins. Considering the sole Archean detritus and Yilgarn Craton-like source for the Petter Calc-silicate, it is still possible that the sediment was deposited in a similar time frame to that of the Quartpot Pelite, albeit on a different cratonic margin. The dating of detrital zircons from other samples of the Petter Calc-silicate would help to resolve this issue.

References

Johnson, SP, Sheppard, S, Rasmussen, B, Wingate, MTD, Kirkland, CL, Muhling, JR, Fletcher, IR and Belousova, E 2010, The Glenburgh Orogeny as a record of continent–continent collision: Geological Survey of Western Australia Record 2010/5, 54p.

Pirajno, F, Occhipinti, SA and Swager, CP 1998, Geology and tectonic evolution of the Palaeoproterozoic Bryah, Padbury, and Yerrida Basins (formerly Glengarry Basin), Western Australia — implications for the history of the south-central Capricorn Orogen: Precambrian Research, v. 90, p. 119–140.

Nelson, DR 1998, 142905: paragneiss, Lucys Bore; Geochronology Record 330: Geological Survey of Western Australia, 4p.

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QUARTPOT PELITE (P_-CHq-mln)

Legend narrative

Biotite–plagioclase–quartz(–K-feldspar–garnet–sillimanite) gneiss and migmatitic pelitic gneiss intruded by c. 1970 Ma sheets and veins of coarse-grained foliated biotite metagranite; minor amphibolite and calc-silicate

Rank	Formation
Parent	Camel Hills Metamorphics (P_-CH-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmeb, P_-MO-gp, P_-MO-mgmu
Underlying units	AP_-mgnl-YNAY, A-mgnl-YNA

Summary

The Quartpot Pelite of the Camel Hills Metamorphics forms low rocky outcrops throughout the Errabiddy Shear Zone and largely consists of pelitic and psammitic schist or gneiss interlayered with minor quartzite, calc-silicate gneiss, and amphibolite (Sheppard and Occhipinti, 2000). Many of the pelitic gneisses are migmatitic indicating that they have been metamorphosed at high metamorphic grade; however, in the southeast and west-southwest part of the Errabiddy Shear Zone, the Quartpot Pelite and the Petter Calc-silicate lack any evidence for migmatization, consistent with a decrease in metamorphic grade from northwest to southeast across the Errabiddy Shear Zone. The Quartpot Pelite was sourced from a currently unexposed Paleoproterozoic terrane with an age of 2095–2000 Ma (possibly a proto-Dalgaringa arc), during the earliest event (D_{1g}) of the Glenburgh Orogeny.

Distribution

The Quartpot Pelite of the Camel Hills Metamorphics outcrops extensively within the Errabiddy Shear Zone on the eastern part of ERRABIDDY and the southern edge of LANDOR, and extends west-southwest onto the northern part of the ERONG. The unit typically forms low rocky exposures.

Lithology

The Quartpot Pelite largely consists of pelitic and psammitic schist or gneiss interlayered with minor quartzite, calc-silicate gneiss, and amphibolite. Many of the pelitic gneisses are migmatitic, particularly in the area southeast of Randell Well on northern ERONG, and extending east-northeast into the region northeast of Errabiddy Homestead. To the southeast and west-southwest, medium-grade metasedimentary rocks of both the Quartpot Pelite and the Petter Calc-silicate are present, consistent with a decrease in metamorphic grade from northwest to southeast across the Errabiddy Shear Zone.

The migmatites commonly show stromatic, schollen (raft), and nebulitic structures (nomenclature after Mehnert, 1968; Ashworth, 1985), with medium-grained, heterogeneous siliceous diatexite melt locally forming up to 70% of the rock. Within the melt phase, lenticular rafts of restite consisting of refractory psammite and biotite-rich material are preserved. In places, veins of more homogeneous, externally derived melt cut the in situ migmatite. The stromatic migmatites sometimes grade into nebulitic migmatite, indicating local increased degrees of in situ partial melting.

At the northern end of the Quartpot Pelite outcrop on ERRABIDDY, and on northern ERONG, medium-grade pelitic gneiss and schist contain only small amounts of leucosome, but showing little evidence of having melted. These schists and gneisses contain muscovite–biotite(–garnet).

Age code	Proterozoic	P_-
Stratigraphic code	Camel Hills Metamorphics, Quartpot Pelite	CHq-
Rock type	metasedimentary siliciclastic: pelite	ml
Lithname	pelitic gneiss	n
Rock code		**P_-CHq-mln**
Additional lithologies	amphibolite, calc-silicate rock	

Contact relationships

The Quartpot Pelite is in faulted contact with leucocratic granitic gneiss (AP_-mgnl-YNAY, A-mgnl-YNA) and augen gneiss and porphyritic granite (A-mgmu) of the Narryer Terrane. The relationship of the Quartpot Pelite with rocks of the Glenburgh Terrane is unknown, but contacts are likely to be faulted as are those with the Petter Calc-silicate.

Veins and sheets of coarse-grained leucocratic tonalite and granodiorite (P_-BB-gtl) intrude pelitic gneiss on LANDOR. Medium-grained, even-textured biotite granite (P_-MO-gmeb) and strongly porphyritic, foliated granite (P_-MO-mgmu) intruded migmatitic gneiss at the northern end of the belt. The migmatites were also extensively intruded by veins, sheets, and dykes of coarse-grained biotite–muscovite granite and pegmatite (P_-MO-gp).

Geochronology

P_-CHq-mln	*Maximum*	*Minimum*
Age (Ma)	2001 ± 26	1955 ± 7
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Johnson et al., 2010	Nelson, 1999

All three samples from the Quartpot Pelite (GSWA 142905, 142910, 168944; Nelson, 1998, 1999, 2001) are dominated by detrital zircons with $^{207}Pb^{*}/^{206}Pb^{*}$ dates in the range 2095–1985 Ma, and this age component is defined by >55% of the dated zircons (68 of 119 analyses). The samples also contain two distinct age components, at c. 2250 and c. 2175 Ma, and individual zircons as old as c. 2890 Ma (Johnson et al., 2010). Calculated zircon crystallinity suggests that the range of zircon dates between 2095 and 1985 Ma in all three samples reflects the true ages of the zircons and does not result from variable loss of radiogenic Pb (Johnson et al., 2010). Significant age components for the combined data from all three samples can be resolved at 2080, 2075, 2065, 2050, 2030, 2025, and 2000 Ma, and reflect derivation from a source or sources of different ages (Johnson et al., 2010). The youngest age component, at 2001 ± 26 Ma, is interpreted as a maximum age of deposition of the sedimentary protolith.

Two samples (GSWA 142905 and 142910) contain high-U, low Th/U structureless zircon rims that are interpreted to have grown during high grade D_{2g} metamorphism (Johnson et al., 2010). These rims yielded dates of 1952 ± 14 Ma (GSWA 142905) and 1955 ± 7 Ma (GSWA 142910) indicating that the Quartpot Pelite was deposited in an interval between c. 2000 and c. 1955 Ma, an age that overlaps with the earliest deformation and metamorphism associated with the Glenburgh Orogeny, i.e., D_{1g} (Johnson et al., 2010). Currently there are no known rocks in the Gascoyne Province with ages between 2095 and 2005 Ma and therefore the source of these abundant detrital zircons is unknown. However, it is possible that there are older, currently unexposed parts of the Dalgaringa arc (proto-Dalgaringa arc) that may have been uplifted and eroded during the D_{1g} event of the Glenburgh Orogeny to source the Quartpot Pelite.

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PETTER CALC-SILICATE (P_-CHp-mk)

Legend narrative

Calc-silicate gneiss; coarse-grained plagioclase–quartz–diopside–tremolite and diopside–plagioclase rocks, and fine-grained quartz–plagioclase–garnet–hornblende rock

Rank	Formation
Parent	Camel Hills Metamorphics (P_-CH-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MOer-gmvg, P_-MO-gp (intrusive); P_-CHq-mln (?conformable)

Summary

The Petter Calc-silicate comprises calc-silicate schist or gneiss, some of it quartz rich, along with minor amounts of pelitic schist and gneiss, and amphibolite. The unit is confined to fault slices in the Errabiddy Shear Zone where it forms low strike ridges, although at one locality it is interlayered with fine grained amphibolite. The Petter Calc-silicate was deposited sometime between 2608–1959 Ma directly from the Yilgarn Craton possibly as a calc-rich passive margin sequence. The rocks were metamorphosed at high grade during the D_{2g} event of the Glenburgh Orogeny at 1965–1950 Ma.

Distribution

On Errabiddy and Landor, the Petter Calc-silicate is mainly restricted to fault-bounded slices within the Errabiddy Shear Zone. Calc-silicate gneiss typically forms low rubbly and bouldery strike ridges with a dark-brown pattern on aerial photographs.

Lithology

The Petter Calc-silicate is composed of calc-silicate schist or gneiss (P_-CHp-mk) and interlayered quartzite and quartz–diopside rock (P_-CHp-xmtq-mkq), and minor pelitic schist or migmatitic pelitic gneiss and amphibolite.

Calc-silicate rocks are pale green on a fresh surface, but typically weather to a reddish-brown exterior. The calc-silicate gneiss is compositionally layered, with alternations of tremolite- and clinopyroxene-rich layers and quartz-rich layers, up to several centimetres thick. The calc-silicate rocks range from fine- to coarse-grained with radiating bundles of pale-green tremolite– actinolite or clinopyroxene within the compositional layering.

About 2.5 km north-northwest of Erong Homestead (locality 10a of Occhipinti et al., 2001), a raft of Petter Calc-silicate within the Erong Granite consists of calc-silicate rock and a distinctive para-amphibolite, which largely comprises tremolite, diopside, and talc, and pelitic and psammitic schist, which largely comprises biotite, quartz, plagioclase, epidote, and garnet. The calc-silicate and para-amphibolite contains a fine, 1–10 mm-thick compositional layering, which is interpreted as original bedding. The Mg-rich mineralogy may be indicative of an evaporite protolith.

Age code	Proterozoic	P_-
Stratigraphic code	Camel Hills Metamorphics, Petter Calc-silicate	CHp-
Rock type	metasedimentary carbonate	
Lithname	metacarbonate	mk
Rock code		**P_-CHp-mk**
Additional lithologies	quartzite, amphibolite, pelitic schist	

Contact relationships

About 2.5 km north-northwest of Erong Homestead (Locality 10a of Occhipinti et al., 2001), rocks of the Petter Calc-silicate form a raft in the Erong Granite (P_-MOer-gmvg). On Errabiddy, calc-silicate gneiss is interlayered with fine-grained amphibolite (P_-CH-mwa) east of Black Adder Well. Calc-silicate gneiss is also intruded by veins and dykes of coarse-grained pegmatite and leucocratic granite of the Moorarie Supersuite (P_-MO-gp). On the eastern part of Errabiddy, the Petter Calc-silicate, is in faulted contact with the Quartpot Pelite (P_-CHq-mln).

Geochronology

P_-CHp-mk	*Maximum*	*Minimum*
Age (Ma)	2001	1955
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Johnson et al., 2010	Nelson, 1999a

There are few reliable age constraints on the age of the Petter Calc-silicate, mainly because the calc-silicate contains little to no zircon, and because the unit forms fault-bounded slices there is a lack of cross-cutting relationships with other datable lithologies. However, a single sample of quartz-rich calc-silicate gneiss (GSWA142908; Nelson, 1999b) did yield abundant zircons that were subsequently dated by the U–Pb SHRIMP technique. The detrital zircons yielded a maximum depositional age of c. 2600 Ma. A maximum depositional age of c. 2600 Ma is provided by the youngest zircon in a quartz-rich calc-silicate gneiss (GSWA 142908; Nelson 1999b). A more conservative estimate is provided by the youngest nine analyses, which indicate a weighted mean ^{207}Pb*/^{206}Pb* date of 2608 ± 4 Ma.

A single zircon rim in this sample has a moderate Th/U ratio of 0.3 and yields a ^{207}Pb*/^{206}Pb* date of 1944 ± 5 Ma (1σ), interpreted as the age of high-grade metamorphism. However, a more reliable constraint on the age of metamorphism is 1955 ± 7 Ma, obtained from 12 analyses of zircon rims in sample GSWA 142910 of the Quartpot Pelite (Nelson, 1999a), which shares the same structural and metamorphic history as the Petter Calc-silicate. This date also provides a younger limit for sedimentation, which occurred between 2610 and 1955 Ma. A statistical comparison of the detrital zircon age modes within the Petter Calc-silicate sample with those of representative granite samples along the northern Yilgarn Craton, including the Yarlarweelor Gneiss Complex, produces a good correlation (Johnson et al., 2010), suggesting that the Petter Calc-silicate sediment was sourced directly from the Yilgarn Craton. Considering the sole Archean detritus and Yilgarn Craton-like source for the Petter Calc-silicate, it is still possible that the sediment was deposited during the same interval as the Quartpot Pelite (2001–1955 Ma), albeit on a different cratonic margin. The dating of detrital zircons from other samples of the Petter Calc-silicate would help to resolve this issue.

References

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PETTER CALC-SILICATE; subunit (P_-CHp-xmtq-mkq)

Legend narrative

Quartzite and quartz–diopside rock

Rank	Member
Parent	PETTER CALC-SILICATE (P_-CHp-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA

Summary

Quartzite and quartz–diopside rock are minor components of the Petter Calc-silicate.

Distribution

Quartzite and quartz–diopside rock outcrops as a series of low, rugged strike ridges interlayered with calc-silicate gneiss and amphibolite (P_-CH-mwa) east of Vince Bore on ERRABIDDY (Occhipinti and Sheppard, 2000).

Lithology

The quartzite component is white or pale grey, foliated, and has a mortar texture.

Age code	Proterozoic	P_-
Stratigraphic code	Camel Hills Metamorphics, Petter Calc-silicate	CHp-
Mixed or xenolith-bearing	Mixed	x
Rock type 1	metasedimentary siliciclastic: psammite	mt
Lithname 1	quartzite	q
Rock type 2	metasedimentary carbonate	-mk
Lithname 2	calc-silicate rock	q
Rock code		**P_-CHp-xmtq-mkq**

Geochronology

P_-CHp-xmtq-mkq	*Maximum*	*Minimum*
Age (Ma)	2001	1955
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Johnson et al., 2010	Nelson 1999

This unit has not been dated directly. However, it is interpreted to be an integral part of the Petter Calc-silicate, hence its maximum and minimum age constraints are the same as those for the parent calc-silicate unit.

References

Johnson, SP, Sheppard, S, Rasmussen, B, Wingate, MTD, Kirkland, CL, Muhling, JR, Fletcher, IR and Belousova, E 2010, The Glenburgh Orogeny as a record of continent–continent collision: Geological Survey of Western Australia Record 2010/5, 54p.

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Camel Hills Metamorphics; subunit (P_-CH-mi)

Legend narrative

Metamorphosed banded iron-formation; quartz–magnetite rock

Rank	Formation
Parent	Camel Hills Metamorphics (P_-CH-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA

Summary

Metamorphosed banded iron-formation is restricted to a single occurrence on southeastern Errabiddy.

Distribution

Metamorphosed banded iron-formation (P_-CH-mi) forms a layer about 1 km long and 2 m thick, about 2 km west-northwest of Wheelo Bore on southeastern Errabiddy (Occhipinti and Sheppard, 2000). Although its contacts with the surrounding rocks are unexposed, the unit occurs centrally within a 5 km wide package of intercalated Petter Calc-silicate gneisses and amphibolite, making this unit distinct from the other unassigned metamorphosed banded iron-formation (P_-mi-GAG) which occurs in conjunction with schists of the Moogie Metamorphics.

Lithology

Metamorphosed banded iron-formation consists of finely banded quartz–magnetite rock.

Age code	Proterozoic	P_-
Stratigraphic code	Camel Hills Metamorphics, Petter Calc-silicate	CHp-
Rock type	metasedimentary other chemical: meta-iron formation	
Lithname	meta-iron formation	mi
Rock code		**P_-CH-mi**

Geochronology

P_-CH-mi	*Maximum*	*Minimum*
Age (Ma)	2001	1955
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Johnson et al., 2010	Nelson, 1999

This unit has not been dated directly. However, this unit is interpreted to be a part of the Camel Hills Metamorphics, and therefore has similar maximum and minimum age constraints.

References

Johnson, SP, Sheppard, S, Rasmussen, B, Wingate, MTD, Kirkland, CL, Muhling, JR, Fletcher, IR and Belousova, E 2010, The Glenburgh Orogeny as a record of continent–continent collision: Geological Survey of Western Australia, Record 2010/5, 54p.

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Camel Hills Metamorphics; subunit (P_-CH-mwa)

Legend narrative

Amphibolite; fine grained hornblende–plagioclase–quartz–epidote–titanite rock

Rank	Formation
Parent	Camel Hills Metamorphics (P_-CH-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	P_-MO-gp, P_-MO-gmeb (intrusive)

Summary

Fine-grained amphibolite is a minor component of the Camel Hills Metamorphics, mainly being restricted to a 25 km^2 package on southwestern Errabiddy.

Distribution

A 7 km long, 5 km wide package of fine-grained amphibolite is present east of Black Adder Well on southwestern Errabiddy. The unit is interlayered with subordinate fine- and coarse-grained calc-silicate gneiss of the Petter Calc-silicate. The amphibolite forms low, rounded hills covered in rubble.

Lithology

The amphibolite is fine grained and structureless apart from one amygdaloidal layer about 50 cm thick (Zone 50, MGA 520700E 7199600N), which may suggest a volcanic component within what appears to be a dominantly intrusive sequence.

Age code	Proterozoic	P_-
Stratigraphic code	Camel Hills Metamorphics, Petter Calc-silicate	CHp-
Rock type	meta-igneous mafic	mw
Lithname	amphibolite	a
Rock code		**P_-CH-mwa**

Contact relationships

Amphibolite is tectonically interlayered with subordinate fine- and coarse-grained calc-silicate gneiss (P_-CHp-mk). Numerous veins and dykes of muscovite–biotite granite and pegmatite (P_-MO-gp) intruded along the foliation of the amphibolite. At the northeastern end of the exposure fine-grained, weakly foliated amphibolite is net-veined by massive, medium-grained, even-textured biotite granite (P_-MO-gmeb).

Geochronology

P_-CH-mwa	*Maximum*	*Minimum*
Age (Ma)	2001	1955
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Johnson et al., 2010	Nelson, 1999

The age of this amphibolite is unknown. The unit has been assigned a Paleoproterozoic age because it lacks refolded folds, unlike amphibolites of Archean age in the Narryer Terrane. In addition, the amphibolite east of Black Adder Well is not associated with any granitic gneiss. However, because the amphibolite is interpreted to be part of the Camel Hills Metamorphics, it has been assigned similar maximum and minimum age constraints.

References

Johnson, SP, Sheppard, S, Rasmussen, B, Wingate, MTD, Kirkland, CL, Muhling, JR, Fletcher, IR and Belousova, E 2010, The Glenburgh Orogeny as a record of continent–continent collision: Geological Survey of Western Australia, Record 2010/5, 54p.

Nelson, DR 1999, 142910: paragneiss, Pannikan Bore; Geochronology Record 335: Geological Survey of Western Australia, 4p.

Bertibubba Supersuite (P_-BB-g)

Legend narrative

Granite and metagranitic rocks

Rank	Supersuite
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA

Summary

Granites of the Bertibubba Supersuite intruded the Yarlarweelor Gneiss Complex and the southern edge of the Gascoyne Province, and form fault-bounded slices within the Errabiddy Shear Zone. These granites are the first common element to the Yilgarn Craton and Gascoyne Province. Most of the dated granites from the Bertibubba Supersuite have igneous crystallization ages between 1965–1955 Ma, but a specimen of one of the granite dykes that intruded the southern margin of the Gascoyne Province has an igneous crystallization age of 1945 ± 14 Ma. The older granites (1965–1955 Ma) are variably deformed, but the younger dykes (1945 Ma) are not, suggesting deformation occurred during the D_{2g} event of the Glenburgh Orogeny (1965–1950 Ma) indicating that the Bertibubba Supersuite represents a series of syn- to post-tectonic intrusions.

Distribution

The bulk of the plutons that belong to the Bertibubba Supersuite intruded rocks of the Yarlarweelor Gneiss Complex and Camel Hills Metamorphics in the Errabiddy Shear Zone on ERONG and YALBRA, or the Yarlarweelor Gneiss Complex on MARQUIS. However, dykes of leucocratic tonalite and granodiorite also intrude the southern edge of the Gascoyne Province (Glenburgh Terrane) on GLENBURGH.

Lithology

Most of the Bertibubba Supersuite consists of equigranular and porphyritic, biotite metamonzogranite. In the Glenburgh Terrane, dykes that are assigned to the Bertibubba Supersuite consist of leucocratic, biotite tonalite, and granodiorite.

Age code	Proterozoic	P_-
Stratigraphic code	Bertibubba Supersuite	BB-
Rock type	Igneous granitic	g
Rock code		**P_-BB-g**

Contact relationships

Granites belonging to the Bertibubba Supersuite intruded Archean rocks of the Yarlarweelor Gneiss Complex and the Paleoproterozoic metasedimentary rocks of the Camel Hills Metamorphics. Granite dykes interpreted to be part of the supersuite, also intruded metagranitic rocks of the 2005–1970 Ma Dalgaringa Supersuite in the Paradise Zone along the southern edge of the Gascoyne Province.

Geochronology

P_-BB-g	*Maximum*	*Minimum*
Age (Ma)	1961 ± 6	1945 ± 14
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2001	Nelson, 1999a

Seven samples of Bertibubba Supersuite metagranites that intruded the Errabiddy Shear Zone and Yarlarweelor Gneiss Complex have been dated using SHRIMP U–Pb zircon methods. These samples (GSWA 142850, 142911, 142912, 168946, 139464, 142929; Nelson, 1998, 1999a–c, 2000, 2001) together with sample NK/38 of Kinny et al., (2004) yielded igneous crystallization ages between 1961 ± 6 Ma and 1945 ± 14 Ma.

References

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Nelson, DR 1999b, 142850: foliated monzogranite, Nanular Bore; Geochronology Record 366: Geological Society of Western Australia, 4p.

Nelson, DR 1999c, 142912: foliated biotite monzogranite, Gidgee Bore; Geochronology Record 337: Geological Survey of Western Australia, 4p.

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CAJOU MONZOGRANITE
(P_-BBcj-gm)

Legend narrative

Equigranular and porphyritic, medium-grained biotite monzogranite

Rank	Formation
Parent	Bertibubba Supersuite (P_-BB-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA

Summary

The Cajou Monzogranite intrudes the Yilgarn Craton within the Errabiddy Shear Zone. Two specimens of the Cajou Monzogranite were sampled for SHRIMP U-PB zircon geochronology, yielding identical igneous crystallization ages of 1961 ± 3 Ma (Nelson, 1998, 1999).

Distribution

The Cajou Monzogranite outcrops extensively within the Errabiddy Shear Zone on Erong, where it intrudes Archean granites of the Yilgarn Craton.

Lithology

The Cajou Monzogranite consists of equigranular and porphyritic, medium-grained biotite monzogranite.

Age code	Proterozoic	P_-
Stratigraphic code	Bertibubba Supersuite, Cajou Monzogranite	BBcj-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
Rock code		**P_-BBcj-gm**

Geochronology

P_-BBcj-gm	*Maximum*	*Minimum*
Age (Ma)	1961 ± 3	1961 ± 3
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1998, 1999	Nelson, 1998, 1999

Two samples (GSWA 142911 and 142912) of the Cajou Monzogranite were collected for SHRIMP U–Pb zircon geochronology, and yielded indistinguishable igneous crystallization ages of 1961 ± 3 Ma (Nelson, 1998, 1999). Sample GSWA 142911 also included 12 analyses of late Archean xenocrysts.

References

Nelson, DR 1998, 142911: foliated porphyritic biotite monzogranite, Erong Springs Homestead; Geochronology Record 336: Geological Survey of Western Australia, 4p.

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YAMAGEE GRANITE (P_-BBya-mgm)

Legend narrative

Foliated, medium- and fine-grained, equigranular biotite metamonzogranite; minor leucocratic biotite–garnet metamonzogranite

Rank	Formation
Parent	Bertibubba Supersuite (P_-BB-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmeb, P_-BBya-mgmu
Underlying units	P_-BBya-mgmu

Summary

The Yamagee Granite is part of the Bertibubba Supersuite, which intrudes the reworked northern margin of the Narryer Terrane (Yarlarweelor Gneiss Complex), Camel Hills Metamorphics, and the southern edge of the Gascoyne Province. The Yamagee Granite forms a thick sheet-like pluton that intruded Archean granitic rocks of the Yarlarweelor Gneiss Complex, before being deformed and metamorphosed during the Capricorn Orogeny. A specimen of the Yamagee Granite sampled for SHRIMP U–Pb zircon geochronology yielded an igneous crystallization age of 1958 ± 4 Ma.

Distribution

The Yamagee Granite forms a very thick sheet-like pluton that intrudes the Yarlarweelor Gneiss Complex on western MARQUIS. Most of the intrusion is exposed as rubbly outcrops along the flanks of creeks incised into an old land surface. Smaller isolated exposures toward the western edge of MARQUIS probably consist of a series of sheets. The latter are assigned to the Yamagee Granite because they have only one foliation and, unlike low-strain equivalents of the granitic gneisses, they intruded amphibolite lenses that had a pre-existing foliation.

Derivation of name

The Yamagee Granite is named after the Yamagee Bore (Zone 50, MGA 568640E 7190550N) on MARQUIS.

Lithology

The Yamagee Granite consists of two phases: variably foliated, medium- to fine-grained, equigranular biotite metamonzogranite (P_-BBya-mge), which forms the bulk of the intrusion; and a composite sheet-like body of foliated, medium-grained, porphyritic, biotite metamonzogranite (P_-BBya-mgp). There is no sharp contact between the two phases; rather, it is a transition from sheets of dominantly one rock type to sheets dominantly of the other. Contacts between individual sheets are parallel to the foliation in the intrusion, and thus the relative ages of the rock types cannot be established. Leucocratic biotite–garnet metamonzogranite is a minor component of the equigranular phase.

The Yamagee Granite ranges from weakly foliated to locally strongly foliated and moderately well banded. Pegmatite veins and thin dykes are widespread, but only locally abundant. The veins and dykes are commonly parallel to the foliation in the granite. In places the veins and the foliation are folded about mesoscopic upright, isoclinal D_{2n} folds. Weakly deformed samples of the equigranular phase consist of a few percent subhedral microcline phenocrysts in a fine- to medium-grained, granular groundmass of plagioclase, microcline, quartz, and biotite. Magnetite, zircon, and apatite are accessory minerals. Strongly deformed samples have a foliation defined by seams of biotite and a grain-flattening fabric defined by tabular quartz and plagioclase crystals. Both weakly and strongly deformed rocks are overprinted by a low- to medium-grade metamorphism, responsible for sutured quartz boundaries, and replacement of plagioclase and magnetite by fine-grained sericite and epidote.

Age code	Proterozoic	P_-
Stratigraphic code	Bertibubba Supersuite, Yamagee Granite	BBya-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
Rock code		**P_-BBya-mgm**

Contact relationships

The Yamagee Granite intruded early to late Archean granitic gneiss as well as amphibolite and metasedimentary gneisses. About 6 km northwest of Nanular Bore (Zone 50, MGA 556640E 7195550N and 556040E 7197750N) foliated and diffusely banded, medium-grained, equigranular metamonzogranite assigned to the Yamagee Granite intruded leucocratic granitic gneiss, thick lenses of amphibolite, and thin lenses of metasedimentary rock.

Geochronology

P_-BBya-mgm	*Maximum*	*Minimum*
Age (Ma)	1958 ± 4	1958 ± 4
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1999	Nelson, 1999

Foliated, medium-grained equigranular metamonzogranite of the Yamagee Granite, about 2 km southeast of Nanular Bore on MARQUIS, was sampled for SHRIMP U–Pb zircon geochronology (GSWA 142850). Twenty-three concordant or near-concordant analyses of 23 zircons indicate a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1958 ± 4 Ma, interpreted as the igneous crystallization age of the metamonzogranite (Nelson, 1999).

References

Nelson, DR 1999, 142850: foliated monzogranite, Nanular Bore; Geochronology Record 366: Geological Society of Western Australia, 4p.

YAMAGEE GRANITE; subunit (P_-BBya-mgmu)

Legend narrative

Medium-grained, porphyritic biotite metamonzogranite; round phenocrysts of K-feldspar; foliated

Rank	Member
Parent	YAMAGEE GRANITE (P_-BBya-mgm)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-BBya-mgm
Underlying units	P_-BBya-mgm

Summary

The porphyritic phase of the Yamagee Granite is enclosed within the main, equigranular phase.

Distribution

The porphyritic phase of the Yamagee Granite (P_-BBya-mgp) forms a thick sheet (~0.5 km thick) on central MARQUIS within the main, equigranular phase. There is no sharp contact between the two phases; rather, it is a transition from sheets of dominantly one rock type to sheets dominantly of the other. Contacts between individual sheets are parallel to the foliation in the intrusion, and thus the relative ages of the rock types cannot be established.

Lithology

The porphyritic phase of the Yamagee Granite contains about 20% rounded phenocrysts of K-feldspar, 1.0 – 1.5 cm in diameter a fine- to medium-grained, granular groundmass of plagioclase, microcline, quartz, and biotite. Strongly deformed samples have a foliation defined by seams of biotite and a grain-flattening fabric defined by tabular quartz and plagioclase crystals.

Age code	Proterozoic	P_-
Stratigraphic code	Bertibubba Supersuite, Yamagee Granite	BBya-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	—	
2nd qualifier	augen	u
Rock code		**P_-BBya-mgmu**

Contact relationships

Contacts between the porphyritic and equigranular phases of the Yamagee Granite are parallel to a tectonic foliation; the relative ages of these units could not be established.

Geochronology

P_-BBya-mgmu	*Maximum*	*Minimum*
Age (Ma)	1958	1958
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 1999	Nelson, 1999

The porphyritic phase of the Yamagee Granite has not been dated directly, but is inferred to be the same age as the main equigranular phase of the unit, which is dated at 1958 ± 4 Ma (Nelson, 1999).

References

Nelson, DR 1999, 142850: foliated monzogranite, Nanular Bore; Geochronology Record 366: Geological Society of Western Australia, 4p.

Bertibubba Supersuite; subunit (P_-BB-gtl)

Legend narrative

Fine-grained, massive, leucocratic tonalite and granodiorite

Rank	Formation
Parent	Bertibubba Supersuite (P_-BB-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	P_-DAna-mgtl; P_-CHq-mln

Summary

Veins and sheets of coarse-grained leucocratic tonalite belonging to the Bertibubba Supersuite intrude pelitic gneiss of the Quartpot Pelite in the Errabiddy Shear Zone on LANDOR and ERONG. Dykes of leucocratic tonalite and granodiorite also intrude granitic rocks of the Dalgaringa Supersuite on southern GLENBURGH in the Paradise Zone. A dyke sampled for SHRIMP U–Pb zircon geochronology yielded an igneous crystallization age of 1945 ± 14 Ma, within uncertainty of the igneous crystallization ages of plutons of the Bertibubba Supersuite that intrude the Errabiddy Shear Zone and northern edge of the Narryer Terrane.

Distribution

Dykes of massive leucocratic tonalite and granodiorite, typically 1–3 m wide and up to 400 m long, intrude the leucocratic phase of the Nardoo Granite (P_-DAna-mgtl) in the southern part of GLENBURGH. The dykes are widespread, but only locally abundant.

Lithology

The dykes of massive leucocratic tonalite and granodiorite are composed of plagioclase, quartz, and minor amounts of biotite (7–8%), with or without a few percent microcline. Small amounts (about 1–2%) of primary muscovite are present in some samples.

Age code	Proterozoic	P_-
Stratigraphic code	Bertibubba Supersuite	BB-
Rock type	Igneous granitic	g
Lithname	tonalite	t
1st qualifier	leuco-	l
Rock code		**P_-BB-gtl**

Contact relationships

Most dykes of leucocratic tonalite and granodiorite cut the foliation in the Nardoo Granite, and strike in one of two orientations: 100–110° or 140–150°.

Geochronology

P_-BB-gtl	*Maximum*	*Minimum*
Age (Ma)	1945 ± 14	1945 ± 14
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1999	Nelson, 1999

A leucocratic biotite tonalite dyke about 4.5 km west-southwest of Nardoo Well (Zone 50, MGA 445050E 7186390N; GSWA 142929) was sampled for SHRIMP U–Pb zircon dating (Nelson, 1999). Twenty-seven concordant and variably discordant analyses were obtained from 25 zircons. Nelson (1999) assigned most of the zircons to three groups. Group 1 consists of five concordant analyses of 4 zircons that yield a weighted mean date of 1945 ± 14 Ma. Group 2 comprises six concordant and variably discordant analyses of 6 zircons that yield a weighted mean date of 1979 ± 13 Ma. Group 3 consists of six concordant and variably discordant analyses of 5 zircons that yield a weighted mean date of 2042 ± 12 Ma. The remaining analyses have $^{207}Pb^{*}/^{206}Pb^{*}$ ratios indicating ages in excess of 2150 Ma. The date of 1945 ± 14 Ma provided by the five concordant analyses of Group 1 were interpreted as the time of crystallization of the dyke (Nelson, 1999).

References

Nelson, DR 1999, 142929: biotite trondhjemite dyke, Nardoo Bore; Geochronology Record 316: Geological Survey of Western Australia, 4p.

Glenburgh Orogeny

Event type	tectonic: collisional orogeny
Child event	D_{1g}, D_{2g}
Tectonic setting	orogen: collisional orogen
Metamorphic facies from	amphibolite facies: undivided
Metamorphic facies to	granulite facies: cordierite–K-feldspar zone

Summary

The Glenburgh Orogeny (2005–1950 Ma) is considered to be roughly equivalent to the combined age range of the Dalgaringa Supersuite and the syn-tectonic part of the Bertibubba Supersuite. The orogeny is interpreted to record the tectonomagmatic evolution of an Andean-type arc along the southern margin of the Glenburgh Terrane and its subsequent collision with the Yilgarn Craton. Two discrete tectonometamorphic episodes are recognized within this orogeny (D_{1g}/M_{1g} and D_{2g}/M_{2g}), both of which have been dated directly from the growth of new metamorphic zircon and monazite. D_{1g}/M_{1g} is dated at 2005–1985 Ma and is interpreted to record the construction of the continental margin arc in the middle crust, whereas D_{2g}/M_{2g} is dated at 1965–1950 Ma, and is interpreted to record the terminal closure of the oceanic tract with collision between a previously combined Pilbara Craton – Glenburgh Terrane and the Yilgarn Craton.

Distribution

The effects of the Glenburgh Orogeny are recognized across the southern part of the Gascoyne Province, and in the adjacent Errabiddy Shear Zone. In detail the D_{1g}/M_{1g} event is recorded only in gneissic granites of the Dalgaringa Supersuite in the Paradise Zone, whereas the D_{2g}/M_{2g} event is recorded across the region from the Errabiddy Shear zone to the Mooloo Zone. In the Bryah and Padbury Basins, originally flat-lying D_1 structures interpreted to reflect thrusting were considered by Pirajno et al. (2000) to have formed during the Glenburgh Orogeny.

Description

The Glenburgh Orogeny comprises two discrete tectonometamorphic episodes (D_{1g} and D_{2g}), both of which have been dated directly from the growth of new metamorphic zircon and monazite. D_{1g} is restricted entirely to the Paradise Zone, where it is represented by the pervasive development of gneissic fabrics within meta-igneous rocks of the Dalgaringa Supersuite and within strips of pelitic diatexite and mafic granulite that are intercalated with the gneissic granites. Associated M_{1g} peak metamorphic assemblages record metamorphism mainly in the middle amphibolite facies but pelitic diatexites and mafic granulites in the central part of the Paradise Zone indicate peak conditions, at least locally, in the granulite facies. The presence of hercynitic spinel – corundum – almandine-garnet in pelitic diatexites is interpreted by Schulters and Bohlen (1988) to indicate moderate- to high-pressure and temperature conditions, in the range ~7–10 kbar and 800–1000°C. Metamorphism and deformation were contemporaneous with arc magmatism between 2005 Ma and 1985 Ma, and suggest that D_{1g} was associated with the construction of the Dalgaringa Arc in the middle crust (Johnson et al., 2010). The D_{2g} event is pervasively recorded in all lithologies from the Errabiddy Shear Zone through to the Mooloo Zone in the southern part of the Gascoyne Province. The widespread production of subhorizontal gneissic fabrics, folds and foliations indicate the predominance of large horizontal shortening components during D_{2g} deformation. M_{2g} metamorphism was contemporaneous with D_{2g} and was responsible for the widespread migmatization of pelitic and semi-pelitic lithologies of the Camel Hills Metamorphics and Moogie Metamorphics. However, the wholesale destruction and retrogression of these peak metamorphic assemblages during subsequent lower grade metamorphism preclude the precise determination of peak metamorphic conditions across the region. The presence of garnet and sillimanite porphyroblasts within pelitic diatexite lithologies indicates metamorphic conditions peaked in the upper amphibolite to lower granulite facies with pressures and temperatures at about 5–9 kbar and >650°C (e.g. Rigby, 2009). The widespread and pervasive nature of D_{2g} within lithologies interpreted to have been on different sides of the Dalgaringa Arc and subducting oceanic tract (i.e., on the Pilbara Craton – Glenburgh Terrane or Yilgarn Craton sides), combined with the large horizontal shortening components and peak metamorphic grades associated with M_{2g}, are interpreted to record the collision between a previously assembled Pilbara Craton – Glenburgh Terrane with the Yilgarn Craton along the Errabiddy Shear Zone. Intrusion of the granitic Bertibubba Supersuite throughout the southern Gascoyne Province is coeval with D_{2g}, and is interpreted as a series of syntectonic intrusions that stitch the two cratons (Occhipinti et al., 2004).

Geochronology

Glenburgh Orogeny	*Maximum*	*Minimum*
Age (Ma)	2002 ± 3 Ma	1947 ± 11 Ma
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1999a	Johnson et al., 2010

The Glenburgh Orogeny is considered to be roughly equivalent to the combined age range of the Dalgaringa Supersuite and the syntectonic part of the Bertibubba Supersuite (2005–1950 Ma). Two discrete tectonometamorphic episodes have been recognized within this orogeny (D_{1g} and D_{2g}), both of which have been dated directly using metamorphic zircon and monazite. Although D_{1g} has been precisely dated (SHRIMP U–Pb geochronology of metamorphic zircon rims around older detrital grains) from a diatexite at 1997 ± 10 Ma (GSWA 185942; Wingate et al., 2010), field evidence suggests that D_{1g} was a much longer-lived event, possibly spanning the entire age range of the older parts of the Dalgaringa Supersuite (i.e. 2002 ± 3 to 1987 ± 4 Ma; Nelson, 1999a,b). A large number of precise SHRIMP U–Pb ages have been obtained from metamorphic zircon and monazite that grew within pelitic diatexites and semi-pelitic schists (now retrogressed) during the D_{2g} event

(Johnson et al., 2010). The age of metamorphic zircon and monazite, irrespective of the lithological composition or geographical location in which they grew, provide an age range for D_{2g} of c. 1965 to c. 1950 Ma, which is coincident with the age range of the syn-tectonic granitic Bertibubba Supersuite.

Tectonic setting

The Glenburgh Orogeny records the tectonomagmatic evolution of an Andean-type arc along the southern margin of a previously assembled Pilbara Craton – Glenburgh Terrane, and the subsequent collision of this entity with the Yilgarn Craton. The Dalgaringa Supersuite in the Paradise Zone along the southern margin of the Glenburgh Terrane records a near-continual record of continental arc magmatism (Sheppard et al., 2004) and accompanying deformation between 2005 Ma and 1985 Ma (Occhipinti and Sheppard, 2001). The presence of older, slightly isotopically evolved (Lu–Hf isotope system) detrital zircon within the Quartpot Pelite, suggest that continental arc magmatism (in a proto-Dalgaringa arc) may extend back as far as c. 2080 Ma (Johnson et al, 2010). The presence of Dalgaringa Supersuite-aged granitic components within the Halfway Gneiss indicate that arc magmatism took place within the Glenburgh Terrane, presumably along its southern margin so that subduction of oceanic crust was toward the northwest under the Glenburgh Terrane (Sheppard et al., 2004; Johnson et al., 2010). Within the currently exposed parts of the Dalgaringa Supersuite deformation associated with D_{1g} appears to have spanned the entire 2005–1985 Ma period. Combined with the moderate- to high-pressure, high-temperature nature of M_{1g}, this tectonomagmatic event is interpreted to represent construction of the continental arc within mid crustal levels. The Quartpot Pelite of the Camel Hills Metamorphics appears to have been deposited as a result of this deformation being deposited between 2000–1955 Ma (Johnson et al., 2010). Juxtaposition of the Quartpot Pelite with lithologies from the opposite side of the oceanic tract (i.e., the Petter Calc-silicate) is interpreted to have occurred during D_{2g} with the Errabiddy Shear Zone representing the suture. Although no relict ophiolitic slices appear to have been preserved, the interleaving of lithologies with different provenance, the pervasive nature of subhorizontal D_{2g} deformation, and the moderate-pressure and moderate- to high-temperature nature of the metamorphism all suggest that D_{2g}/M_{2g} was the result of collision between the Pilbara–Glenburgh Craton with the Yilgarn Craton. This event is precisely dated from the growth of metamorphic zircon and monazite in the highest grade lithologies to between c. 1965 Ma and c. 1950 Ma (Johnson et al., 2010). Along with D_{2g}/M_{2g}, the coeval granitic Bertibubba Supersuite is the first element common to the northwestern Yilgarn Craton through to the Paradise Zone in the Glenburgh Terrane.

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Glenburgh Orogeny D_{1g}/M_{1g}

Event type	deformation: compressional, metamorphic: undivided
Tectonic units affected	Glenburgh Terrane
Tectonic setting	orogen: continental arc
Metamorphic texture/ tectonic feature	diatexitic, gneissose, foliated, schistose
Metamorphic facies from	amphibolite facies: undivided
Metamorphic facies to	granulite facies: cordierite–K-feldspar zone

Summary

The oldest tectonic fabric that can be attributed to the Glenburgh Orogeny is referred to as D_{1g} (and the corresponding mineral assemblage, M_{1g}). This predominantly gneissic fabric is recognized only within the Paradise Zone of the Gascoyne Province and is developed in meta-igneous rocks of the Dalgaringa Supersuite and strips of pelitic diatexite and mafic granulite that are intercalated with the gneissic granites. The Dalgaringa Supersuite metagranites have geochemical and isotopic compositions that indicate formation in an Andean-type arc. Associated M_{1g} assemblages record metamorphism mainly in the middle amphibolite facies but pelitic diatexites and mafic granulites in the central part of the Paradise Zone indicate peak conditions, at least locally, in the granulite facies. Metamorphism and deformation were contemporaneous with arc magmatism between 2005–1985 Ma and suggest that D_{1g} was associated with the construction of the arc in the middle crust.

Distribution

The oldest tectonic fabric that can be attributed to the Glenburgh Orogeny, D_{1g} (and the corresponding mineral assemblage, M_{1g}), is recognized only within the Paradise Zone of the Gascoyne Province. The predominantly gneissic fabric is developed within 2005–1985 Ma-aged metatonalites, metagranodiorites and metamonzogranites of the Dalgaringa Supersuite (Occhipinti and Sheppard, 2001; Occhipinti et al., 2004) and discontinuous strips of mafic granulite and pelitic diatexite that are intercalated with these gneisses.

Description

In the Paradise Zone the D_{1g} fabrics are represented predominantly by a gneissic banding and foliation. Folding, including tight to isoclinal, moderately plunging folds, are only locally developed.

Occhipinti and Sheppard (2001) recorded the presence of relict garnet porphyroblasts within many of the Dalgaringa Supersuite metagranites. Intercalated strips of amphibolite suggest that metamorphic conditions in D_{1g} peaked at upper amphibolite facies throughout most of the zone. However, in the central part of the zone around Paradise Well, discontinuous lenses of mafic granulites and pelitic diatexites indicate that some parts of the Dalgaringa Supersuite underwent peak metamorphism at upper amphibolite to granulite facies; these metamafic rocks commonly contain a peak metamorphic assemblage of either hypersthene–clinopyroxene–plagioclase or plagioclase–clinopyroxene–hypersthene(–garnet) (Occhipinti and Sheppard, 2001).

The pelitic diatexites are described by Johnson et al., (2010) as coarse-grained granoblastic rocks with mm- to cm-scale discontinuous leucosomes parallel to the regional D_{1g} gneissic fabrics. The diatexite leucosomes (GSWA 185942) contain an assemblage of cordierite–sillimanite–hercynitic spinel–biotite–quartz–corundum. The cordierite forms 1–5 mm-diameter porphyroblasts, with the core regions intergrown with abundant fibrolite mats. The outer 0.25 – 1 mm part of the porphyroblasts are free of sillimanite, but are partially mantled by coarse-grained (0.5 – 2 mm diameter) euhedral sillimanite blades. The cores of these sillimanites host hercynitic spinel and corundum. Tabular biotite blades are intergrown within the cordierite–sillimanite coronas and appear to be in textural equilibrium with these phases; however in the matrix, which comprises quartz–cordierite–biotite, the biotite blades are not in textural equilibrium and are mantled by fringes of fibrolite and cordierite. The mesosomes (GSWA 144823) contain an assemblage of garnet–sillimanite – gahnitic-spinel – plagioclase–biotite–quartz. Garnet is found within 10–20 mm-thick biotite-rich seams and forms 5–10 mm-diameter porphyroblasts that contain inclusions of both biotite and sillimanite. Outside of these seams, quartz and plagioclase are more prevalent with biotite plates with exsolved pockets of ilmenite mantled by fringes of fibrolite and cordierite and with the biotite exsolving small pockets of ilmenite. Discontinuous sillimanite-rich seams up to 10–15 mm wide are composed of euhedral sillimanite blades with minor biotite–quartz–plagioclase. The sillimanite cores are replaced by anhedral gahnitic spinel.

The assemblages documented above, along with mesoscale leucosomes, imply moderate- to high-temperature conditions that were conducive to incipient melting. The replacement of hercynitic spinel with corundum is interpreted by Schulters and Bohlen (1988) to indicate moderate to high pressure and temperature conditions in the range ~7–10 kbar and 800–1000°C. The alignment of the mesoscale melt fabrics with the regional S_{1g} foliation suggest that this melting event was synchronous with D_{1g}, and that migmatization may have been a response to the inclusion and burial of these pelitic strips within the mid crustal parts of an active continental arc. The structural relationship between these granulite facies rocks and the surrounding amphibolite rocks is unclear, but it is suggested that the two were juxtaposed after the D_{1g}/M_{1g} event (Occhipinti et al., 2004).

Geochronology

Glenburgh Orogeny D_{1g}	*Maximum*	*Minimum*
Age (Ma)	2002 ± 3 Ma	1987 ± 4 Ma
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1999a	Nelson, 1999b

The age of the D1g event has been precisely dated at 1997 ± 10 Ma, using SHRIMP U–Pb geochronology of rims on zircons from melt veins that developed within a pelitic diatexite (GSWA 185942) during high-grade metamorphism (Wingate et al., 2010). However, the Dalgaringa Supersuite records a near-continual record of arc magmatism and accompanying deformation between 2005 and 1985 Ma (Occhipinti and Sheppard, 2001), suggesting that D_{1g} was a much longer-lived event than the apparent single event recorded in the diatexite. The age of metamorphism recorded in the diatexite represents the time that the metasedimentary rocks underwent melting with production of a near-anhydrous mineral assemblage, which would have precluded the growth of any new metamorphic zircon during the subsequent prolonged M_{1g} event. Therefore, the age of D_{1g} is taken to be the age range of the oldest and youngest deformed rocks of the Dalgaringa Supersuite (i.e. 2005–1985 Ma).

Tectonic setting

The Dalgaringa Supersuite is a near-continuous record of continental arc magmatism (Sheppard et al., 2004) and accompanying deformation between 2005 Ma and 1985 Ma (Occhipinti and Sheppard, 2001). Combined with the moderate- to high-pressure nature of M_{1g} metamorphism (Johnson et al., 2010), this suggests that D_{1g} occurred as a result of construction of the arc in the middle crust.

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Glenburgh Orogeny D_{2g}/M_{2g}

Event type	deformation: compressional, metamorphic: regional
Parent event	Glenburgh Orogeny
Tectonic setting	orogen: collisional orogen
Metamorphic texture/ tectonic feature	diatexitic, gneissose, foliated, schistose
Metamorphic facies from	amphibolite facies: undivided
Metamorphic facies to	amphibolite facies: sillimanite–K-feldspar zone

Summary

Deformation and metamorphism associated with a second event of the Glenburgh Orogeny is referred to as D_{2g} (and associated metamorphic assemblages as M_{2g}), and it was pervasively imparted on all rocks from the Errabiddy Shear Zone through to the Mooloo Zone in the southern part of the Gascoyne Province. The earliest structure preserved in pelitic to semi-pelitic lithologies of the Moogie Metamorphics and Camels Hills Metamorphics is a subhorizontal mm- to cm-scale gneissic banding that reflects discontinuous leucocratic melt segregations formed during migmatization. In the more psammitic and quartzitic lithologies, this D_{2g} fabric is represented as an intense bedding-parallel composite foliation. In the quartzofeldspathic meta-igneous lithologies, especially those of the Halfway Gneiss, D_{2g} is heterogeneously developed as mm- to cm-scale gneissic banding defined by alternating leucocratic and mesocratic layers with abundant discontinuous 1–25 cm-thick pegmatites. The banding is commonly complexly folded, showing both type 2 and 3 interference folds most of which show no consistency in orientation. Nearly all the fabrics and folds are, or were, subhorizontal, indicating the predominance of large horizontal shortening components during D_{2g} deformation and metamorphism. Although poorly constrained due to the intense alteration of peak metamorphic mineral assemblages during subsequent metamorphic events, M_{2g} metamorphism is interpreted to have peaked between 5–9 kbar and >650°C. The M_{2g} metamorphism has been precisely dated by SHRIMP U–Pb geochronology of metamorphic zircon and monazite within the medium- to high-grade pelitic and semi-pelitic lithologies of both the Camel Hills Metamorphics and Moogie Metamorphics at between c. 1965 and c. 1950 Ma.

Distribution

Deformation and metamorphism associated with the second event of the Glenburgh Orogeny is referred to as D_{2g} (and associated metamorphic assemblages as M_{2g}). The D_{2g} event is characterized by gneissic fabrics, folds, and metamorphic assemblages that are prevalent throughout the Paradise and Mooloo Zones of the Glenburgh Terrane, and the Errabiddy Shear Zone.

Description

In the Paradise Zone, D_{2g} is characterized mainly by mesoscopic tight to isoclinal upright folds that are accompanied by a penetrative axial planar foliation that is especially well developed in the c. 1975 Ma Nardoo Granite (Occhipinti and Sheppard, 2001). Rare F_{2g} fold hinges in the older parts (i.e. 2005–1985 Ma) of the Dalgaringa Supersuite and in the pelitic diatexite (Johnson et al., 2010) indicate that the D_{2g} fabric is developed sub-parallel to both the gneissic banding and D_{1g} foliation.

In the Mooloo Zone, heterogeneous D_{2g} fabrics and folds are developed pervasively throughout the Moogie Metamorphics and Halfway Gneiss. The earliest structure preserved in the Moogie Metamorphics is subhorizontal mm- to cm-scale gneissic banding that reflects discontinuous leucosomes formed during migmatization. In the unmelted psammitic lithologies this D_{2g} fabric is represented by an intense bedding-parallel composite foliation. Although the medium- to high-grade M_{2g} metamorphic diatexite assemblages were completely retrogressed to lower grade assemblages during the Capricorn Orogeny, many localities still show particularly well-preserved diatexite textures (Johnson et al., 2010). At one locality in particular, on the southwestern slopes of Mount Dalgety on Daurie Creek (SPJDAU000005), the retrogressed pelitic diatexite (sample GSWA 184161) contains euhedral 5–10 cm porphyroblasts of garnet (pseudomorphed by chloritoid), which sit within 1–10 cm-thick biotite-rich restitic layers, that are wrapped by discontinuous leucosomes of quartz–feldspar–sillimanite (now sericite). The relict garnet porphyroblasts contain coarse quartz and biotite inclusion trails that are continuous with the external D_{2g} fabric, but display minor dextral shear rotation; presumably during locally prolonged D_{2g} deformation. Within the more psammitic parts of the Moogie Metamorphics, the local preservation of bedding (graded bedding and compositional layering) alongside diatexite textures in the pelites, demonstrate that melting, migmatization, and porphyroblast growth during D_{2g} was a function of composition, rather than variations in metamorphic grade.

The Halfway Gneiss at most localities contains a mm- to cm-scale gneissic banding defined by alternating leucocratic (quartz–feldspar) and mesocratic (biotite–quartz–feldspar(–hornblende)) layers with abundant discontinuous 1–25 cm-thick pegmatites. On northern Daurie Creek, the gneissic fabric in the Halfway Gneiss contains abundant leucocratic material dated at c. 2006 Ma (Occhipinti et al., 2001) providing a maximum age for its development. On the northern part of Glenburgh and Daurie Creek, the Halfway Gneiss is intercalated with pelitic diatexites and psammitic schists of the Moogie Metamorphics, but itself contains only a simple, openly folded gneissic fabric. This suggests that the Halfway Gneiss did not see both of the Glenburgh events and that the gneissic fabric must be contemporaneous with the medium- to high-grade D_{2g} fabrics within the Moogie schists. Farther north on southern Yinnetharra, these gneissic fabrics are commonly complexly folded showing both type 2 and 3 interference folds (Ramsey and Huber, 1987), most of which show no consistency in orientation, or the development of any new fabrics. The age of this refolding event(s) is unclear but may either be related to locally prolonged D_{2g} deformation or to subsequent Paleoproterozoic to Neoproterozoic reworking events

(Johnson et al., 2010). The continuity of the medium- to high-grade S_{2g} fabrics in the Moogie Metamorphics with those in the Halfway Gneiss suggest that M_{2g} in the Halfway Gneiss must have occurred at similar metamorphic grade to that in the Moogie Metamorphics.

Metamorphism (M_{2g}) appears to have accompanied D_{2g} deformation throughout the southern part of the Gascoyne Province (Occhipinti and Sheppard, 2001), but was not of uniform grade. In the Paradise Zone the grade of M_{2g} metamorphism is difficult to establish as there appears to be no significant retrogression or overprinting of the higher grade granulite facies M_{1g} assemblages, most likely due to the anhydrous nature of these assemblages (Occhipinti et al., 2004). In the amphibolite grade gneisses, garnet appears to be replaced with clots of fine grained biotite; in the calc-silicate rocks, pargasite and diopside are rimmed or replaced along fractures with tremolite (Occhipinti et al., 2004), whereas the gneissic fabric in the Nardoo Granite is defined by biotite–quartz–oligoclase to andesine–epidote (Occhipinti and Sheppard, 2001). Collectively these features suggest that M_{2g} metamorphism in the Paradise Zone peaked at lower amphibolite facies.

All lithologies in the Errabiddy Shear Zone are in faulted contact with each other and contain a single, pervasive fabric associated with D_{2g} deformation and metamorphism. The Archean granitic rocks, such as the Warrigal Gneiss (Sheppard and Occhipinti, 2000), contain a gneissic fabric defined by alternating mesocratic and leucocratic layers, whereas rocks of the Camel Hills Metamorphics contain either a strong migmatitic or gneissic fabric depending on their lithological composition and whether or not they were melted. This uniformly consistent S_{2g} fabric was originally flat lying and is parallel to lithological contacts suggesting that it developed during tectonic imbrication (Occhipinti et al., 2004). In the pelitic to semi-pelitic rocks of the Quartpot Pelite, intensive migmatization produced alternating mm- to cm-scale mesocratic and leucocratic layers consisting of sillimanite–biotite and quartz–plagioclase–K-feldspar, respectively. The growth of abundant garnet over this composite S_{2g} foliation–layering suggests that garnet grew synchronously with, to slightly post, D_{2g} deformation (Occhipinti et al., 2004).

In the Errabiddy Shear Zone and Mooloo Zone M_{2g} was responsible for the melting of pelitic and semi-pelitic lithologies of the Camel Hills Metamorphics and Moogie Metamorphics, indicating that M_{2g} was of significantly higher grade than that in the Paradise Zone. However, due to wholesale retrogression of the M_{2g} metamorphic assemblages during the subsequent 1820–1770 Ma Capricorn Orogeny, it is difficult to precisely determine the peak conditions attained during D_{2g}. Irrespective, textural pseudomorphs and the fragmentary preservation of peak metamorphic porphyroblasts within pelitic and semi-pelitic diatexite lithologies suggests that both garnet and sillimanite porphyroblasts were abundant phases in these rocks as part of an equilibrium assemblage (Occhipinti and Sheppard, 2001; Johnson et al., 2010). In typical pelitic compositions garnet and sillimanite are stable over a wide range of pressures (5–9 kbar) and temperatures, although the presence of in situ melts within these lithologies suggests that temperatures exceeded the wet solidus (i.e. during partial melting at >650°C; e.g. Rigby, 2009). The lack of kyanite anywhere within the Gascoyne Province suggests that M_{2g} metamorphism may have proceeded at moderately steep geothermal gradients. In the southwestern part of the Errabiddy Shear Zone, the pelitic and semi-pelitic lithologies of the Quartpot Pelite lack any features indicative of melting and migmatization. They contain an assemblage of quartz–muscovite–biotite with minor garnet and plagioclase consistent with metamorphism only to mid amphibolite-facies (Sheppard and Occhipinti, 2000), suggesting that there was a decrease in the metamorphic grade of M_{2g} from northeast to southwest across the Errabiddy Shear Zone (Occhipiniti et al., 2004).

Geochronology

Glenburgh Orogeny D_{2g}	*Maximum*	*Minimum*
Age (Ma)	1966 ± 7	1947 ± 11
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Johnson et al., 2010	Johnson et al., 2010

During D_{2g}, the growth of new zircon (mainly as rims around older inherited zircon grains) and monazite was ubiquitous during high-grade metamorphism and migmatization of pelitic and semi-pelitic lithologies of the Camel Hills Metamorphics and Moogie Metamorphics. This period of metamorphic zircon and monazite growth occurred throughout the southern Gascoyne Province, from the Errabiddy Shear Zone to the Mooloo Zone. Nine samples yielded precise U–Pb ages constraining D_{2g} to between c. 1965 Ma and c. 1950 Ma (Johnson et al., 2010).

In detail, precise ages from metamorphic zircon were obtained from two samples of Quartpot Pelite (GSWA 142905 and 142910) at 1952 ± 14 Ma and 1959 ± 6 Ma, one of Petter Calc-silicate (GSWA 142908) at 1944 ± 5 Ma, and three samples of the Mumba Psammite from the Moogie Metamorphics (GSWA 184161, 164369, and NP20; Kinny et al., 2004) at 1952 ± 4 Ma, 1959 ± 6 Ma, and 1934 ± 43 Ma. Three precise ages were obtained from metamorphic or recrystallized monazite from three samples of the Mumba Psammite (GSWA 164369, 164713, and 164333) at 1958 ± 6 Ma, 1966 ± 7 Ma, and 1947 ± 11 Ma (importantly, the age of metamorphic monazite and zircon within sample GSWA 164369 are statistically identical). From these data, two potential age outliers are present: the date of Kinny et al. (2004) and that from the Petter Calc-silicate. The result of Kinny et al. (2004) of 1934 ± 43 Ma was acquired from three analyses of three metamorphic rims; the resulting age is imprecise but within uncertainty of those obtained by the GSWA of 1965–1950 Ma. The metamorphic age obtained from the Petter Calc-silicate (GSWA 142908) of 1944 ± 5 (1σ) Ma was acquired from a single analysis of a single metamorphic zircon rim, and the resulting age is slightly younger than that obtained from the other GSWA samples (but still within 2 sigma uncertainty). Without additional analyses from this sample it is also not possible to determine if this single analysis is an outlier in a slightly older age component. Therefore, the maximum and minimum ages for D_{2g} metamorphism and deformation are taken to be the ages obtained from GSWA samples 164713

(1966 ± 7 Ma) and 164333 (1947 ± 11 Ma) for which there are sufficient analyses to define the age components.

Tectonic setting

Metamorphism and deformation associated with the D_{2g} event is present throughout the entire Glenburgh Terrane and is the first event common to all zones including those exotic to the Glenburgh Terrane (i.e. the Errabiddy Shear zone), suggesting that juxtaposition and interleaving of units took place at this time. Throughout the region M_{2g} peaked in the upper amphibolite facies with the widespread and extensive production of anatectic melts in pelitic to semi-pelitic rocks of the Camel Hills Metamorphics and Moogie Metamorphics. Although no relict ophiolitic slices appear to have been preserved, the interleaving of lithologies with different provenance along the Errabiddy Shear Zone, the pervasive nature of subhorizontal D_{2g} deformation (i.e. thrusting) and moderate-pressure, moderate- to high-temperature metamorphism all suggest that D_{2g} deformation and accompanying metamorphism were the result of collision between the Pilbara Craton – Glenburgh Terrane and the Yilgarn Craton along the Errabiddy Shear Zone. Collision was accompanied by syntectonic granites of the Bertibubba Supersuite, which is also the first common magmatic component across the region having intruded from the Yilgarn Craton through to the Paradise Zone in the Glenburgh Terrane.

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Unnamed unit (AP_-mgn-YNAY)

Legend narrative

Granite gneiss; reworked during the Paleoproterozoic

Rank	Suite
Parent	Unnamed unit (AP_-mg-YNAY)
Tectonic units	CAPRICORN OROGEN, Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA

Age code	Archean–Proterozoic	AP_-
Rock type	meta-igneous felsic intrusive	mg
Lithname	granitic gneiss	n
Tectonic code	Narryer Terrane, Yarlarweelor Gneiss Complex	-YNAY
Rock code		**AP_-mgn-YNAY**

Summary

Reworked Archean granitic gneiss of the Narryer Terrane is the major component of the Yarlarweelor Gneiss Complex. The unit is a composite of Archean and Paleoproterozoic components, and Archean fabrics were extensively overprinted during the Paleoproterozoic. Archean granitic gneiss, and late Archean granite dykes, plugs, and veins were pervasively reworked during the Paleoproterozoic Capricorn Orogeny, and intruded by abundant sheets and veins of coarse-grained biotite granite and pegmatite between c. 1815 Ma and c. 1795 Ma. In low-strain zones the late Archean granites are locally preserved.

Distribution

Reworked granitic gneiss is confined to the Yarlarweelor Gneiss Complex. The unit outcrops widely on MARQUIS and ERRABIDDY, and along the northern edge of GOULD and MOORARIE, and the western edge of MILGUN. The reworked granitic gneiss forms low, rocky hills and is dissected by a close-spaced network of dendritic creeks. The gneisses are commonly weathered, but exposure is good.

Lithology

Reworked granitic gneiss consists of two mappable units: leucocratic granitic gneiss (AP_-mgnl-YNAY) and mesocratic granitic gneiss (AP_-mgnw-YNAY). Of these two units, leucocratic granitic gneiss is by far the most voluminous and widespread. Mesocratic granitic gneiss is the dominant type of gneiss only in the eastern part of MARQUIS, north of the Morris Fault.

Leucocratic granitic gneiss comprises medium-grained leucocratic gneiss with thin, discontinuous layers of biotite, and fine- to medium-grained, strongly banded leucocratic granitic gneiss. Lower strain domains of the gneiss indicate that the precursors were mainly medium- and coarse-grained monzogranite and granodiorite.

The bulk of the mesocratic granitic gneiss is composed of fine- to medium-grained, strongly banded, biotite-rich granitic gneiss with 10–20% layer-parallel veins of pegmatite and coarse-grained granite. The rocks consist of dark-grey, biotite-rich layers about 1–4 cm thick, alternating with paler, more quartzofeldspathic layers up to 2 cm thick. Lower strain domains indicate that the protolith of much of the gneiss was a tonalite or mafic granodiorite.

Contact relationships

Reworked granitic gneiss is tectonically interleaved with amphibolite, calc-silicate gneiss, metamorphosed iron-formation, and quartzite and quartz–diopside rock. The gneiss is extensively intruded by sheets of porphyritic to equigranular, medium- to very coarse-grained metagranite and pegmatite (P_-MO-mgmp), dykes of medium-grained, equigranular biotite monzogranite (P_-MO-gmeb), and by the Yamagee Granite and Discretion Granite.

Geochronology

AP_-mgn-YNAY	*Maximum*	*Minimum*
Age (Ma)	3298 ± 6	1813 ± 8
Age	Paleoarchean	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nutman et al., 1991	Nelson, 1998

Nutman et al. (1991) reported a SHRIMP U–Pb zircon age of 3298 ± 6 Ma for a sample of banded, equigranular leucocratic granitic gneiss from near Midnight Bore on MOORARIE. In conjunction with the remapping, Nelson (1998) dated a leucocratic granitic gneiss from a low-strain zone about 4 km south-southeast of Stevie Bore on MOORARIE. Most of the zircons define a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date 3292 ± 4 Ma, interpreted as the crystallization age of the monzogranite precursor (Nelson, 1998). A sample of mesocratic granitic gneiss about 2 km northeast of Jubilee Bore on MARQUIS contains components with ages ranging from early to late Archean (Nelson, 1998). Two concordant analyses indicating a mean date of 2637 ± 3 Ma provide an estimate of the age of the youngest component in the gneiss, and hence a minimum age for its formation. Sheets and veins of porphyritic to equigranular, medium- to very coarse-grained metagranite and pegmatite (P_-MO-mgmp) form an intimate part of the reworked granitic gneiss, and were intruded during deformation and metamorphism (Sheppard and Swager, 1999); a date of 1813 ± 8 Ma for one of these sheets provides a minimum age for the reworked granitic gneiss.

References

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Sheppard, S and Swager, CP 1999, Geology of the Marquis 1:100 000 sheet: Geological Survey of Western Australia, 1:100 000 Geological Series Explanatory Notes, 21p.

Unnamed unit (AP_-mgnl-YNAY)

Legend narrative

Leucocratic granitic gneiss; derived from 3300–2660 Ma biotite granite and granitic gneiss, intruded by sheets and veins of coarse-grained granite and pegmatite (P_-MO-mgp); all deformed and metamorphosed at c. 1810 Ma

Rank	Formation
Parent	Unnamed unit (AP_-mgn-YNAY)
Tectonic units	CAPRICORN OROGEN,Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Overlying units	AP_-mgnw-YNAY, A-mkq-YNA, A-mkqx-YNA, A-mtq-YNA, A-mi-YNA, A-mwa-YNA, A-mwax-YNA, A-moa-YNA, A-mat-YNA, A-max-YNA (faulted); P_-MO-mgmp, P_-MO-gmeb, P_-BBya-mgm, P_-BBya-mgmu, P_-DUdn-gmp, P_-DUdn-gme, P_-DUdn-gma (intrusive)

Summary

Reworked leucocratic granitic gneiss is confined to the Yarlarweelor Gneiss Complex. Reworked leucocratic granitic gneiss consists of several extensively and intimately interlayered rock types that have been repeatedly deformed and metamorphosed. The unit is a composite of Archean and Paleoproterozoic components, and the Archean fabrics were extensively overprinted during the Paleoproterozoic. In low-strain areas, Archean structures and late Archean granites are locally preserved.

Distribution

Reworked, leucocratic granitic gneiss outcrops over most of the southern half of MARQUIS, where it is the most widespread and abundant unit on the map sheet, and on the adjacent northern margin of MOORARIE and eastern ERRABIDDY. The gneiss forms an easterly trending belt that swings to trend northerly along the eastern edge of MARQUIS. The granitic gneiss is part of a belt of gneisses extending from the Mount Narryer region (Williams and Myers, 1987; Nutman et al., 1991, 1993) to about 200 km southwest of MARQUIS. The granitic gneisses on MARQUIS form a zone of low, rocky hills strongly dissected by a close-spaced network of dendritic creeks. The gneisses are commonly weathered, but exposure is good along the flanks of the hills.

Lithology

Reworked, leucocratic granitic gneiss is a composite of at least two different rock types, and also includes subordinate amounts of mesocratic granitic gneiss (AP_-mgnw-YNAY). The two main rock types are medium-grained leucocratic gneiss with thin, discontinuous layers of biotite, and fine- to medium-grained, strongly banded granitic gneiss. Lower strain domains of the gneiss indicate that the precursors were mainly medium- and coarse-grained monzogranite and granodiorite, with some tonalitic and syenogranitic components. The gneiss contains abundant thin pegmatite veins and bands. Much of the pegmatite is probably Paleoproterozoic in age. The rocks display a variety of textures reflecting different strain states and overprinting by lower grade metamorphic events. Most of the rocks consist of various proportions of plagioclase, microcline, quartz, biotite (up to 10%), and accessory allanite, zircon, apatite, and trace magnetite. In some samples amoeboid and polygonal granoblastic textures and antiperthitic plagioclase provide evidence of high-grade metamorphism. Samples from zones of very low strain may display recrystallized igneous textures. Abundant secondary epidote and sericite, recrystallization of quartz, and fine-grained granophyric textures indicate widespread overprinting by lower grade metamorphism.

Age code	Archean–Proterozoic	AP_-
Rock type	meta-igneous felsic intrusive	mg
Lithname	granitic gneiss	n
1st qualifier	–	
2nd qualifier	leucocratic	l
Tectonic code	Narryer Terrane, Yarlarweelor Gneiss Complex	-YNAY
Rock code		**AP_-mgnl-YNAY**
Additional lithologies	metamonzogranite	

Contact relationships

Reworked, leucocratic granitic gneiss is tectonically interleaved with mesocratic granitic gneiss (AP_-mgnw-YNAY). There are no sharp boundaries between the leucocratic and mesocratic granitic gneiss units, and they are interleaved on both a mesoscopic and megascopic scale. Mapped boundaries define areas of dominance of one gneiss type over the other. The leucocratic granitic gneiss is also tectonically interleaved with amphibolite, calc-silicate gneiss, metamorphosed iron-formation, and quartzite and quartz–diopside rock. The gneiss is extensively intruded by sheets of coarse-grained metagranite and metapegmatite (P_-MO-mgmp), dykes of medium-grained biotite granite (P_-MO-gmeb), and by the Yamagee Granite (P_-BBya-mgm, P_-BBya-mgmu), and Discretion Granite (P_-DUdn-gmp, P_-DUdn-gme, P_-DUdn-gma).

Geochronology

AP_-mgnl-YNAY	*Maximum*	*Minimum*
Age (Ma)	3298 ± 6	1813 ±8
Age	Paleoarchean	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nutman et al., 1991; Nelson, 1998	Nelson, 1998b

Nutman et al. (1991) reported a SHRIMP U–Pb zircon age of 3298 ± 6 Ma for a sample of banded, equigranular granitic gneiss from near Midnight Bore on MOORARIE, a few kilometres south of the southern edge of the MARQUIS sheet. In conjunction with this remapping, granitic gneiss from a low-strain zone just south of MARQUIS, about 4 km south-southeast of Stevie Bore (Zone 50, MGA 564987E 7177440N on MOORARIE), was sampled for SHRIMP U–Pb zircon geochronology. The sample (GSWA 142847) is a foliated and recrystallized monzogranite with lenticular aggregates of fine-grained biotite, and is characterized by an absence of pegmatitic layers or veins. The date of 3292 ± 4 Ma is interpreted as the time of crystallization of the granitic precursor to the gneiss (Nelson, 1998a). This sample is representative of a rock type that forms much of the leucocratic granitic gneiss unit, and confirms that early Archean crust of the Narryer Gneiss Complex (Myers, 1988) is abundant on MARQUIS, MOORARIE, and ERRABIDDY.

In addition to the sample of leucocratic gneiss, a folded granite dyke that intrudes the gneiss, was sampled at the same locality for SHRIMP U–Pb zircon geochronology (GSWA 142848). This sample is a fine-grained, equigranular, monzogranite that was deformed and recrystallized at low metamorphic grade. SHRIMP analysis yielded a date of 2656 ± 4 Ma, interpreted as the age of igneous crystallization of the monzogranite dyke (Nelson, 1999). A minimum age for the reworked leucocratic gneis is provided by sheets and veins of coarse-grained metagranite and metapegmatite (P_-MO-mgmp) dated at 1813 ± 8 Ma (Nelson, 1998b).

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Unnamed unit (AP_-mgnw-YNAY)

Legend narrative

Mesocratic granitic gneiss; derived from 3350–2640 Ma biotite granite and granitic gneiss, intruded by sheets and veins of coarse-grained granite and pegmatite (P_-MO-mgp); all deformed and metamorphosed at c. 1810 Ma

Rank	Formation
Parent	Unnamed unit (AP_-mgn-YNAY)
Tectonic units	CAPRICORN OROGEN, Narryer Terrane, Yilgarn Craton, WESTERN AUSTRALIA
Overlying units	AP_-mgnl-YNAY, A-mkq-YNA, A-mkqx-YNA, A-mtq-YNA, A-mi-YNA, A-mwa-YNA, A-mwax-YNA, A-moa-YNA, A-mat-YNA, A-max-YNA (faulted); P_-MO-mgmp, P_-MO-gmeb, P_-BBya-mgm, P_-BBya-mgmu, P_-DUdn-gmp, P_-DUdn-gme, P_-DUdn-gma (intrusive)

Summary

Reworked mesocratic granitic gneiss outcrops in the Yarlarweelor Gneiss Complex, and is a composite of Archean and Paleoproterozoic components. Reworked mesocratic granitic gneiss includes late Archean granites that were deformed and metamorphosed during the Capricorn Orogeny, and are now contained within the gneissic layering.

Distribution

Reworked mesocratic granitic gneiss is the dominant type of gneiss in the eastern part of Marquis, north of the Morris Fault. The gneiss also outcrops over a small area on eastern Errabiddy. Reworked mesocratic granitic gneiss contains minor to subordinate amounts of finely interleaved reworked leucocratic granitic gneiss (AP_-mgnl-YNAY). Like the reworked leucocratic granitic gneiss, the reworked mesocratic granitic gneiss is also a composite of Archean and Paleoproterozoic components, and Archean fabrics were largely overprinted during the Paleoproterozoic. The mesocratic gneiss forms low rounded hills and scattered outcrops amongst colluvium, but the rock is commonly quite fresh.

Lithology

The bulk of the reworked mesocratic granitic gneiss is composed of fine- to medium-grained, strongly banded, biotite-rich granitic gneiss with 10–20% layer-parallel veins of pegmatite and coarse-grained granite. The rocks consist of dark-grey, biotite-rich layers about 1–4 cm thick, alternating with paler, more quartzofeldspathic layers up to 2 cm thick. Despite the intensity of deformation, much of the gneiss has a granoblastic texture. Lower strain domains indicate that the protolith of much of the gneiss was a tonalite or mafic granodiorite. Samples of mesocratic gneiss consist of plagioclase, quartz, microcline, biotite (up to 15%), and accessory zircon, allanite, and apatite. In high-grade rocks, the plagioclase is oligoclase–andesine, green hornblende may be preserved, and amoeboid or polygonal granoblastic textures dominate. Recrystallized quartz, oligoclase, and widespread secondary epidote and sericite in many samples indicate a lower grade metamorphic overprint.

Age code	Archean–Proterozoic	AP_-
Rock type	meta-igneous felsic intrusive	mg
Lithname 1	granitic gneiss	n
1st qualifier	—	
2nd qualifier	mesocratic	w
Tectonic code	Narryer Terrane, Yarlarweelor Gneiss Complex	-YNAY
Rock code		**AP_-mgnw-YNAY**
Additional lithologies	metamonzogranite	

Contact relationships

Reworked, mesocratic granitic gneiss is tectonically interleaved with reworked leucocratic granitic gneiss (AP_-mgnl-YNAY). There are no sharp boundaries between the mesocratic and leucocratic granitic gneiss units, and they are interleaved on both a mesoscopic and megascopic scale. Mapped boundaries define areas of dominance of one gneiss type over the other. Reworked mesocratic granitic gneiss is also interleaved with amphibolite, calc-silicate gneiss, metamorphosed iron-formation, and quartzite and quartz–diopside rock. The gneiss is extensively intruded by sheets of medium- to very coarse-grained metagranite and pegmatite (P_-MO-mgmp), dykes of medium-grained biotite granite (P_-MO-gmeb), and by the Yamagee Granite (P_-BBya-mgm, P_-BBya-mgmu) and Discretion Granite (P_-DUdn-gmp, P_-DUdn-gme, P_-DUdn-gma).

Geochronology

AP_-mgnw-YNAY	*Maximum*	*Minimum*
Age (Ma)	3352 ± 3	1813 ±83
Age	Paleoarchean	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1998a	Nelson, 1998c

Strongly banded, grey, biotite-rich gneiss with numerous layer-parallel veins of coarse-grained granite and pegmatite about 2 km northeast of Jubilee Bore on Marquis was sampled for SHRIMP U–Pb zircon geochronology (GSWA 142853). Analysed zircons from the sample indicate the rock contains components with ages ranging from early to late Archean (Nelson, 1998a). Two concordant analyses with a mean ^{207}Pb*/^{206}Pb*ratio corresponding to a date of 2637 ± 3 Ma provide an estimate of the age of the youngest component in the gneiss, and hence a minimum age for its formation. The oldest component comprises two weakly discordant analyses with a weighted mean ^{207}Pb*/^{206}Pb*ratio corresponding to a date of 3352 ± 3 Ma (Nelson, 1998a). Most of the analyses from the sample do not define discrete groups and many of the zircons are rounded. These features led Nelson (1998a) to suggest a large sedimentary component to the gneiss. However, such an interpretation is not supported by the granodioritic to tonalitic compositions, and the absence of aluminous minerals in the gneisses.

The age of youngest component in the mesocratic gneiss is within uncertainty of igneous crystallization ages of some late Archean granitic rocks that intrude Archean mesocratic gneiss (A-mgn-YNA) to the west of Errabiddy Homestead. For example, a plug of mesocratic porphyritic biotite granite (A-gmp-YNA), that intrudes Archean mesocratic gneiss 6 km to the west-southwest of Beedarry Well, has been dated at 2630 ± 4 Ma (GSWA 142906; Nelson, 1998b). Therefore, reworked mesocratic granitic gneiss includes late Archean granites that were deformed and metamorphosed during the Capricorn Orogeny, and are now contained within the gneissic layering. A minimum age for the reworked leucocratic gneis is provided by sheets and veins of coarse-grained metagranite and metapegmatite (P_-MO-mgmp) dated at 1813 ± 8 Ma (Nelson, 1998b).

References

Nelson, DR 1998a, 142853: granite gneiss, Jubilee Well rockhole; Geochronology Record 369: Geological Survey of Western Australia, 4p.

Nelson, DR 1998b, 142906: coarse porphyritic monzogranite, Beedarry Bore; Geochronology Record 331: Geological Survey of Western Australia, 4p.

Nelson, DR 1998c, 142849: foliated coarse-grained monzogranite, northeast of White Well; Geochronology Record 365: Geological Survey of Western Australia, 4p.

Leake Spring Metamorphics
(P_-LS-xmd-mk)
formerly P_-MR-xmd-mk

Legend narrative

Pelitic and psammitic schist; calc-silicate rock; minor amphibolite

Rank	Group
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	Moorarie Supersuite, Durlacher Supersuite, Thirty Three Supersuite, Mundine Well Dolerite Suite (intrusive); Pooranoo Metamorphics, Mount Augustus Sandstone, Edmund Group (unconformable)
Underlying units	Halfway Gneiss, Moogie Metamorphics, Middle Spring Granite (unconformable)

Summary

The Leake Spring Metamorphics (previously the 'Morrissey Metamorphic Suite' and 'Morrissey Metamorphics', both invalid) is a package of siliciclastic metasedimentary rocks, with some intercalated calc-silicate rock and amphibolite, which outcrops across the northern two-thirds of the Gascoyne Province. The Leake Spring Metamorphics do not outcrop in the Mooloo and Paradise Zones at the southern end of the province. The metamorphic rocks are thought to pass, with decreasing metamorphic grade, into the Ashburton Formation to the north (Williams, 1986). The Leake Spring Metamorphics have a maximum depositional age of c. 1840 Ma, and were deposited before the 1820–1770 Ma Capricorn Orogeny and the associated Moorarie Supersuite.

Distribution

The Leake Spring Metamorphics outcrop throughout the Boora Boora Zone at the northern end of the Gascoyne Province, where they are thought to pass, with decreasing metamorphic grade, into the Ashburton Formation of the Wyloo Group (Williams, 1986), and in the Limejuice and Mutherbukin Zones. They are not recognized in the Mangaroon Zone owing to high-grade metamorphism and widespread deformation in that zone during the 1680–1620 Ma Mangaroon Orogeny. The Leake Spring Metamorphics have not been identified in the Mooloo and Paradise Zones at the southern end of the province, nor within the Errabiddy Shear Zone.

Many of the metasedimentary rocks previously assigned to the 'Morrissey Metamorphic Suite' belong to metasedimentary packages that either pre-date the 2005–1950 Ma Glenburgh Orogeny (Moogie Metamorphics or Camel Hills Metamorphics) or post-date the 1820–1770 Ma Capricorn Orogeny (Pooranoo Metamorphics).

Derivation of name

The Leake Spring Metamorphics are named after Leake Spring in the southwestern corner of Mount Augustus. This unit was previously known as the 'Morrissey Metamorphic Suite' and, subsequently, the 'Morrissey Metamorphics'. The name Morrissey Metamorphic Suite was introduced by Williams et al. (1979) for a series of "...Proterozoic shelf and trough sediments" in the Gascoyne 'Province', although a full definition was not given. Williams (1986) used the name to refer to a "…suite of metamorphosed and deformed sediments (and minor volcanics) which form a supracrustal sequence throughout the Gascoyne Province...it is intruded by early to middle Proterozoic granitoids, and is unconformably overlain by late-orogenic sediments of the Mount James Formation and Middle Proterozoic, post-orogenic sediments of the Bangemall Group". Rocks of the Morrissey Metamorphic Suite were previously considered to be part of the Wyloo Group (Daniels, 1975; Gee, 1979). The suite was named after Morrissey Hill in the central part of the Mount Phillips 1:250 000 sheet.

The Morrissey Metamorphic Suite was thought to correlate, and to have been contiguous, with lower grade rocks of the Ashburton Formation of the Wyloo Group to the north, and the Bryah and Yerrida Groups (formerly 'Glengarry Group') to the east-southeast (Daniels, 1975; Gee, 1979; Williams, 1986). These sedimentary packages were interpreted to have been deposited in a 'geosynclinal' trough bounded by shelves along the edge of the Pilbara and Yilgarn cratons. Implicit in the use of the term Morrissey Metamorphic Suite, was the assumption that there was only one main tectonic event that overprinted the rocks — the Capricorn Orogeny; in other words, all medium- to high-grade metasedimentary rocks in the Gascoyne Complex were metamorphosed during the Capricorn Orogeny and, therefore, must belong to the Morrissey Metamorphic Suite.

The Morrissey Metamorphic Suite was renamed as the Morrissey Metamorphics by Martin et al. (2006) and Sheppard et al. (2007) and used in a more restricted sense to refer to siliciclastic sedimentary rocks, and minor mafic volcanic or high-level intrusive rocks, that were deposited across the northern two-thirds of the Gascoyne Province after c. 1840 Ma, and which were first deformed and metamorphosed during the 1820 to 1770 Ma Capricorn Orogeny and intruded by voluminous granites of the Moorarie Supersuite. The term 'Suite' was dropped because it is used for intrusive igneous rocks with a close association in time, space, and origin.

Lithology

The bulk of the Leake Spring Metamorphics comprises interlayered psammitic and pelitic schist, pelitic schist, subordinate amounts of psammitic schist and amphibolite, and minor calc-silicate rock, chert, ultramafic schist, and metamorphosed banded iron-formation. Pelitic and psammitic gneiss are rare. Interlayered psammitic and pelitic schist is particularly abundant in the Limejuice

Zone where, in lower strain-zones, graded bedding and quartzofeldspathic compositions suggest that the rocks may have originally been turbidites (e.g. around Leake Spring in the southwestern corner of Mount Augustus). Pelitic schists with assemblages comprising muscovite–biotite–quartz–plagioclase–garnet–iron oxide, staurolite–muscovite–biotite–quartz(–garnet), muscovite–biotite–quartz–plagioclase–magnetite, quartz–muscovite–biotite–plagioclase, and staurolite–garnet–biotite–muscovite(–andalusite) outcrop throughout the Limejuice Zone, and in the Mutherbukin Zone and the eastern end of the Boora Boora Zone.

Amphibolite lenses and thin layers, up to a few metres wide are a widespread but volumetrically minor component of the Morrissey Metamorphics. However, in the northwestern part and along the western edge of Pink Hills, amphibolites are abundant. The margins of most of the amphibolites are either not exposed or are strongly sheared, but on Pink Hills amphibolites locally preserve textures implying a volcanic or volcaniclastic origin (see P_-LS-mwa). Calc-silicate rock and ultramafic schist (actinolite schist and actinolite–chlorite–sericite schist) are widespread, but very minor, rock types; whereas chert and metamorphosed banded iron-formation have very restricted distributions.

Age code	Proterozoic	P_-
Stratigraphic code	Leake Spring Metamorphics	LS-
Mixed or xenolith-bearing	Mixed	x
Rock type 1	metasedimentary siliciclastic	
Lithname 1	metasiliciclastic rock; undivided	md
Rock type 2	metasedimentary carbonate	
Lithname 2	metacarbonate	-mk
Rock code		**P_-LS-xmd-mk**
Additional lithologies	amphibolite, ultramafic schist (volcanic or undivided), metamorphosed banded iron-formation, metachert	

Contact relationships

The Leake Spring Metamorphics are extensively intruded by numerous granites of the 1820–1775 Ma Moorarie Supersuite, particularly in the Limejuice and Boora Boora Zones. Additionally, in the Mutherbukin Zone, and to a lesser extent in the Boora Boora and Limejuice Zones, the Leake Spring Metamorphics are intruded by granites of the 1680–1620 Ma Durlacher Supersuite. In the Nardoo Hills area along the northern edge of Yinnetharra, the Leak Spring Metamorphics are intruded by c. 910 Ma granite of the Thirty Three Supersuite.

The Leake Spring Metamorphics are inferred to unconformably overlie the Middle Spring Granite on eastern Pink Hills and western Candolle. The original relationship between the Leake Spring Metamorphics and the Moogie Metamorphics and Halfway Gneiss is unclear, as the latter two units largely outcrop only in the Mooloo and Paradise Zones, where the Leake Spring Metamorphics are absent. The Leake Spring Metamorphics is faulted against the Moogie Metamorphics and Halfway Gneiss on western Pink Hills and adjacent eastern Candolle. At the northern end of the Clever Mary Hills on southeastern Pink Hills, psammitic and pelitic schist of the Leake Spring Metamorphics is inferred to unconformably overly Moogie Metamorphics and Halfway Gneiss, but the contact is not exposed.

The Leake Spring Metamorphics are unconformably overlain by the Pooranoo Metamorphics and by the Edmund Group. The relationship between the Leake Spring Metamorphics and Pooranoo Metamorphics is not well exposed. A probable, low-angle unconformity between the two is present near Reid Well on northeastern Yinnetharra (Locality B15, MGA Zone 50 430812E 7287905N; Martin et al., 2006). The relationship is best demonstrated in the Limejuice Zone where the Morrissey Metamorphics are everywhere intruded by the Moorarie Supersuite, which is in turn unconformably overlain by several scattered outliers of the Pooranoo Metamorphics. The Leake Spring Metamorphics is unconformably overlain by the base of the Edmund Group over a wide area in both the Boora Boora and Limejuice Zones on, respectively, Maroonah and Candolle. For example, an angular unconformity between crenulated schist of the Leake Spring Metamorphics and overlying pebbly sandstone of the Edmund Group is exposed about 250 m northwest of Peak Bore on Candolle (site SXSCDL008288).

Geochronology

P_-LS-xmd-mk	*Maximum*	*Minimum*
Age (Ma)	1842 ± 5	1807 ± 3
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Wingate et al., in prep.	Wingate et al., 2009b

The maximum depositional age of the Leake Spring Metamorphics is constrained by results for two detrital zircon samples, whereas the minimum depositional age is provided by numerous granite intrusions of the Minnie Creek batholith and by a preliminary monazite age from pelitic schist along the northern edge of the Minnie Creek batholith. A sample (GSWA 180935) of interlayered pelitic and psammitic schist of the Leake Spring Metamorphics from Leake Spring on southwestern Mount Augustus yielded a maximum depositional age of 1961 ± 7 Ma (Kirkland et al., 2009). However, the best estimate of the maximum depositional age is provided from a foliated metasandstone south of Nardoo Well on southern Mount Phillips where 36 concordant detrital zircon grains provide an age of 1842 ± 5 Ma (Wingate et al., 2009a). The oldest intrusion into the Leake Spring Metamorphics is a foliated metatonalite from the Minnie Creek batholith, which has an igneous crystallization age of 1807 ± 3 Ma (Wingate et al., 2009b), thus providing the minimum constraint for deposition of the package.

References

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Leake Spring Metamorphics; subunit (P_-LS-mhs) formerly P_-MR-mhs

Legend narrative

Pelitic and psammitic schist; quartz–biotite–muscovite–feldspar schist, quartz–sericite–biotite schist, quartz–sericite–chlorite schist; minor metasandstone and granule metaconglomerate

Rank	Formation
Parent	Leake Spring Metamorphics (P_-LS-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-LS-mlsm, P_-LS-xmh-mwa (conformable and faulted); P_-MOru-mgm, P_-MO-mgml, P_-MO-gmp, P_-MO-gte, P_-MO-gmeb, P_-MO-gma, P_-MO-gmaf, P_-MO-mgg, P_-MO-mgn, P_-MO-mgnl, P_-MO-xmg-m, P_-MOmi-mgmn, P_-MOmi-mgmy (faulted), P_-DUda-mgmu, P_-DU-gmv, P_-DU-gmvt, P_-DU-mgm, P_-DU-mgmb, P_-DU-mgmt (intrusive); P_-_au-sp, P_-MEi-kd, P_-MEi-sl, P_-MEk-sl, P_-MEy-st (unconformable)
Underlying units	AP_-_ha-mgnl, AP_-_ha-mgnw, P_-MGm-mtq (faulted)

Summary

Interlayered pelitic and psammitic schist is one of the most voluminous and widespread units of the Leake Spring Metamorphics. The unit mainly outcrops in the Limejuice Zone, but interlayered pelitic and psammitic gneiss is also present in the Mutherbukin Zone to the south, and low-grade interlayered pelite and psammite outcrops in the Boora Boora Zone in the north of the Gascoyne Province. In areas of low strain, the rocks are feldspathic and characterized by grading from coarse-grained sandstone at the base of beds to siltstone at the top. Most of the rocks are schistose, but an earlier gneissic fabric is preserved in places, particularly in the belts along the southern margin of the Minnie Creek batholith on Pink Hills and Candolle. Interlayered pelitic and psammitic schist has a maximum depositional age of c. 1840, and is intruded by a wide range of granites of the 1820–1775 Ma Moorarie Supersuite.

Distribution

Interlayered pelitic and psammitic schist outcrops as a belt along the axis of the Minnie Creek batholith (where its distribution appears to be controlled by a major east-southeast trending shear zone), and along the southern and northern margins of the Minnie Creek batholith. The unit also forms numerous rafts and inclusions within granites of the batholith. The largest outcrop of interlayered pelitic and psammitic schist is on Pink Hills and Candolle, where it forms an easterly trending belt more than 50 km long and up to 7 km wide along the southern margin of the Minnie Creek batholith. Interlayered pelitic and psammitic schist is a widespread, if not voluminous, unit on eastern Mount Phillips and the adjacent western edge of Mount Augustus. Interlayered pelitic and psammitic schist assigned to the Leake Spring Metamorphics, outcrops as a series of large rafts and screens within granitic rocks north of Mount James on Yinnetharra. In the Boora Boora Zone, interlayered pelite and psammite at low to medium metamorphic grade, comprises a series of large rafts and screens (the largest of which is more than 12 km^2) in the area between the Laura and Telfer South prospects on Maroonah.

Most exposures of the interlayered pelitic and psammitic schist are weathered or deeply weathered, and the unit typically forms low hills or strike ridges with closely spaced drainage. These metasedimentary rocks are typically strongly weathered and ferruginous close to the unconformity with the overlying Edmund Group. In the area north of the Clever Mary Hills on Pink Hills, the pelitic and psammitic schist forms isolated, very deeply weathered (commonly saprolitic) exposures.

Lithology

In the belts along the northern edge and the axis of the Minnie Creek batholith, interlayered pelitic and psammitic schist of the Leake Spring Metamorphics mainly comprises medium-grained quartz–muscovite schist (psammite) and fine- to medium-grained quartz–biotite–chlorite schist or quartz–feldspar–mica schist (pelite). Lower strain domains show the psammites to be metamorphosed medium- to coarse-grained sandstone. Along the southern margin of the batholith, interlayered pelitic and psammitic schist of the Leake Spring Metamorphics comprises medium-grained quartz–muscovite–biotite schist and fine- to medium-grained quartz–chlorite–muscovite schist after medium- to coarse-grained sandstone and fine-grained sandstone, and dark green quartz–chlorite–muscovite–magnetite pelitic schist, respectively. Lenses or layers of quartzite up to 2 m thick are present in places, particularly on northwestern Pink Hills.

In places, evidence of metamorphism at higher grade is preserved; for instance, some of the psammites and semi-pelites in the southeastern corner of Mount Phillips contain dismembered leucosomes. In the area immediately north of Boss Bore on southwestern Mount Augustus, chlorite-rich pelitic schist commonly contains pseudomorphs of muscovite or sericite after ?andalusite porphyroblasts. Locally, domains of medium-grained granoblastic quartz–plagioclase–muscovite–biotite gneiss are preserved within low-grade quartz–sericite–muscovite–sodic-plagioclase–chlorite–iron-oxide schist. At the Pink Hills immediately north of Burringurah on eastern Pink Hills and northwest of Recovery Bore on western Candolle, pelitic and psammitic rocks with a gneissic or granofelsic texture are preserved. Despite this, the original assemblages inferred to comprise andalusite–cordierite–quartz–plagioclase–biotite–muscovite(–tourmaline), have now been retrogressed to sericite–quartz–muscovite–chlorite–biotite–andalusite schists.

East of Lucky Bore on the eastern edge of Yinnetharra, pelitic and psammitic schist assigned to the Leake Spring Metamorphics includes coarse-grained biotite-rich pelitic gneiss and fine- to medium-grained semi-pelitic or psammitic gneiss as layers less than a few tens of metres thick within gneissic granites of the Moorarie Supersuite. A sample of semi-pelitic gneiss from this area comprises fine-grained quartz–biotite–andalusite–plagioclase–cordierite(–rutile) gneiss. The bulk of the rock is composed of quartz and chocolate-brown biotite, but minor development of myrmekitic textures suggests presence of some plagioclase. Andalusite forms xenoblastic sieved porphyroblasts around 1mm in diameter commonly with bundles of fine secondary chlorite (after fibrolite) with or without sericite along the margins. Cordierite is rare and marked by minor pinite alteration along fractures.

Interlayered pelitic and psammitic rocks also outcrop in the Boora Boora Zone. In the area about 6 km east of Middle Bore, these rocks consist of interbedded metamorphosed siltstone and feldspathic pebbly sandstone. The rocks have been metamorphosed at low grade and graded bedding is preserved. Sandstone beds are 0.3 – 1.0 m thick and contain clasts of quartz and lesser feldspar up to 1 cm in diameter, but mostly 2–6 mm. Some feldspar clasts are tabular suggesting the sediment may have been locally derived. To the northwest, the rocks increase in grade through phyllite and fine-grained schist to muscovite–quartz–biotite–andalusite–garnet schist. The schists contain idioblastic or subidioblastic porphyroblasts of andalusite up to 2.5 cm in diameter, which have been pseudomorphed by sericite. The porphyroblasts may contain an S_1 fabric, and are wrapped or flattened by an S_2 crenulation schistosity.

Age code	Proterozoic	P_-
Stratigraphic code	Leake Spring Metamorphics	LS-
Rock type	metasedimentary siliciclastic: psammite and pelite; interlayered	mh
Lithname	psammitic and pelitic schist; interlayered	s
Rock code		**P_-LS-mhs**
Additional lithologies	psephitic schist	

Contact relationships

Basement to the pelitic and psammitic schist has not been identified. Pelitic and psammitic schist is intruded by, or forms rafts and inclusions within, numerous granites of the Moorarie Supersuite including the Rubberoid Granite (P_-MOru-mgm); leucocratic, weakly foliated, equigranular muscovite(–biotite) monzogranite (P_-MO-mgml); medium- and coarse-grained porphyritic biotite monzogranite (P_-MO-gmp); equigranular to sparsely porphyritic, biotite tonalite and granodiorite (P_-MO-gte); equigranular biotite monzogranite (P_-MO-gmeb); and pink, fine-grained equigranular to seriate biotite monzogranite (P_-MO-gmaf). On northern Mount Phillips, pelitic and psammitic schist is also intruded by medium-grained, muscovite–biotite granodiorite and monzogranite (P_-DU-gmv) of the Durlacher Supersuite. Pelitic and psammitic schist is in faulted contact with the Middle Sping Granite on eastern Pink Hills and Candolle. The contacts are parallel to a gneissic layering (S_1) in both units.

Northwest of 12 Mile Well in the centre of Mount Phillips, there appears to be a contact (folded low-angle ?unconformity) between interlayered pelitic and psammitic schist of the Leake Spring Metamorphics to the southeast and Pooranoo Metamorphics to the northwest. The precise location of the contact is not known, but at least as far northwest as site LXBMP638 (Zone 50, MGA 431024E 7312654N) — about 3 km west-northwest of 12 Mile Well — rafts of quartz–biotite schist are present within granite of the Minnie Creek batholith, indicating that these rocks belong to the Leake Spring Metamorphics and not the Pooranoo Metamorphics. In contrast to the pelitic and psammitic schist of the Leake Spring Metamorphics, the Pooranoo Metamorphics are characterized by phyllite and very low-grade metasandstone with abundantly preserved cross-bedding. On the western edge of Mount Augustus, pelitic and psammitic schist of the Leake Spring Metamorphics is unconformably overlain by the Mount Augustus Sandstone.

Basement to the pelitic and psammitic schist has not been identified, perhaps with the exception of the Middle Spring Granite on eastern Pink Hills and western Candolle. The contact between the Middle Spring Granite and interlayered pelitic and psammitic schist is parallel to gneissic layering (S_{1n}) in both rock units. There are neither veins nor dykes of the Middle Spring Granite in the pelitic and psammitic schist, nor inclusions of the latter in the Middle Spring Granite. These relationships suggest that the Middle Spring Granite may form basement to the Leake Spring Metamorphics, including the interlayered pelitic and psammitic schist.

Geochronology

P_-LS-mhs	*Maximum*	*Minimum*
Age (Ma)	1842	1807
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., 2009a	Kirkland et al., 2009a

A sample (Kirkland et al., 2009b) of interlayered pelitic and psammitic schist of the Leake Spring Metamorphics from Leake Spring on southwestern Mount Augustus yielded a maximum depositional age of 1961 ± 7 Ma for the precursor sandstone. However, the best estimate of the maximum depositional age for the Leake Spring Metamorphics — and the interlayered pelitic and psammitic schist — is from a foliated metasandstone within staurolite–garnet–biotite–muscovite(–andalusite) schist (P_-LS-mlst) south of Nardoo Well on southern Mount Phillips. This sample yielded a weighted mean date of 1842 ± 5 Ma (Wingate et al., in prep.). A minimum age for the interlayered pelitic and psammitic schist is provided by the ages of granites that intrude the schist in the Limejuice Zone including; medium-grained, equigranular biotite monzogranite (P_-MO-gmeb) at 1782 ± 5 Ma; medium- and coarse-grained porphyritic biotite monzogranite (P_-MO-gmp) at 1795 ± 8 Ma; equigranular to sparsely porphyritic, biotite tonalite and granodiorite (P_-MO-gte) at 1787 ± 5 Ma. In the Boora Boora Zone, pelitic and psammitic schist is intruded by foliated and gneissic granites, one of which near Mundong Well (GSWA 169088) is dated at 1806 ± 7 Ma (Nelson, 2004). However, the oldest phase of the Minnie

Creek batholith, which extensively intrudes the Leake Spring Metamorphics, is a foliated tonalite with an igneous crystallization age of 1807 ± 3 Ma (Kirkland et al., 2009a), which is taken to be the minimum age for deposition of this unit.

References

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009a, 183205: schistose metatonalite, Mallet Well; Geochronology Record 753: Geological Survey of Western Australia, 4p.

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Nelson, DR 2004, 169088: foliated biotite monzogranite, Mundong Well; Geochronology dataset 45; in Compilation of geochronology data, June 2006 update: Geological Survey of Western Australia

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Leake Spring Metamorphics; subunit (P_-LS-mlsg) formerly P_-MR-mlsg

Legend narrative

Pelitic schist and gneiss; muscovite–biotite–quartz–plagioclase–garnet–iron-oxide and staurolite–muscovite–biotite–quartz(–garnet) rock

Rank	Formation
Parent	Leake Spring Metamorphics (P_-LS-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-mgts, P_-MO-gte, P_-MO-gmeb, P_-MOru-mgm, P_-MO-mgg, P_-DUpi-gmg (intrusive); P_-DUda-mgmu, P_-DU-mgm (faulted); P_-MEi-kd (unconformable)
Underlying units	AP_-_ha-mgn, AP_-_ha-mgnl (faulted)

Summary

Garnet- or staurolite-bearing pelitic schist and gneiss of the Leake Spring Metamorphics form widely scattered outcrops along the southern margin of the Minnie Creek batholith. Most units form strips either tectonically interleaved with, or as inclusions within, younger (meta) granites of the Moorarie and Durlacher Supersuites. Pelitic schist and gneiss also includes minor interlayered garnetiferous quartzite and psammitic schist. Garnet and/or staurolite porphyroblasts are commonly up to 1–2 cm diameter and commonly contain inclusion trails that preserve evidence of deformation fabrics that are older than that preserved on the outcrop scale. Garnet- or staurolite-bearing pelitic schist and gneiss have a maximum depositional age of c. 1840, and are intruded by a wide range of granites of the 1820–1775 Ma Moorarie Supersuite.

Distribution

Garnet- or staurolite-bearing pelitic schist and gneiss of the Leake Spring Metamorphics form widely scattered outcrops along the southern margin of the Minnie Creek batholith in the central part of EUDAMULLAH. Much of the unit on western EUDAMULLAH is covered by regolith, where the schist and gneiss probably forms an easterly trending belt nearly 20 km long and up to about 5 km wide. Strips, up to 5 km long, of garnet-bearing pelitic schist outcrop between Howler Well and Midway Bore in the northwestern corner of PINK HILLS. A fault-bounded wedge of fine-grained schist or phyllite with small garnet porphyroblasts in the Ti Tree Syncline on the boundary between YINNETHARRA and PINK HILLS is also assigned to this unit. On the western part of YINNETHARRA around Mulka Well, there are two fault slices of garnet-bearing pelitic schist.

Lithology

Garnet- or staurolite-bearing pelitic schist and gneiss are typically strongly weathered, particularly in the western part of EUDAMULLAH where there are extensive outliers of relict and residual units. The most common rock type is a muscovite–biotite–quartz–plagioclase–garnet–iron-oxide schist, with lesser amounts of staurolite–muscovite–biotite–quartz(–garnet) schist. In the centre of EUDAMULLAH northwest of Granite Well, the rocks are gneisses and locally contain sillimanite (fibrolite). Pelitic schist and gneiss also includes minor interlayered garnetiferous quartzite and psammitic schist. On northwestern PINK HILLS, the schists contain scattered porphyroblasts of garnet up to about 1 cm in diameter, which are wrapped by an S_2 upright schistosity. Garnet-bearing schist in the Chalba Shear Zone on western YINNETHARRA locally preserves an early S_1 gneissic layering, with folded or boudinaged leucosomes.

Wine-red garnet porphyroblasts are 3–10 mm in diameter and in places may be pseudomorphed by biotite. At site SXSEUD6616 (Zone 50, MGA 372012E 7313904N) garnet porphyroblasts contain inclusions of fibrolite. Staurolite–muscovite–biotite–quartz(–garnet) schists are particularly abundant on the western part of EUDAMULLAH. Here staurolite porphyroblasts are up to 2 cm long, although in some layers they are up to 6cm long. West-northwest of Tommie Well on eastern EUDAMULLAH, staurolite porphyroblasts contain curved and folded inclusion trails of quartz and rutile. These inclusion trails are oblique or perpendicular to the schistosity in the matrix. Around Mulka Well on YINNETHARRA the schists comprise muscovite, biotite, garnet, quartz, and tourmaline. The rocks contain felted masses of muscovite (after ?sillimanite) and biotite with a weak preferred orientation, and subidioblastic porphyroblasts of garnet and tourmaline.

Age code	Proterozoic	P_-
Stratigraphic code	Leake Spring Metamorphics	LS-
Rock type	metasedimentary siliciclastic: pelite	ml
Lithname	pelitic schist	s
1st qualifier	–	
2nd qualifier	garnet	g
Rock code		**P_-LS-mlsg**
Additional lithologies	quartzite	

Contact relationships

Garnet- or staurolite-bearing pelitic schist and gneiss is inferred to be conformable with other metasedimentary units of the Leake Spring Metamorphics. The schist and gneiss is intruded by several phases of the 1820–1775 Ma Moorarie Supersuite along the southern edge of the Minnie Creek batholith, and southeast of Howler Well on northwestern PINK HILLS, garnet schist is intruded by megacrystic metamonzogranite of the c. 1675 Ma Pimbyana Granite. South of Murrumburra Pool on the western edge of PINK HILLS, garnet schist and phyllite is unconformably overlain by the Irregully Formation of the Edmund Group.

The nature of the basement on which protoliths to the schist and gneiss were deposited is unknown. Garnet-bearing schist and gneiss is faulted against the Archean–Paleoproterozoic Halfway Gneiss in the Ti Tree Syncline on the boundary between YINNETHARRA and PINK HILLS, and within the Chalba Shear Zone on the western edge of YINNETHARRA. In the latter area the schists are also faulted against granites of the 1680–1620 Ma Durlacher Supersuite (Davey Well Granite (P_-DUda-mgmu) and P_-DU-mgm).

Geochronology

P_-LS-mlsg	*Maximum*	*Minimum*
Age (Ma)	1842	1807 ± 3
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Isotopic
References	Wingate et al., in prep.	Kirkland et al., 2009

The garnet- or staurolite-bearing pelitic schist and gneiss has not been directly dated but it is inferred to be conformable with other metasedimentary units of the Leake Spring Metamorphics. The best estimate of the maximum depositional age for the Leake Spring Metamorphics — and the interlayered pelitic and psammitic schist — is 1842 ± 5 Ma, for a foliated metasandstone layer within staurolite–garnet–biotite–muscovite(–andalusite) schist (P_-LS-mlst) south of Nardoo Well on southern Mount Phillips (Wingate et al., in prep.).

Garnet- or staurolite-bearing pelitic schist and gneiss of the Leake Spring Metamorphics is intruded by several phases of the 1820–1775 Ma Moorarie Supersuite, the oldest of which is a sparsely porphyritic biotite tonalite (P_-MO-gte) dated at 1807 ± 3 Ma (GSWA 183205; Kirkland et al., 2009).

References

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009, 183205: schistose metatonalite, Mallet Well; Geochronology Record 753: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, Johnson, SP and Sheppard, S in prep., 190668; metasandstone, Nardoo Well: Geological Survey of Western Australia.

Leake Spring Metamorphics; subunit (P_-LS-mlsm) formerly P_-MR-mlsm

Legend narrative

Pelitic schist; muscovite–quartz–biotite–plagioclase–magnetite and quartz–muscovite–biotite–plagioclase schist

Rank	Formation
Parent	Leake Spring Metamorphics (P_-LS-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gte, P_-MO-gmeb, P_-MO-gmp, P_-MO-gge, P_-MO-mgg, P_-MO-mgms, P_-MO-mgmz, P_-MOru-mgm, P_-MO-xmg-m, P_-DU-gmvt, P_-DU-gmlt, P_-DU-gmp (intrusive); P_-MOmi-mgmn, P_-MOmi-mgmy (faulted); P_-MEy-st (unconformable)

Summary

Muscovite-rich pelitic schist is a widespread component of the Leake Spring Metamorphics, mainly forming discontinuous belts along the northern and southern edges of the Limejuice Zone. The schist also outcrops in the Boora Boora Zone at the northern end of the province. The schists mainly consist of varying proportions of muscovite (or sericite), quartz, biotite, plagioclase, chlorite, and magnetite. Relict sillimanite (or bundles of sericite after what is inferred to have been sillimanite), garnet, or staurolite are preserved in places, as is an early gneissic layering. These features, and the presence of interleaved amphibolite, indicate that the schists are the product of retrogression of pelitic or semi-pelitic gneisses. Although muscovite-rich pelitic schist has not been directly dated it is interpreted to have the same age range as the other units within the Leake Spring Metamorphics (1840–1810 Ma).

Distribution

Muscovite-rich pelitic schist of the Leake Spring Metamorphics outcrops in two main belts, along the northern and southern edges of the Minnie Creek batholith on EUDAMULLAH and MOUNT PHILLIPS. The southeast trending belt along the northern edge of the batholith bifurcates around East Minnie Well on northeastern EUDAMULLAH. This belt continues farther northwest onto MANGAROON, where it is entirely concealed beneath surficial deposits. Along the southern margin of the batholith, discontinuous screens and rafts of pelitic schist are present on eastern EUDAMULLAH, southeastern MOUNT PHILLIPS, and adjacent northeastern YINNETHARRA. Farther to the southeast on eastern PINK HILLS and western CANDOLLE muscovite-rich pelitic schist forms partly dismembered belts along the southern margin of the Minnie Creek batholith. Muscovite-rich pelitic schist also outcrops in an east-southeasterly trending belt about 12 km wide along the southern edge of the Boora Boora Zone on MAROONAH. The rocks form large rafts and screens within foliated and gneissic granodiorite and tonalite (P_-MO-mgg).

Lithology

The muscovite-rich pelitic schist unit comprises muscovite–biotite–quartz–plagioclase–magnetite schist and quartz–muscovite–biotite–plagioclase schist. Layers of psammitic schist or quartzite are commonly found within the schist. Lower strain zones show an early centimetre-scale compositional layering in the pelitic schist. Most of the schists are deeply weathered.

In the area between Newell Well and 26 Mile Well on northeastern EUDAMULLAH the schists locally contain small porphyroblasts of garnet (or weathered ?garnet) up to 3 mm in diameter that are enclosed by the foliation. In places the schists contain folded leucosomes. In the northern belt of schists between Limejuice Well on northern MOUNT PHILLIPS and Stone Tank Well on northern EUDAMULLAH, the rocks may contain boudins of quartz–tourmaline veins and pods and lenses of tourmaline-rich rock. At site SXSEUD6825 (Zone 50, MGA 381341E 7334070N), mica schist contains sericite pseudomorphs after small ?andalusite porphyroblasts.

In the fold north of Middle Spring on PINK HILLS muscovite–chlorite–quartz–magnetite schist locally preserves evidence of an earlier gneissic layering, in part defined by thin parallel quartz veins, that is largely overprinted by the intense upright schistosity. Rarely, porphyroblasts of staurolite or garnet are preserved. At site SXSPKH008159 about 2 km north-northeast of No. 2 Bore near the eastern edge of PINK HILLS (Zone 50, MGA 493358E 7258896N) a small exposure consisting of partly retrogressed migmatitic pelitic gneiss is preserved. About 3.5 km east-southeast of this locality (Site SXSPKH008159), retrogressed pelitic gneiss is exposed with bundles of sericite possibly after sillimanite. Thin layers of amphibolite are common within the schists, further attesting to the presence of an earlier higher grade metamorphic event.

In the Boora Boora Zone most of the schists comprise varying proportions of muscovite, quartz, sericite, biotite, and chlorite. Muscovite porphyroblasts up to 1 cm in diameter are common at many localities. In places the rocks contain limonitized ?magnetite porphyroblasts 2–3 mm in diameter. Some exposures preserve evidence of an early gneissic layering or pegmatite banding folded about the dominant upright schistosity, indicating that the present assemblages reflect retrogression of higher grade rocks. Near the western edge of MAROONAH, the rocks include muscovite–quartz–biotite–plagioclase(–sillimanite) schist.

Age code	Proterozoic	P_-
Stratigraphic code	Leake Spring Metamorphics	LS-
Rock type	metasedimentary siliciclastic: pelite	ml
Lithname	pelitic schist	s
1st qualifier	–	
2nd qualifier	muscovite	m
Rock code		**P_-LS-mlsm**
Additional lithologies	psammitic schist	

Contact relationships

Muscovite-rich pelitic schist is intruded by a large number of granites of the Minnie Creek batholith (P_-MO-gte, P_-MO-gmeb, P_-MO-gmp, P_-MO-gge, P_-MO-mgg, P_-MO-mgms, P_-MO-mgmz, P_-MOru-mgm, P_-MO-xmg-m), all of which are part of the 1820–1775 Ma Moorarie Supersuite. The pelitic schist is also intruded by several different phases of the 1680–1620 Ma Durlacher Supersuite (P_-DU-gmvt, P_-DU-gmlt, P_-DU-gmp) and associated tourmaline pegmatite dykes and veins. Muscovite-rich pelitic schist is unconformably overlain by the Yilgatherra Formation at the base of the Edmund Group southwest of Peak Bore and around K4 Well on CANDOLLE. The muscovite-rich pelitic schist is inferred to be conformable with other metasedimentary units of the Leake Spring Metamorphics. The nature of the basement on which protoliths to the schist were deposited is unclear.

Geochronology

P_-LS-mlsm	*Maximum*	*Minimum*
Age (Ma)	1842	1807
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., in prep.	Kirkland et al., 2009

Muscovite-rich pelitic schist has not been directly dated but it is inferred to be conformable with other metasedimentary units of the Leake Spring Metamorphics. The best estimate of the maximum depositional age for the Leake Spring Metamorphics — and the interlayered pelitic and psammitic schist — is 1842 ± 5 Ma, for the youngest detrital zircon within a foliated metasandstone layer within staurolite–garnet–biotite–muscovite(–andalusite) schist (P_-LS-mlst) south of Nardoo Well on southern Mount Phillips (Wingate et al., in prep.).

Muscovite-rich pelitic schist is intruded by numerous phases of the 1820–1775 Ma Moorarie Supersuite in the Minnie Creek batholith. Several samples have been dated from granite units that directly intrude the pelitic schist. The oldest dated sample (GSWA 88412; Bodorkos et al., 2006), which has a SHRIMP U–Pb zircon age of 1801 ± 5 Ma, was taken from leucocratic, sparsely porphyritic biotite metamonzogranite (P_-MO-mgmz) west of Bently Well on northeastern EUDAMULLAH. However, the oldest phase of the Minnie Creek batholith, which extensively intrudes the Leake Spring Metamorphics, is a foliated tonalite with an igneous crystallization age of 1807 ± 3 Ma (Wingate et al., 2009b) and which is taken to be the minimum age for deposition of this unit.

References

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Leake Spring Metamorphics; subunit (P_-LS-mlst) formerly P_-MR-mlst

Legend narrative

Pelitic and semipelitic schist; staurolite–garnet–biotite–muscovite(–andalusite) schist

Rank	Formation
Parent	Leake Spring Metamorphics (P_-LS-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-mgsl, P_-DUda-mgmu, P_-POb-mxq, P_-POb-mlsm, P_-POs-mtqs, P_-MEi-kd (faulted); P_-TT-gmlt, P_-TT-gmpt, P_-TT-gpvt (intrusive)

Summary

Pelitic and semipelitic staurolite–garnet–biotite–muscovite(–andalusite) schist defines a belt about 60 km long and up to 2.5 km wide along the northern part of the Mutherbukin Zone on Mount Phillips and Yinnetharra. This unit is characterized by the presence of abundant, coarse-grained staurolite porphyroblasts that are up to 6 cm long. Garnet porphyroblasts the size of golf balls are present on parts of southern Mount Phillips. Overall, the rocks become somewhat finer grained, and the staurolite and garnet porphyroblasts smaller, southeast along the belt toward the northeastern corner of Yinnetharra.

Distribution

Staurolite–garnet–biotite–muscovite(–andalusite) schist of the Leake Spring Metamorphics is largely restricted to southwest of the Ti Tree Syncline along the northern edge of the Mutherbukin Zone. The schists outcrop in a belt trending east-southeast from southwestern Mount Phillips onto northern Yinnetharra, then to the southeast subparallel to the Ti Tree Syncline, converging obliquely to the southeast with this structure just north of Thomas River on eastern Yinnetharra. This belt is at least 60 km long and around 2 km wide.

Lithology

Pelitic and semi-pelitic staurolite–garnet–biotite–muscovite(–andalusite) schist is distinguished from other pelitic units of the Leake Spring Metamorphics and from the Pooranoo Metamorphics by the presence of abundant staurolite porphyroblasts. Staurolite porphyroblasts 4–6 cm long are not uncommon in the area to the north and northwest of Morrissey Hill on southern Mount Phillips and northern Yinnetharra, but towards Reid Well on northeastern Yinnetharra, the rocks overall become finer grained, with fewer large staurolite and garnet porphyroblasts. Most of the schists are quite weathered, but they also become intensely weathered nearer to the unconformities with the overlying Pooranoo Metamorphics and Edmund Group in the Ti Tree Syncline on northeastern Yinnetharra.

Some of the staurolite–garnet–biotite–muscovite (–andalusite) schists contain two generations of staurolite: large porphyroblasts and smaller crystals that define a lineation. Staurolite porphyroblasts commonly overprint an S_1/S_2 schistosity. Inclusion trails show that porphyroblast growth post-dated an early S_1 foliation and some rotation of that foliation near porphyroblast margins, suggesting that growth may be late synkinematic with S_2. Garnet porphyroblasts may reach the same size as golf balls northwest of Morrissey Hill. These porphyroblasts show the same relationship to the fabrics as the staurolite porphyroblasts. In some samples garnet forms small idioblastic inclusions in staurolite. On northeastern Yinnetharra between Reid Well and Camel Hill, garnet commonly forms 2–5 mm idioblastic crystals. Staurolite and garnet may be partly replaced by fine-grained chlorite. Zircon and monazite are prominent accessory minerals in some samples. Zircons range from near euhedral to well-rounded.

Age code	Proterozoic	P_-
Stratigraphic code	Leake Spring Metamorphics	LS-
Rock type	metasedimentary siliciclastic: pelite	ml
Lithname	pelitic schist	s
1st qualifier	–	
2nd qualifier	staurolite	t
Rock code		**P_-LS-mlst**
Additional lithologies	semipelitic schist	

Contact relationships

Staurolite–garnet–biotite–muscovite(–andalusite) schist appears to be conformable with other units of the Leake Spring Metamorphics. Thin lenses and layers of amphibolite (P_-LS-mwa) within the schist are present in most areas. The unit is intruded by several granites of the Moorarie, Durlacher and Thirty Three Supersuites, as well as numerous pegmatite veins and dykes of the Thirty Three Supersuite. On northeastern Yinnetharra staurolite–garnet–biotite–muscovite(–andalusite) schist is in contact with units of the Pooranoo Metamorphics, and the Edmund Group within the Ti Tree Syncline. The contacts appear to be partly sheared unconformities. West of Perseverance Well on northern Yinnetharra, the contact between the staurolite–garnet–biotite–muscovite(–andalusite) schist and Pooranoo Metamorphics is a shear zone. The base of the staurolite–garnet–biotite–muscovite(–andalusite) schist is not exposed.

Geochronology

P_-LS-mlst	*Maximum*	*Minimum*
Age (Ma)	1842 ± 5	1807
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Inferred
References	Varvell, 2001; Wingate et al., in prep.	Kirkland et al., 2009

The depositional age of the staurolite–garnet–biotite–muscovite(–andalusite) schist is not well defined. A specimen of semi-pelitic schist sampled about 2 km southwest of Nardoo Well, near the southern edge of MOUNT PHILLIPS, has a maximum depositional age of 1840 ± 4 Ma (Varvell 2001). Foliated metasandstone from the same site was resampled to check the accuracy of this maximum depositional age, because a sample of pelite from the same unit suggested that it was deposited after c. 1660 Ma. However, the youngest age component in the metasandstone sample, GSWA 190668, is 1842 ± 5 Ma (Wingate et al., 2009a); this age is indistinguishable from the result obtained by Varvell (2001), and is the best estimate of the maximum depositional age for the staurolite–garnet–biotite–muscovite(–andalusite) schist.

A minimum age of deposition is provided by the first identifiable metamorphic fabric in the staurolite–garnet–biotite–muscovite(–andalusite) schist, which has been dated at 1030–990 Ma (Sheppard et al., 2007), and the oldest granites that demonstrably intruded the schist belong to the 995–955 Ma Thirty Three Supersuite. The staurolite–garnet–biotite–muscovite(–andalusite) schist is inferred to be conformable with other metasedimentary units of the Leake Spring Metamorphics and as such has the same age constraints. The oldest magmatic rock to intude the Leake Spring Metamorphics is a foliated metatonalite from Mallet Well that is dated at 1807 ± 3 Ma (Kirkland et al., 2009).

References

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Leake Spring Metamorphics; subunit (P_-LS-mts) formerly P_-MR-mts

Legend narrative

Psammitic schist; quartz–chlorite–muscovite schist

Rank	Formation
Parent	Leake Spring Metamorphics (P_-LS-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmp, P_-MO-gmeb, P_-MO-mgts, P_-MO-xmg-m (intrusive); P_-MOmi-mgmn, P_-MOmi-mgmy (faulted)

Summary

Psammitic schist is a minor unit of the Leake Spring Metamorphics, mainly being restricted to the southeast part of the Limejuice Zone, along the southern margin of the Minnie Creek batholith. At the southeastern end of the Limejuice Zone on CANDOLLE, quartzite is a constituent of the unit. Psammitic schist is intruded by various granites of the Moorarie Supersuite.

Distribution

Psammitic schist (P_-LS-mts) of the Leake Spring Metamorphics is restricted to an area of about 40 km^2 southwest of Mount Samuel on southwestern MOUNT AUGUSTUS. It forms numerous screens and inclusions, the largest of which is around 1.5 km^2, within granites of the Minnie Creek batholith. Psammitic schist forms two small windows, the larger of which is 4 km^2, within the Middle Spring Granite on eastern PINK HILLS and western CANDOLLE, and two rafts within granite of the Moorarie Supersuite immediately north of Division Well on CANDOLLE.

Lithology

The majority of the psammitic schist consists of quartz–chlorite–muscovite schist, commonly with a fine-scale (millimetre- to centimetre-scale) compositional banding. Thickly bedded psammitic schist is rare. Most of the rocks are fine grained although, locally, coarse-grained schist after granule sandstone is present. Many of the rocks contain muscovite porphyroblasts 2–5 mm in diameter, and some layers contain magnetite porphyroblasts. On eastern PINK HILLS and the adjacent western part of CANDOLLE, rubbly outcrop of medium-grained quartzite is an important component of the unit. The quartzite is a coarsely recrystallized, sugary-textured rock with 0.5 – 1 m partings which may represent tectonized bedding planes.

Age code	Proterozoic	P_-
Stratigraphic code	Leake Spring Metamorphics	LS-
Rock type	metasedimentary siliciclastic: psammite	mt
Lithname	psammitic schist	s
Rock code		**P_-LS-mts**
Additional lithologies	quartzite	

Contact relationships

Psammitic schist forms rafts and inclusions within: equigranular biotite monzogranite (P_-MO-gmeb); coarse-grained porphyritic biotite monzogranite (P_-MO-gmp); mesocratic, biotite metatonalite and metamorphosed quartz-diorite (P_MO-mgts); and mesocratic biotite metagranodiorite to metamonzogranite and pale grey, layered biotite(–muscovite) metamonzogranite (P_-MO-xmg-m); as well as being intruded by dykes and veins of the same phases. Psammitic schist and quartzite is tectonically interleaved with the Middle Spring Granite. Psammitic schist is not in direct contact with any of the other Leake Spring Metamorphic units.

Geochronology

P_-LS-mts	*Maximum*	*Minimum*
Age (Ma)	1842	1807
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., in prep.	Kirkland et al., 2009

Psammitic schist has not been directly dated but it is inferred to be conformable with other metasedimentary units of the Leake Spring Metamorphics. The best estimate of the maximum depositional age for the Leake Spring Metamorphics — and the psammitic schist — is 1842 ± 5 Ma, for the youngest detrital zircon within a foliated metasandstone layer within staurolite–garnet–biotite–muscovite(–andalusite) schist (P_-LS-mlst) south of Nardoo Well on southern Mount Phillips (Wingate et al., in prep.).

A minimum age for deposition of the protolith of the psammitic schist is provided by U–Pb zircon dates for two granites that intrude the schist, including medium-grained equigranular biotite monzogranite (P_-MO-gmeb) at 1782 ± 5 Ma, and medium- and coarse-grained porphyritic biotite monzogranite (P_-MO-gmp) at 1795 ± 8 Ma. However, the oldest phase of the Minnie Creek batholith, which extensively intrudes the Leake Spring Metamorphics, is a foliated tonalite with an igneous crystallization age of 1807 ± 3 Ma (Kirkland et al., 2009) which is taken to be the minimum age for deposition of this unit.

References

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009, 183205: schistose metatonalite, Mallet Well; Geochronology Record 753: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, Johnson, SP and Sheppard, S in prep., 190668; metasandstone, Nardoo Well: Geological Survey of Western Australia.

Leake Spring Metamorphics; subunit (P_-LS-mc) formerly P_-MR-mc

Legend narrative

Metachert

Rank	Formation
Parent	Leake Spring Metamorphics (P_-LS-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-mgms

Summary

Metachert of the Leake Spring Metamorphics is restricted to the northern margin of the Minnie Creek batholith on northeastern EUDAMULLAH where it forms a 7 km long belt of metre-wide inclusions within foliated, mesocratic, biotite monzogranites of the Moorarie Supersuite. The metachert is typically massive and strongly jointed, although locally it is crudely layered and cut by a network of quartz veins.

Distribution

Metachert of the Leake Spring Metamorphics comprises several layers in a belt about 7 km long and 1 km wide around the Minga Bar Fault on northeastern EUDAMULLAH. One of the layers extends a short distance onto MOUNT PHILLIPS to the east.

Lithology

Metachert of the Leake Spring Metamorphics comprises heterogeneous pale brown, grey, and off-white metachert layers with crude layering. Layering is subparallel or parallel to the prevailing tectonic foliation. Metachert is typically cut by a network of quartz veins, some of which are strongly deformed. Metachert is mainly massive and strongly jointed, but some porous zones are locally present. Some metachert is associated with strongly foliated muscovite-bearing quartzite.

Age code	Proterozoic	P_-
Stratigraphic code	Leake Spring Metamorphics	LS-
Rock type	metasedimentary other chemical	
Lithname	metachert	mc
Rock code		**P_-LS-mc**

Contact relationships

Metachert is mainly hosted by deeply weathered, foliated, mesocratic biotite monzogranite (P_-MO-mgms). The contacts are not exposed, but the monzogranite is inferred to have intruded the chert.

Geochronology

P_-LS-mc	*Maximum*	*Minimum*
Age (Ma)	1842	1807
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., in prep.	Kirkland et al., 2009

No samples of metachert have been dated directly, and there are few age constraints available from other stratigraphic units. This unit is interlayered with metamorphosed iron-formation interpreted to be part of the Leake Spring Metamorphics (P_-LS-mi). The metachert was intruded by c. 1801 Ma foliated mesocratic biotite monzogranite (P_-MO-mgms) in the northern part of the Minnie Creek batholith in the Limejuice Zone (Bodorkos et al., 2006). The best estimate of the maximum depositional age for the Leake Spring Metamorphics — and the metachert — is from a foliated metasandstone within staurolite–garnet–biotite–muscovite(–andalusite) schist (P_-LS-mlst) south of Nardoo Well on southern Mount Phillips. The youngest zircons in this sample yield a date of 1842 ± 5 Ma (Wingate et al., 2009a). The oldest phase of the Minnie Creek batholith, which extensively intrudes the Leake Spring Metamorphics, is a foliated tonalite with an igneous crystallization age of 1807 ± 3 Ma (Kirkland et al., 2009) and which is taken to be the minimum age for deposition of this unit. Therefore, the metachert is inferred to have a depositional age between 1842 ± 5 Ma and 1807 ± 3 Ma.

References

Bodorkos, S, Love, GJ and Wingate, MTD 2006, 88412: foliated porphyritic monzogranite, Bentley Well; Geochronology Record 611: Geological Survey of Western Australia, 4p.

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009, 183205: schistose metatonalite, Mallet Well; Geochronology Record 753: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, Johnson, SP and Sheppard, S in prep., 190668; metasandstone, Nardoo Well: Geological Survey of Western Australia.

Leake Spring Metamorphics; subunit (P_-LS-mi) formerly P_-MR-mi

Legend narrative

Metamorphosed banded and granular iron-formation

Rank	Formation
Parent	Leake Spring Metamorphics (P_-LS-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA

Summary

Metamorphosed banded and granular iron-formation is restricted to the northwestern corner of MAROONAH in the Boora Boora Zone, where it forms layers or lenses up to 30 m thick. Most of the iron formation is granular, but locally it contains chert bands 3–7 mm thick. The unit is either interlayered with calc-silicate gneiss of the Leake Spring Metamorphics or tectonically interleaved with foliated and gneissic granodiorite and tonalite of the Moorarie Supersuite.

Distribution

Metamorphosed banded and granular iron-formation (P_-LS-mi) of the Leake Spring Metamorphics is confined to the northwestern corner of MAROONAH, in the Boora Boora Zone. The unit outcrops as rubbly strike ridges.

Lithology

Metamorphosed iron-formation comprises semi-continuous layers or lenses up to 30 m thick. Most of the iron formation is granular, but locally it contains chert bands 3–7 mm thick. Metamorphosed iron-formation comprises magnetite, grunerite, and quartz, with secondary hematite and goethite.

Age code	Proterozoic	P_-
Stratigraphic code	Leake Spring Metamorphics	LS-
Rock type	metasedimentary other chemical: meta-iron formation	
Lithname	meta-iron formation	mi
Rock code		**P_-LS-mi**

Contact relationships

Metamorphosed banded and granular iron-formation is either interlayered with calc-silicate gneiss (P_-LS-mk) or tectonically interleaved with foliated and gneissic granodiorite and tonalite (P_-MO-mgg) west of Boora Boora Bore.

Geochronology

P_-LS-mi	*Maximum*	*Minimum*
Age (Ma)	1842	1807
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., in prep.	Kirkland et al., 2009

No samples of metamorphosed iron-formation have been dated directly, and there are few age constraints available from other stratigraphic units in contact with the metamorphosed iron-formation. This unit is interlayered with calc-silicate rocks interpreted to be part of the Leake Spring Metamorphics (P_-LS-mk). The best estimate to date of the maximum depositional age for the Leake Spring Metamorphics — and the metamorphosed iron-formation — is from a foliated metasandstone within staurolite–garnet–biotite–muscovite(–andalusite) schist (P_-LS-mlst) south of Nardoo Well on southern Mount Phillips. The youngest zircons in this sample, GSWA 190668, yield a date of 1842 ± 5 Ma (Wingate et al.,in prep.). The oldest phase of the Minnie Creek batholith, which extensively intrudes the Leake Spring Metamorphics, is a foliated tonalite with an igneous crystallization age of 1807 ± 3 Ma (Kirkland et al., 2009) and which is taken to be the minimum age for deposition of this unit.

References

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009, 183205: schistose metatonalite, Mallet Well; Geochronology Record 753: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, Johnson, SP and Sheppard, S in prep., 190668; metasandstone, Nardoo Well: Geological Survey of Western Australia.

Leake Spring Metamorphics; subunit (P_-LS-mk) formerly P_-MR-mk

Legend narrative

Calc-silicate gneiss and schist; fine grained

Rank	Formation
Parent	Leake Spring Metamorphics (P_-LS-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-xmgm-m, P_-MOru-mgm, P_-MO-mgn (intrusive); P_-MOmi-mgmn, P_-MO-mgnl (faulted)
Underlying units	

Summary

Calc-silicate gneiss and schist (P_-LS-mk) are a minor component of the Leake Spring Metamorphics. These rocks generally form layers, less than a few metres thick, as inclusions or rafts within younger granites or as lenses tectonically interleaved with the Middle Spring Granite. Calc-silicate gneiss and schist is typically fine and medium grained, strongly banded, locally includes marble, and may be interlayered with psammitic and pelitic schist.

Distribution

Calc-silicate gneiss and schist (P_-LS-mk) is a minor component of the Leake Spring Metamorphics in the Boora Boora, Limejuice, and Mutherbukin Zones. The largest exposure of this rock unit is as a near-continuous layer up to about 120 m thick and 4 km long that defines a megascopic refolded fold centred on Boora Boora Bore on MAROONAH. Elsewhere in the Boora Boora Zone, calc-silicate rocks form layers less than a few metres thick and a few tens of metres long. In the Limejuice Zone, calc-silicate gneiss and schist outcrops as two rafts or lenses 1.75 by 0.25 km and 0.25 by 0.05 km around O'Connor Well near the southern edge of MOUNT PHILLIPS. Calc-silicate gneiss and schist are also locally present as inclusions in granites of the Minnie Creek batholith, or as lenses tectonically interleaved with the Middle Spring Granite. In the area centred about 10 km northwest of Middle Spring on PINK HILLS, several layers of calc-silicate gneiss up to 1 km long are exposed. Narrow pods or lenses (<20 m wide) of calc-silicate gneiss are a minor but widespread feature of the Leake Spring Metamorphics in the Mutherbukin Zone.

Lithology

Calc-silicate gneiss and schist is typically fine and medium grained, and strongly banded. In places, it includes marble and may be interlayered with psammitic and pelitic schist. Calc-silicate gneiss is composed of medium- to fine-grained diopside–zoisite–titanite–plagioclase–quartz with thin layers of zoisite–quartz–titanite(–diopside). Calc-silicate schist shows extensive tremolite replacement of diopside, and albite–oligoclase after original plagioclase. Calc-silicate rocks also include cream to pale green marble in the Boora Boora Zone, and in the Limejuice Zone about 10 km northwest of Middle Spring. In the Mutherbukin Zone on YINNETHARRA calc-silicate rocks include fine-grained, greenish-grey epidote–quartz–plagioclase–tremolite–titanite–microcline gneiss. Xenoblastic colourless and weakly pleochroic epidote probably comprises roughly 80% or more of the rock; quartz and plagioclase and minor microcline are interstitial to epidote. Titanite is distributed as inclusions through the major mineral phases.

Age code	Proterozoic	P_-
Parent	Leake Spring Metamorphics	LS-
Rock type	metasedimentary carbonate	
Lithname	metacarbonate	mk
Rock code		**P_-LS-mk**

Contact relationships

Banded calc-silicate gneiss forms inclusions within interlayered mesocratic biotite metagranodiorite and pale-grey biotite(–muscovite) metamonzogranite (P_-MO-xmg-m) in the southwest corner of MOUNT AUGUSTUS (for example, about 1.8 km northwest of O'Connor Well at Zone 50, MGA 444520E 7293060N) and in the adjacent northwest corner of PINK HILLS. Northwest of Middle Spring on PINK HILLS the calc-silicate gneiss is also intruded by banded biotite metamonzogranite of the Rubberoid Granite (P_-MOru-mgm). On the eastern edge of YINNETHARRA, east of Lucky Bore, lenses of calc-silicate gneiss are included within, and tectonically interleaved with, gneissic granites of the Moorarie Supersuite (P_-MO-mgn). In the area northwest and northeast of Middle Spring, layers of calc-silicate gneiss are tectonically interleaved within gneissic metamonzogranite of the Middle Spring Granite.

Geochronology

P_-LS-mk	*Maximum*	*Minimum*
Age (Ma)	1842	1807
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., in prep.	Kirkland et al., 2009

No samples of calc-silicate gneiss and schist have been dated directly. However, these rock types are interlayered with and, presumably, were interbedded with, extensive psammitic and pelitic schist. The best estimate to date of the maximum depositional age for the Leake Spring Metamorphics — and the calc-silicate gneiss and schist — is from a foliated metasandstone within staurolite–garnet–biotite–muscovite(–andalusite) schist (P_-LS-mlst) south of Nardoo Well on southern Mount Phillips. The youngest zircons in this sample, GSWA 190668, yield a date of 1842 ± 5 Ma (Wingate et al., in prep.).

All of the rocks of the Leake Spring Metamorphics were intruded by a range of granites belonging to the 1820–1775 Ma Moorarie Supersuite. Among the oldest of these granites is equigranular to sparsely porphyritic biotite tonalite and granodiorite (P_-MO-gte) of the Minnie Creek batholith dated at 1807 ± 3 Ma (GSWA 183205; Kirkland et al., 2009).

References

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009, 183205: schistose metatonalite, Mallet Well; Geochronology Record 753: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, Johnson, SP and Sheppard, S in prep., 190668; metasandstone, Nardoo Well: Geological Survey of Western Australia.

Leake Spring Metamorphics; subunit (P_-LS-mwa) formerly P_-MR-mwa

Legend narrative

Amphibolite and actinolite–plagioclase schist

Rank	Formation
Parent	Leake Spring Metamorphics (P_-LS-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-gmv, P_-MO-gmp, P_-MO-mggn

Summary

Amphibolite and actinolite–plagioclase schist are widespread in the Leake Spring Metamorphics, although typically not abundant, with the exception of a few concentrations perhaps a couple of hundred metres thick. The vast majority of the amphibolite and actinolite–plagioclase schist is too deformed and recrystallized to preserve any evidence of either an extrusive or intrusive origin. However, on northwestern Pink Hills finely interlayered amphibolite, quartzite, and quartz-rich amphibolite implies that the mafic rocks had a volcanic or volcaniclastic protolith. In the Boora Boora Zone in the north of the province, the coarse-grained and layered nature of some metagabbros suggests that they were intrusions.

Distribution

Amphibolite and actinolite–plagioclase schist outcrop widely in the Limejuice Zone, although the mafic rocks are typically not voluminous. However, amphibolite forms numerous rafts 200–700 m long and 50–150 m wide in the Limejuice Well and Bassitt Bore areas on eastern Mount Phillips. On the western edge of Pink Hills, and farther to the northeast on the same map sheet (east of Midway Bore), mafic metavolcanic rocks are finely interlayered with psammitic and pelitic schists (P_-LS-xmh-mwa). In the Boora Boora Zone, amphibolite and actinolite–plagioclase–epidote schist are tectonically interleaved with foliated and gneissic granites of the Moorarie Supersuite. Here the mafic rocks form lenses typically less than 2 m thick and less than 50 m long, most of which are too small to show on the map. However, in the northwestern corner of Maroonah, composite layers up to 100 m thick and 3 km long are exposed.

Lithology

In the Limejuice Zone most of the amphibolite and actinolite–plagioclase schist is fine- to medium-grained and reasonably homogeneous. Locally the rocks are coarse grained. Most of the amphibolites are fine-grained rocks with a polygonal texture, comprising hornblende (straw-yellow – green – dark-green), plagioclase, quartz, and titanomagnetite. Where the amphibolites have been overprinted by lower grade events, hornblende is partially replaced by a bluish-green actinolitic hornblende or actinolite, plagioclase is recrystallized to a more sodic variety with fine-grained epidote and sericite, and titanomagnetite is pseudomorphed by epidote and titanite.

In the Boora Boora Zone on northwestern Maroonah, rare thicker layers of amphibolite are heterogeneous, ranging from a medium-grained rock with a granoblastic texture to a porphyritic leucogabbro with a relict igneous texture. In the Boora Boora Zone on Maroonah most of the mafic rocks consist of fine- to medium-grained epidote amphibolite or actinolite gneiss. Typically, the rocks comprise bluish-green actinolite or green actinolitic hornblende, clinozoisite, and quartz, with minor titanite. Porphyritic leucogabbro contains plagioclase phenocrysts up to 1 cm in diameter pseudomorphed by granular clinozoisite, sericite, and sodic plagioclase, with interstitial actinolitic hornblende, clinozoisite, and sericite.

Age code	Proterozoic	P_-
Stratigraphic code	Leake Spring Metamorphics	LS-
Rock type	meta-igneous mafic	mw
Lithname	amphibolite	a
Rock code		**P_-LS-mwa**
Additional lithologies	mafic schist	

Contact relationships

Amphibolite and actinolite–plagioclase schist of the Leake Spring Metamorphics form inclusions and rafts within coarse-grained, porphyritic biotite monzogranite of the Moorarie Supersuite (P_-MO-gmp), and medium-grained muscovite–biotite granodiorite and monzogranite (P_-DU-gmv) of the Durlacher Supersuite. In the Boora Boora Zone about 5 km east-northeast of Minga Springs (Zone 50, MGA 361480E 7444890N), inclusions of massive actinolite–clinozoisite–quartz rock in granodiorite gneiss (P_-MO-mggn) are exposed. For many of the mafic rocks it is difficult to determine an intrusive or extrusive origin, as contacts are not exposed, or are faulted. However, some localities on Maroonah preserve evidence suggestive of an intrusive origin whereas on northwestern Pink Hills there is good evidence for the amphibolites there having an extrusive origin. In the area about 6 km northeast of Boora Boora Bore (Zone 50, MGA 357080E 7455280N), layered metagabbro, including porphyritic metaleucogabbro, is exposed. The contact with the enclosing granitic gneiss is faulted, but the coarse porphyritic and fractionated nature of some metagabbro layers suggests that they may be intrusive. In a creek pavement about 6 km east-southeast of Mundong Well (Zone 50, MGA 361310E 7438650N) fine-grained amphibolite layers less than 0.5 m-thick truncate gneissic layering in granitic gneiss at a low angle. Amphibolite also contains rare inclusions of granitic gneiss attesting to an intrusive origin.

In contrast, exposures in the area east of Midway Bore on northwestern Pink Hills preserve good evidence for a volcanic or volcaniclastic origin for some of the amphibolites there (see P_-LS-xmh-mwa). These rocks are finely interlayered with psammitic and pelitic schist, unlike many amphibolites elsewhere, so it is not clear as to whether or not the extrusive nature of these rocks can be extrapolated to the remainder of the amphibolites.

Geochronology

P_-LS-mwa	*Maximum*	*Minimum*
Age (Ma)	1842	1807
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., in prep.	Kirkland et al., 2009

Amphibolite and actinolite–plagioclase schist have not been dated directly. However, evidence of a volcanic origin for the amphibolites on PINK HILLS suggests that many of the amphibolites were basalts deposited at the same time as the siliciclastic metasedimentary rocks that constitute the bulk of the Leake Spring Metamorphics. The best estimate of the maximum depositional age for the Leake Spring Metamorphics — and the amphibolite and actinolite–plagioclase schist — is from a foliated metasandstone within staurolite–garnet–biotite–muscovite(–andalusite) schist (P_-LS-mlst) south of Nardoo Well on southern Mount Phillips. The youngest zircons in this sample, GSWA 190668, yield a date of 1842 ± 5 Ma (Wingate et al., in prep.), which is indistinguishable from the result obtained by Varvell (2001).

Amphibolite and actinolite–plagioclase schist are intruded by coarse-grained, porphyritic biotite monzogranite (P_-MO-gmp), which is dated at 1795 ± 8 Ma (Evans et al., 2003). However, the oldest phase of the Minnie Creek batholith, which extensively intrudes the Leake Spring Metamorphics, is a foliated tonalite with an igneous crystallization age of 1807 ± 3 Ma (Kirkland et al., 2009) and which is taken to be the minimum age for deposition of this unit.

References

Evans, DAD, Sircombe, KN, Wingate, MTD, Doyle, M, McCarthy, M, Pidgeon, RT and Van Nierkerk, HS 2003, Revised geochronology of magmatism in the western Capricorn Orogen at 1805–1785 Ma: Diachroneity of the Pilbara–Yilgarn collision: Australian Journal of Earth Sciences, v. 50, p. 853–864.

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Wingate, MTD, Kirkland, CL, Johnson, SP and Sheppard, S in prep., 190668; metasandstone, Nardoo Well: Geological Survey of Western Australia.

Leake Spring Metamorphics; subunit (P_-LS-mus) formerly P_-MR-mus

Legend narrative

Actinolite schist and actinolite–chlorite–sericite schist after ultramafic rock

Rank	Formation
Parent	Leake Spring Metamorphics (P_-LS-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmp, P_-MO-gge, P_-MO-xmg-m, P_-DU-gmvt

Summary

Actinolite schist and actinolite–chlorite–sericite schist is a very minor component of the Leake Spring Metamorphics, largely restricted to a southeast-trending belt on southeastern Mount Phillips and northwestern Pink Hills. The schists were derived from an ultramafic protolith.

Distribution

Actinolite schist and actinolite–chlorite–sericite schist forms several rafts and lenses within, and adjacent to, the southern margin of the Minnie Creek batholith on the southern part of Mount Phillips. One raft is present in the interior of the batholith, about 2.3 km north of 6 Mile Well, and another 6.5 km southeast of Coolianga Spring on northern Pink Hills. Rafts shown on the map are 200–600 m long by 50–200 m wide, but there are also inclusions of actinolite schist locally in the granites that are too small to show.

Lithology

Actinolite schist and actinolite–chlorite–sericite schist are typically strongly weathered, coarse-grained rocks with a decussate texture. Actinolite schist is the main rock type; locally it grades into actinolite–chlorite–sericite schist. The precursors to these rocks are, respectively, pyroxenite and melanogabbro. At one locality 2.3 km north of 6 Mile Well (SXSMTP007250; Zone 50, MGA 438022E 7301898N), the rock is a chlorite(–phlogopite–epidote) schist with abundant apatite and zircon. Southeast of Coolianga Spring on Pink Hills, at site SXSPKH008013 (Zone 50, MGA 474446E 7284461N) the rock consists of actinolite crystals after pyroxene oikocrysts up to 3cm in diameter.

Age code	Proterozoic	P_-
Stratigraphic code	Leake Spring Metamorphics	LS-
Rock type	meta-igneous ultramafic volcanic or undivided	mu
Lithname	ultramafic schist, volcanic or undivided	s
Rock code		**P_-LS-mus**

Contact relationships

Actinolite schist forms rafts and inclusions within equigranular biotite(–muscovite) granodiorite (P_-MO-gge) around Gurangurra Bore and coarse-grained, porphyritic biotite monzogranite (P_-MO-gmp) east of Allan Well and north of 6 Mile Well. Southeast of Coolianga Spring actinolite schist forms a raft within mesocratic biotite metagranodiorite to metamonzogranite and pale-grey, layered biotite(–muscovite) metamonzogranite (P_-MO-xmg-m). South of Smith Well, two lenses of ultramafic rock are in faulted contact with muscovite-rich pelitic schist (P_-LS-mlsm) of the Leake Spring Metamorphics, and are intruded by dykes and veins of leucocratic granite and pegmatite (P_-DU-gmvt).

Geochronology

P_-LS-mus	*Maximum*	*Minimum*
Age (Ma)	1842	1807
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., in prep.	Kirkland et al., 2009a

Actinolite schist and actinolite–chlorite–sericite schist have not been dated directly. The rocks are in faulted contact with muscovite-rich pelitic schist (P_-LS-mlsm) of the Leake Spring Metamorphics, but if they were originally intrusive, then the ultramafic igneous precursor must be younger than the 1961 ± 7 Ma maximum age for a sample (GSWA 180935) of interlayered pelitic and psammitic schist (P_-LS-mhs: Kirkland et al., 2009b) or the 1842 ± 5 Ma maximum depositional age for the staurolite–garnet–biotite–muscovite(–andalusite) schist (P_-LS-mlst: Varvell, 2001; Wingate et al., in prep.).

Actinolite schist and actinolite–chlorite–sericite schist are intruded by several granites, the oldest of which, a coarse-grained porphyritic biotite monzogranite (P_-MO-gmp), is dated at 1795 ± 8 Ma (Evans et al., 2003). However, the oldest phase of the Minnie Creek batholith, which extensively intrudes the Leake Spring Metamorphics, is a foliated tonalite (GSWA 183205) with an igneous crystallization age of 1807 ± 3 Ma (Kirkland et al., 2009a) which is taken to be the minimum age for deposition of this unit.

References

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Leake Spring Metamorphics; subunit (P_-LS-xmh-mwa) formerly P_-MR-xmh-mwa

Legend narrative

Psammitic and pelitic schist and interlayered amphibolite

Rank	Formation
Parent	Leake Spring Metamorphics (P_-LS-xmd-mk)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MOru-mgm, P_-MO-xmg-m

Summary

Psammitic and pelitic schist and interlayered amphibolite outcrops in the northwestern part of Pink Hills. The amphibolite layers are typically a few metres thick, but may be up to 20 m thick. The amphibolites are commonly interlayered with fine-grained, finely banded quartzite, quartz-rich calc-silicate gneiss, and quartz amphibolite. Centimetre-scale layering is present in some amphibolites and the contacts with the psammitic and pelitic schists strongly suggest that the protoliths to the amphibolites were mafic volcanic or volcaniclastic rocks.

Distribution

Psammitic and pelitic schist and interlayered amphibolite outcrops between Midway Bore and Top Spring in the northwestern part of Pink Hills. The largest of the outcrops covers more than 8 km^2 southwest of Binnings Bore, with another substantial concentration of nearly 4.5 km^2 about 6 km east of Midway Bore.

Lithology

Psammitic and pelitic schist and interlayered amphibolite is composed of the same rock types as the psammitic and pelitic schist (P_-LS-mhs), and amphibolite and actinolite–plagioclase schist (P_-LS-mwa) units of the Leake Spring Metamorphics. The amphibolite layers are typically a few metres thick, but may be up to 20 m thick. At their margins, the amphibolites are commonly interlayered with fine-grained, finely banded quartzite, quartz-rich calc-silicate gneiss, and quartz amphibolite. Centimetre-scale layering is present in some amphibolites, and locally they contain thin layers of quartz-rich calc-silicate gneiss. On the western side of Pink Hills, southwest of Binnings Bore, a thick package of amphibolite is interlayered with some quartzite and quartz-rich calc-silicate gneiss. The amphibolites are largely homogeneous, with the exception of local garnet-bearing amphibolite, but near the contacts they commonly contain very thin layers or lenses of hornblende-bearing quartzite and quartz-rich amphibolite. The garnet amphibolites are commonly finely layered.

Most of the amphibolites are polygonal textured rocks comprising hornblende (straw-yellow – green – dark-green), plagioclase, quartz, titanomagnetite, and minor biotite. Pleochroic haloes in hornblende are common, if not widespread. Hornblende is rimmed and replaced along fractures by an optically continuous bluish-green amphibole that is commonly associated with very fine-grained granular opaques (?ilmenite). Small biotite crystals may be intergrown with, or included in, hornblende. Coarser grained biotite crystals form clumps associated with quartz-rich patches. The garnet amphibolites southwest of Binnings Bore on Pink Hills contain layers with sparse scattered xenoblastic garnet porphyroblasts about 4 mm in diameter alternating with layers containing abundant idioblastic to subidioblastic garnet porphyroblasts about 1 mm or less in diameter. The matrix to both layers comprises very fine-grained decussate hornblende, with interstitial plagioclase and quartz, and abundant granular titanite at grain boundaries. Hornblende is pleochroic from straw yellow to blue-green to deep green. Pleochroic haloes in hornblende are common. Garnet porphyroblasts are crammed with blebby inclusions of plagioclase, quartz and titanite, and lesser partly rounded inclusions of hornblende.

Quartz-rich calc-silicate gneisses are fine-grained, finely banded, granoblastic rocks composed of quartz–plagioclase–hornblende–epidote. They commonly contain thin (<3 mm) horizons of amphibolite or quartz-amphibolite. The hornblende content of the quartz-rich calc-silicate rocks ranges between about 10% and 35%. The hornblende is a greenish brown colour with optically continuous rims of a bluish-green hornblende. Some horizons contain ragged, sieved porphyroblasts of a very pale green to pale bluish-green amphibole.

Age code	Proterozoic	P_-
Stratigraphic code	Leake Spring Metamorphics	LS-
Mixed or xenolith-bearing	Mixed	x
Rock type 1	metasedimentary siliciclastic	
Lithname 1	psammite and pelite; interlayered	mh
Rock type 2	meta-igneous mafic	mw
Lithname 2	amphibolite	a
Rock code		**P_-LS-xmh-mwa**

Contact relationships

The contacts between psammitic and pelitic schist and the interlayered amphibolite contain evidence that strongly suggests that the protoliths to the amphibolites were mafic volcanic or volcaniclastic rocks. For example, at site SXSPKH008088, the contacts between amphibolite and quartz-rich calc-silicate gneiss are gradational in places, with fine layers of quartz amphibolite that appear to be compositionally intermediate between the amphibolite and quartz-rich calc-silicate gneiss. At site SXSPKH008059, the contact between amphibolite and quartzite is marked by centimetre-scale interlayering; one low-strain exposure shows an irregular surface. At some localities (e.g. SXSPKH008087) there are what appear to be lenses or clasts of amphibolite in calc-silicate rock, or possible interfingering of amphibolite and quartz-rich calc-silicate rock (SXSPKH008085). At site SXSPKH008059, the contact between amphibolite and quartzite is in part cuspate. The gradational nature of some contacts between amphibolite, quartz amphibolite, quartz-rich calc-silicate rock and quartzite, and their finely interlayered nature suggests that the mafic rocks are volcanic or volcaniclastic in origin, and that the quartz amphibolite and quartz-rich calc-silicate rocks represent varying degrees of reworking of volcanic/volcaniclastic material into quartz-rich sediments.

Geochronology

P_-LS-xmh-mwa	*Maximum*	*Minimum*
Age (Ma)	1842	1807
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., in prep.	Kirkland et al., 2009

The psammitic and pelitic schist and interlayered amphibolite has not been dated directly. However, evidence of a volcanic origin for the amphibolites on PINK HILLS suggests that many of the amphibolites were basalts deposited at the same time as the siliciclastic sedimentary rocks that constitute the bulk of the Leake Spring Metamorphics, and therefore have the same age constraints. The youngest detrital zircons dated at 1842 ± 5 Ma (Wingate et al., in prep.) are from a foliated metasandstone layer within staurolite–garnet–biotite–muscovite(–andalusite) schist (P_-LS-mlst) south of Nardoo Well on southern Mount Phillips.

Psammitic and pelitic schist and interlayered amphibolite is intruded extensively by the Rubberoid Granite (P_-MOru-mgm) and interlayered mesocratic metagranodiorite and pale-grey metamonzogranite with metamorphic rock (P_-MO-xmg-m) both of which have ages between 1804 and 1786 Ma. However, the oldest phase of the Minnie Creek batholith, which extensively intrudes the Leake Spring Metamorphics, is a foliated tonalite (GSWA 183205) with an igneous crystallization age of 1807 ± 3 Ma (Kirkland et al., 2009) which is taken to be the minimum age for deposition of this unit.

References

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Moorarie Supersuite (P_-MO-g)

Legend narrative

Undivided; granite and minor gabbro and metamorphosed equivalents

Rank	Supersuite
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-PO-md, P_-_au-sp, P_-ME-s, CP-LY-sepg (unconformable), P_-DU-g, P_-MW-od (intrusive)
Underlying units	P_-LS-xmd-mk, P_-BB-g, P_-CH-xmd-mk, P_-MG-xmh-mk, AP_-_ha-mgn, AP_-mgnl-YNAY, AP_-mgnw-YNAY, A-mngl-YNA, A-mngw-YNA
Primary mineralogy	biotite

Summary

The Moorarie Supersuite was intruded into the Gascoyne Province, and into the adjacent Yarlarweelor Gneiss Complex and Ashburton Basin, during the Capricorn Orogeny. The supersuite forms the Minnie Creek batholith in the centre of the Gascoyne Province, as well as plutons, dykes, and veins elsewhere. Although much of the granite in the western part of the Capricorn Orogen is now known to belong to younger and older supersuites, the Moorarie Supersuite still comprises a large volume of granite. The Moorarie Supersuite is dominated by granodiorite and monzogranite, and their metamorphosed equivalents, with a conspicuous paucity of coeval mafic rocks. The Minnie Creek batholith is notable for the presence of tonalite, quartz diorite, and some metagabbro.

Distribution

Granites of the Moorarie Supersuite intruded across the Gascoyne Province and into adjacent tectonic units. The Minnie Creek batholith in the Limejuice Zone is composed entirely of granites of the Moorarie Supersuite. The batholith has an exposed length of more than 170 km and is about 30–50 km wide. The western and eastern ends of the batholith are unconformably overlain by younger sedimentary rocks. Substantial volumes of coeval granites were emplaced into the Boora Boora and Mooloo Zones in the northern and southern parts of the region, respectively (Occhipinti and Sheppard, 2001; Martin et al., 2005). Reworked granites of the Moorarie Supersuite form basement to the Pooranoo Metamorphics in the Mangaroon Zone. Granites of the supersuite form plutons that intruded the Ashburton Fold Belt (Krapež and McNaughton, 1999), and large amounts of granite and pegmatite of the Moorarie Supersuite also intruded the Yarlarweelor Gneiss Complex during the Capricorn Orogeny (Occhipinti et al., 1998; Sheppard et al., 2003).

Lithology

In the Limejuice Zone the Minnie Creek batholith comprises biotite-bearing, porphyritic monzogranite, granodiorite, and tonalite plutons, with minor quartz diorite and syenogranite. Igneous muscovite is a very minor component of some granites. Although igneous structures and textures are typically well preserved, many of the rocks have undergone low-grade static metamorphism. Hornblende-bearing granites are rare, mainly being restricted to the quartz diorites, where hornblende is intergrown with biotite. Some tonalites contain intergrowths of recrystallized biotite and epidote, with the shapes of some intergrowths suggesting that they pseudomorphed amphibole. The granites are medium and coarse grained, and range from equigranular to coarsely porphyritic. Many of the granodiorites and tonalites are equigranular to sparsely porphyritic, whereas many of the monzogranites contain up to 30% tabular or round microcline or microperthite phenocrysts that may reach 6 cm in length. Basic and intermediate rocks, including fragments of layered mafic–ultramafic intrusions, are scattered through the batholith as rafts. Some basic rocks have associated net-vein structures indicative of mafic–felsic magma mingling. Round to elliptical basic to intermediate inclusions in the granites are widespread, although not abundant.

In the Mutherbukin Zone, Moorarie Supersuite rocks comprise foliated to gneissic biotite(–muscovite) metamonzogranite, metagranodiorite, and metatonalite. Farther south in the Mooloo Zone, the Moorarie Supersuite forms several large, sheet-like plutons striking in an easterly direction, and associated dykes. These comprise medium-grained, equigranular biotite(–tourmaline–muscovite) monzogranite and biotite(–muscovite) monzogranite, and porphyritic, fine- to medium-grained biotite metagranodiorite (Occhipinti and Sheppard, 2001).

In the Boora Boora Zone, granites of the supersuite are foliated and gneissic granodiorite, with subordinate tonalite and monzogranite. Low-strain areas show the rocks to contain primary biotite, or biotite and minor muscovite; there is no evidence for igneous hornblende. In the Mangaroon Zone, exposure of the Moorarie Supersuite is restricted to rafts or inliers of biotite monzogranite and granodiorite gneiss (Gooche Gneiss; Martin et al., 2005).

In the Yarlarweelor Gneiss Complex (the reworked northern margin of the Yilgarn Craton) Moorarie Supersuite rocks comprise sheets, dykes, and veins. The rock types include: coarse-grained to very coarse-grained, leucocratic biotite granodiorite, monzogranite, and syenogranite; biotite(–muscovite) pegmatite; and medium grained, equigranular to moderately porphyritic biotite granodiorite, monzogranite, and leucocratic tonalite (Sheppard et al., 2003). Mafic rocks are conspicuously absent.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Rock code		**P_-MO-g**
Additional lithologies	metagranitic rock, metagabbro	

Contact relationships

The Moorarie Supersuite intrudes a wide range of units. Over a large part of the Gascoyne Province the supersuite intrudes metasedimentary rocks of the Leake Spring Metamorphics. In the Mooloo Zone the supersuite intrudes metasedimentary rocks of the Moogie Metamorphics, and meta-igneous rocks of the Halfway Gneiss. In the Errabiddy Shear Zone and Yarlarweelor Gneiss Complex, the Moorarie Supersuite intrudes the Camel Hills Metamorphics, the Bertibubba Supersuite, and reworked Archean granitic gneisses (AP_-mgnl-YNAY, AP_-mgnw-YNAY). Along the northern edge of the Yilgarn Craton, the supersuite also intrudes Archean granitic gneisses (A-mngl-YNA, A-mngw-YNA) and late Archean granites.

The Moorarie Supersuite is unconformably overlain by the Pooranoo Metamorphics. This relationship is evident in the Limejuice Zone, but the effects of younger tectonic events have obscured the relationship in the Mangaroon and Mutherbukin Zones. The supersuite is intruded by granites of the Durlacher Supersuite, most notably in the Mangaroon, Boora Boora, and Mutherbukin Zones. The Moorarie Supersuite is unconformably overlain by sedimentary rocks of the Mesoproterozoic Edmund Group to the east and by sedimentary rocks of the Phanerozoic Carnarvon Basin to the west. Numerous dykes of the Neoproterozoic Mundine Well Dolerite Suite intrude the Moorarie Supersuite.

Geochronology

P_-MO-g	*Maximum*	*Minimum*
Age (Ma)	1817 ± 11	1776 ± 8
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1999a	Nelson, 2002

About 50 granites from the Moorarie Supersuite have been dated using SHRIMP U–Pb zircon techniques: the granites yield igneous crystallization ages between 1817 ± 11 Ma and 1776 ± 8 Ma. Overall, magmatism in the southern part of the Gascoyne Province, and adjacent Yarlarweelor Gneiss Complex, appears to be slightly older than in the Minnie Creek batholith and northern Gascoyne Province. The significance of this age trend is unclear.

Apparently older magmatism in the southern part of the province at c. 1825 Ma is restricted to a suite of volumetrically minor peraluminous, two-mica granite dykes and plugs (Occhipinti and Sheppard, 2001). The two dated rocks (GSWA 142924 and 142931) are leucocratic, and contain very low abundances of Zr (<60 ppm), Y (<5 ppm) and REE. These characteristics are shared by several other granites in the region that failed to yield igneous crystallization ages (Sheppard et al., 2007). These two samples were re-examined with cathodoluminescence in 2009, and extra spots analyzed with the SHRIMP. The two samples yield igneous crystallization ages of 1817 ± 11 Ma (GSWA 142931; Nelson, 1999a) and 1812 ± 9 Ma (GSWA 142924; Nelson, 1999b).

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DUMBIE GRANODIORITE
(P_-MOdu-ggp)

Legend narrative

Porphyritic, fine- to medium-grained granodiorite; minor monzogranite; medium to coarse tabular phenocrysts of K-feldspar; locally magnetite and allanite bearing

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmeb, P_-MO-gp, P_MOsc-gm (intrusive); P_-MEy-st (unconformable)
Underlying units	AP_-_ha-mgn, AP_-_ha-mgnl, AP_-_ha-mgnw, P_-MG-mk, P_-MG-mwa, P_-MG-mus (intrusive)
Primary mineralogy	biotite

Summary

The Dumbie Granodiorite is a distinctive unit that forms several large sheets in the Mooloo Zone in the southern Gascoyne Province. The granodiorite is characterized by spindly phenocrysts of K-feldspar, which constitute up to 30% of the rock. Allanite crystals up to 1.5 mm long are a common and widespread feature of the unit. Two samples of the granodiorite have been dated: the two ages are within uncertainty of each other at c. 1810 Ma.

Distribution

The Dumbie Granodiorite (P_-MOdu-ggp) is extensively exposed on northern GLENBURGH. On northeastern GLENBURGH, and on adjacent northwestern LANDOR and southern part of PINK HILLS, the Dumbie Granodiorite forms a large pluton of at least 76 km^2. The Dumbie Granodiorite forms large sheets intruded subparallel to the regional structural grain such as those on southeastern YINNETHARRA and southwestern PINK HILLS, as well as numerous dykes. The Dumbie Granodiorite also outcrops within the Chalba Shear Zone on western YINNETHARRA and westwards onto LOCKIER, as fault-bounded domains. The Dumbie Granodiorite outcrops as boulders, tors, and scattered whalebacks.

Derivation of name

The Dumbie Granodiorite is named after Dumbie Well in the northern part of GLENBURGH (Zone 50, MGA 434300E 7230800N), where the granodiorite is widely exposed.

Lithology

The most abundant rock type in the Dumbie Granodiorite is a grey, fine- to medium-grained granodiorite (or less commonly monzogranite) with up to 30% thin tabular phenocrysts of sanidine or microcline up to 1 cm long. Locally on LANDOR phenocrysts may reach 3 cm long. In places the phenocrysts are oval in shape. K-feldspar phenocrysts contain numerous small inclusions of round quartz and subhedral plagioclase. A few phenocrysts have minor development of microperthite. The groundmass consists of anhedral granular, fine-grained plagioclase, quartz, green–brown biotite, and minor microcline. Biotite is commonly recrystallized and aligned in the foliation. Accessory minerals comprise magnetite, ilmenite, allanite, zircon, and apatite. The large pluton on southern PINK HILLS comprises at least 30% 5–30 mm-long flattened K-feldspar phenocrysts that are strongly aligned within the regional fabric. The phenocrysts are set within a biotite-rich matrix containing plagioclase and quartz. The pluton is cut by discrete 5–30 m-thick dykes of fine grained and only slightly porphyritic Dumbie Granodiorite (e.g at site SPJPKH000807; Zone 50, MGA 489749E 7237114N), that locally are so fine grained that they appear glassy. Some of these dykes contain stubby, 1–2 mm-wide K-feldspar phenocrysts but only make up a maximum of <5% of the rock. Locally, the Dumbie Granodiorite contains small clusters of fine magnetite crystals. Hydrated allanite is a prominent accessory mineral forming brown prismatic crystals up to 1.5 mm long.

Inclusions of amphibolite, fine-grained granodiorite, and biotite schist are common in the Dumbie Granodiorite on LANDOR. These inclusions commonly contain a folded foliation, whereas the porphyritic biotite monzogranite typically only contains one foliation that is subparallel to the axial surfaces of folds contained within the inclusions.

On the southern part of PINK HILLS, medium- to coarse-grained seriate to porphyritic metagranodiorite shows a range of deformation textures from essentially undeformed through to gneissic in local high strain zones. Rafts and inclusions of the gneissic material are contained within, and the gneissic fabrics cut by, finer grained, weakly foliated granodiorite. Both samples were dated, the crystallization ages within uncertainty of each other. These relationships suggest that the Dumbie Granodiorite is in part syn-tectonic with respect to the D_{1n} episode of the Capricorn Orogeny.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite, Dumbie Granodiorite	MOdu-
Rock type	Igneous granitic	g
Lithname	granodiorite	g
1st qualifier	porphyritic	p
Rock code		**P_-MOdu-ggp**

Contact relationships

The Dumbie Granodiorite intrudes the Halfway Gneiss, and calc-silicate gneiss and interleaved amphibolite, actinolite schist, and tremolite schist of the Moogie Metamorphics. The unit is intruded by veins and dykes of medium-grained biotite(–muscovite) granite (P_-MO-gmeb) and coarse-grained granite and pegmatite (P_-MO-gp), and is intruded by the c. 1796 Ma Scrubber Granite (P_MOsc-gm). The main pluton and sheets of Dumbie Granodiorite are foliated, whereas the dykes cutting the regional structural grain at a high angle may be foliated or massive. On southern PINK HILLS the Dumbie Granodiorite is unconformably overlain by Edmund Group sedimentary rocks (P_-MEy-st).

Geochronology

P_-MOdu-ggp	*Maximum*	*Minimum*
Age (Ma)	1811 ± 9	1804 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2000a	Wingate et al., in prep.

The Dumbie Granodiorite was sampled at two localities for SHRIMP U–Pb zircon geochronology. A sample from a deformed portion of medium- to coarse-grained foliated to gneissic metagranodiorite on Pink Hills (GSWA 188975) yielded an igneous crystallization age of 1804 ± 5 Ma (Wingate et al., in prep.). Inclusions of this gneissic unit were included in only very weakly foliated finer-grained granodiorite (GSWA 159987) which yielded an igneous crystallization age of 1810 ± 9 Ma (Nelson, 2000a). Another sample (GSWA 159995) from a large sheet or dyke about 1 km southeast of Middle Well on Glenburgh (Zone 50, MGA 413600E 725500N) yielded an age of 1811 ± 6 Ma (Nelson, 2000b).

References

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KERBA GRANITE (P_-MOkb-gm)

Legend narrative

Equigranular medium-grained biotite monzogranite; locally foliated

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	AP_-_mngl (intrusive); P_-BYnt-xmo-ma (faulted)
Primary mineralogy	biotite

Summary

The Kerba Granite is lithologically identical to medium- to coarse-grained, massive, equigranular to sparsely porphyritic biotite monzogranite (P_-MO-gmeb), and is of the same age. It forms a large sheet intruded along the southeastern margin of the Yarlarweelor Gneiss Complex on MOORARIE.

Distribution

The Kerba Granite is a thick granite sheet in the Yarlarweelor Gneiss Complex that extends from about 4.5 km west of Kerba Bore to 6 km southeast of Top Minniarra Well on northern MOORARIE. The Kerba Granite is mainly massive, and outcrops as tors and pavements.

Derivation of name

The Kerba Granite is named after Kerba Bore on northern MOORARIE.

Lithology

The Kerba Granite consists of K-feldspar, plagioclase, quartz, and biotite, with accessory apatite, opaque minerals, and zircon. Fine-grained muscovite (sericite) partially replaces feldspar, plagioclase, and biotite grains. Locally, the granite is deformed, particularly close to the Kerba Fault and its contact with the Narracoota Formation, where the granite is well foliated to mylonitic. In the area east of Kerba Bore and south of Tommy Bore, the Kerba Granite contains abundant inclusions of Archean granitic gneiss.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite, Kerba Granite	MOkb-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
Rock code		**P_-MOkb-gm**

Contact relationships

The Kerba Granite mainly intruded reworked Archean granites and gneisses (AP_-_mngl-YNAY) of the Yarlarweelor Gneiss Complex, and tectonically interleaved Archean supracrustal rocks. The Kerba Granite is in faulted contact with Paleoproterozoic mafic plutonic rocks of the Narracoota Formation (P_-BYnt-xmo-ma) in the Bryah Group.

Geochronology

P_-MOkb-gm	*Maximum*	*Minimum*
Age (Ma)	1808 ± 6	1808 ± 6
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1998	Nelson, 1998

A sample of foliated monzogranite (GSWA 142851) from the Kerba Granite, 400 m southwest of Kerba Pool, yielded a SHRIMP U–Pb zircon date of 1808 ± 6 Ma, interpreted as the igneous crystallization age of the monzogranite (Nelson, 1998). Ten analyses indicated dates of 3298 to 2030 Ma and are interpreted to represent xenocrysts (Nelson, 1998).

References

Nelson, DR 1998, 142851: recrystallized monzogranite, Kerba Pool; Geochronology Record 367: Geological Survey of Western Australia, 4p.

SCRUBBER GRANITE
(P_-MOsc-gm)

Legend narrative

Biotite(–tourmaline) monzogranite, fine- to medium-grained, equigranular, commonly with abundant clusters of tourmaline; locally nodular texture; massive to weakly foliated

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-POb-mxq, P_-POb-mqef, P_-POb-mtef (unconformable); P_-MEy-st (faulted)
Underlying units	AP_-_ha-mgn, AP_-_ha-mgnl, AP_-_ha-mgnw, P_-MG-mk, P_-MGm-mtsf, P_-MOdu-ggp (intrusive)
Primary mineralogy	biotite

Summary

The Scrubber Granite forms several large sheet-like intrusions, as well as numerous, dykes, plugs, and veins, in the Mooloo Zone in the southern part of the Gascoyne Province. Most of the unit is composed of medium-grained, equigranular biotite(–tourmaline–muscovite) monzogranite. Tourmaline typically forms small crystals scattered through the groundmass, but in places, particularly on Daurie Creek, it forms striking ovoid clusters ('nodules') with quartz. Two samples of the unit selected for SHRIMP U–Pb zircon dating yielded igneous crystallization ages of c. 1800 Ma.

Distribution

The Scrubber Granite (P_-MOsc-gm) forms an extensive unit in the Mooloo Zone of the Gascoyne Province, extending 75 km in an east–west direction across the Glenburgh 1:250 000 sheet, from Landor westward onto Glenburgh and then to Daurie Creek. The unit is also present northeast of Glenburgh on southern Pink Hills and Yinnetharra. On Glenburgh the most abundant outcrop of the Scrubber Granite is 2 km southeast of Middle Well where abundant sheets, up to 3 km wide, intruded rocks of the Halfway Gneiss and Dumbie Granodiorite. On northwestern Landor, the Scrubber Granite forms a pluton of fine- to medium-grained, even-textured biotite(–tourmaline) monzogranite, which locally contains abundant ovoid clusters of tourmaline and biotite, northeast and northwest of Biddenew Well. The pluton comprises sheets that are commonly only a few metres thick, which trend roughly east. On southern Yinnetharra and Pink Hills the Scrubber Granite forms a discontinuous train of small intrusions that were emplaced into the Halfway Gneiss and Moogie Metamorphics. On Daurie Creek the Scrubber Granite forms a singular flattened ovoid-shaped, tourmaline-rich outcrop some 7 km^2 that intrudes an equally large and elongate intrusion of Dumbie Granodiorite.

Derivation of name

The Scrubber Granite is named after Scrubber Bore on central Landor (located at approximately Zone 50, MGA 466100E 7213100N).

Lithology

On northern Glenburgh, southern Yinnetharra and Pink Hills, sheets and veins of the Scrubber Granite are typically of medium-grained, equigranular biotite(–tourmaline–muscovite) monzogranite. Tourmaline may form small crystals scattered through the groundmass, or form ovoid clusters ('nodules') with quartz. In some instances the granite does not contain any biotite, but instead contains abundant muscovite. The sheets are easterly trending. The unit commonly outcrops as whalebacks and tors. The Scrubber Granite is typically massive, but locally well foliated.

Nodules of tourmaline and quartz are characteristic of the Scrubber Granite, although they are not common on Glenburgh. West of Glenburgh, on Daurie Creek, individual isolated and loosely interconnected nodules of tourmaline–quartz are very common within the Scrubber Granite. The variety of these nodules has been documented by Shewfelt et al. (2005). The nodules are composed of tourmaline and quartz, each making up about 45% of the nodule with minor amounts of plagioclase and K-feldspar. The tourmaline replaces both feldspar and biotite, apparently pseudomorphing these minerals where the nodules are best developed. In places, smaller tourmaline crystals are scattered through the groundmass of the Scrubber Granite; the timing of their crystallization relative to the igneous minerals in the groundmass is uncertain. Texturally, the clusters are medium grained and equigranular like their host granite; however, feldspar and biotite are either not present or only rare components. These nodules were studied in considerable detail by Shewfelt (2005) who concluded that they formed by the '...exsolution and rise of buoyant pockets or bubbles of volatile fluid derived from the crystallizing...' granite magma. Veins of quartz and tourmaline locally cut the Scrubber Granite.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite, Scrubber Granite	MOsc-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
Rock code		**P_-MOsc-gm**

Contact relationships

The Scrubber Granite intrudes the Halfway Gneiss, psammitic schist, calc-silicate gneiss, and marble of the Moogie Metamorphics, and Dumbie Granodiorite on northern Glenburgh and southern Yinnetharra and Pink Hills. North of Mount Gascoyne Creek, on northwestern Landor, dykes and veins of the Scrubber Granite intrude porphyritic biotite granodiorite of the Dumbie Granodiorite. On the southeast side of Mount Gascoyne Creek, the Scrubber Granite is faulted against siltstone of the Edmund Group. On southern Pink Hills the

Scrubber Granite is unconformably overlain by low-grade metasedimentary rocks of the Mount James Subgroup and in faulted contact with sediments of the Edmund Group.

Geochronology

P_-MOsc-gm	*Maximum*	*Minimum*
Age (Ma)	1800 ± 7	1796 ± 6
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2001	Nelson, 2000

A sample of Scrubber Granite (GSWA 159996) from about 2.5 km southeast (Zone 50, MGA 413186E 7224116N) of Middle Well yielded an igneous crystallization age of 1796 ± 6 Ma (Nelson, 2000). This result is within uncertainty of the age of 1800 ± 7 Ma for the Scrubber Granite on LANDOR (Nelson, 2001). These two results are similar to igneous crystallization ages between 1810 and 1795 Ma for dykes and sheets of medium-grained, biotite granite (P_-MO-gme, P_-MOkb-gm) on MOORARIE and MARQUIS (Occhipinti and Myers, 1999; Sheppard and Swager, 1999).

References

Nelson, DR 2000, 159996: biotite monzogranite, Claypan Bore; Geochronology Record 231: Geological Survey of Western Australia, 4p.

Nelson, DR 2001, 168939: biotite monzogranite, Trickery Bore; Geochronology Record 209: Geological Survey of Western Australia, 4p.

Occhipinti, SA and Myers, JS 1999, Geology of the Moorarie 1:100 000 sheet: Geological Survey of Western Australia, 1:100 000 Geological Series Explanatory Notes, 20p.

Sheppard, S and Swager, CP, 1999, Geology of the Marquis 1:100 000 sheet: Geological Survey of Western Australia, 1:100 000 Geological Series Explanatory Notes, 21p.

Shewfelt, DA 2005, The nature and origin of Western Australian tourmaline nodules: a petrologic, geochemical and isotopic study: University of Saskatchewan, Saskatoon, MSc thesis (unpublished).

Shewfelt, DA, Ansdell, KM and Sheppard, S 2005, The origin of tourmaline nodules in granites; preliminary findings from the Paleoproterozoic Scrubber Granite: Geological Survey of Western Australia, Annual Review 2004–05, p. 59–63.

Moorarie Supersuite; subunit (P_-MO-gge)

Legend narrative

Equigranular to sparsely porphyritic, medium-grained biotite(–muscovite) granodiorite

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gglb, P_-TT-gpvt
Underlying units	P_-MO-gte
Primary mineralogy	biotite

Summary

Equigranular to sparsely porphyritic, medium-grained biotite(–muscovite) granodiorite forms a large intrusion within the Minnie Creek batholith on northern EUDAMULLAH. The granodiorite is pale grey or greenish-grey, and massive to locally flow banded. A sample of the granodiorite selected for SHRIMP U–Pb zircon dating yielded an igneous crystallization age of 1783 ± 5 Ma.

Distribution

Equigranular biotite(–muscovite) granodiorite forms an elongate intrusion striking southeast, which covers more than 500 km^2 on the northern half of EUDAMULLAH, and extends onto the far southwestern corner of MANGAROON.

Lithology

This unit comprises pale grey or greenish-grey, massive to locally flow banded, biotite(–muscovite) granodiorite and lesser biotite monzogranite; these two rock types typically grade into each other. The majority of the rocks are medium grained, but they may be coarse or fine grained in places. The granodiorite and monzogranite are mostly equigranular or sparsely porphyritic, but varieties with up to 10% tabular K-feldspar phenocrysts 1–3 cm long are locally abundant. Biotite is commonly the sole mafic mineral, but muscovite with a similar grain size to biotite is present locally. A local flow foliation is defined by tabular K-feldspar phenocrysts, inclusions of granite, and biotite-rich schlieren. Plagioclase is commonly a pale green colour owing to partial replacement by fine-grained epidote.

The granodiorite and monzogranite contain scattered round to elliptical inclusions up to about 10 cm in diameter of sparsely porphyritic microgranite. Phenocrysts in the inclusions are the same size and shape as those in the host granite and, in some instances, straddle the contact between inclusion and host rock. These features indicate that the inclusions represent globules of magma within the host granodiorite or monzogranite magma. The granodiorite and monzogranite are intruded by dykes and veins of leucocratic biotite micromonzogranite and microsyenogranite, and minor pegmatite.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname	granodiorite	g
1st qualifier	even-grained/even textured/ equigranular	e
Rock code		**P_-MO-gge**
Additional lithologies	monzogranite	

Contact relationships

Equigranular biotite(–muscovite) granodiorite contains inclusions and, in places, rafts of equigranular to sparsely porphyritic biotite tonalite and granodiorite (P_-MO-gte) along the southern margin of the intrusion. The granodiorite is intruded over a wide area on northwestern EUDAMULLAH by numerous dykes and veins of leucocratic, equigranular biotite granodiorite or monzogranite (P_-MO-gglb), as well as sparse dykes and veins of muscovite- and tourmaline-bearing pegmatite (P_-TT-gpvt).

Geochronology

P_-MO-gge	*Maximum*	*Minimum*
Age (Ma)	1783 ± 5	1783 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Bodorkos et al., 2006	Bodorkos et al., 2006

At Narunah Hill on northwestern EUDAMULLAH, a sample of equigranular medium-grained biotite(–muscovite) granodiorite (P_-MO-gge) yielded a SHRIMP U–Pb crystallization age of 1783 ± 5 Ma (GSWA 88414). The dated sample is typical of much of this intrusion.

References

Bodorkos, S, Love, GJ, Nelson, DR, and Wingate, MTD 2006, 88414: porphyritic monzogranite, Nurunah Hill; Geochronology Record 612: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-ggev)

Legend narrative

Leucocratic, equigranular biotite–muscovite granodiorite; fine to medium grained; massive to weakly foliated

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	P_-DA-xmgt-mgg, P_-DA-mgtw, AP_-mgnl-YNAY, A-mgmu-YNAY, P_-MO-mgmp (intrusive)

Summary

Leucocratic, equigranular biotite–muscovite granodiorite comprises several small plugs and associated dykes in the Paradise Zone of the Gascoyne Province and in the Errabiddy Shear Zone. Most of the rocks are massive or weakly foliated. Three samples from this unit have been dated, with igneous crystallization ages of 1802 ± 9 Ma, 1817 ± 11 Ma, and 1812 ± 9 Ma.

Distribution

Leucocratic, equigranular biotite–muscovite granodiorite comprises several small plugs, and associated dykes, and a series of sheets in the Paradise Zone and Errabiddy Shear Zone. A small plug (~2 km^2) of leucocratic muscovite–biotite granite intrudes leucocratic granitic gneiss about 4 km east of Wheelo Bore (Zone 50, MGA 430740E 7197540N) within the Errabiddy Shear Zone on ERRABIDDY. Veins and dykes of fine-grained leucocratic biotite–muscovite granodiorite also intrude the country rocks up to 3 km away from the plug. On GLENBURGH leucocratic biotite–muscovite granodiorite is mainly confined to a small (about 1 km^2) plug about 4 km north-northeast of Challenger Well (Zone 50, MGA 444040E 7204940N), and to two main outcrops west of Gregory Bore, both in the eastern part of GLENBURGH in the Paradise Zone. The small plug is about 1 km in diameter, but veins and dykes of fine-grained leucocratic biotite–muscovite granodiorite extend up to about 2 km from the plug. Sheets of leucocratic biotite–muscovite granodiorite that intrude granitic gneiss of the Dalgaringa Supersuite east of Gregory Bore are also assigned to this unit (P_-MO-ggev). These granite sheets intrude the granitic gneiss subparallel to fold-axial surfaces in the gneiss and are also locally well foliated.

Lithology

The plugs, veins, and dykes of leucocratic, equigranular biotite–muscovite granodiorite are massive or weakly foliated. The rocks contain up to about 10% combined muscovite and biotite. Some samples contain traces of garnet. The accessory minerals are zircon and apatite. The proportion of plagioclase to microcline indicates that the rocks are mainly granodiorite with minor monzogranite. All samples show a static or weak dynamic metamorphic overprint: quartz is recrystallized to fine-grained polygonal aggregates, plagioclase is largely replaced by fine-grained sericite, clinozoisite, and ?albite, and myrmekitic textures are developed.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname	granodiorite	g
1st qualifier	even-grained/even textured/ equigranular	e
2nd qualifier	muscovite	v
Rock code		**P_-MO-ggev**

Contact relationships

The plug of leucocratic biotite–muscovite granodiorite on GLENBURGH intrudes foliated and gneissic granites of the 2005–1970 Ma Dalgaringa Supersuite. On ERRABIDDY, leucocratic granodiorite intrudes granitic gneiss (AP_-mgnl-YNAY), strongly foliated Archean porphyritic granite (A-mgmu-YNAY), and coarse-grained metagranite and pegmatite (P_-MO-mgmp). Several dykes of muscovite pegmatite intrude the plug of biotite–muscovite granodiorite on GLENBURGH.

Geochronology

P_-MO-ggev	*Maximum*	*Minimum*
Age (Ma)	1817 ± 11	1802 ± 9
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1999a	Nelson, 1998

A sample (GSWA 142900) of leucocratic biotite–muscovite granodiorite from the plug on ERRABIDDY yielded a crystallization age of 1802 ± 9 Ma (Nelson, 1998). This sample also contained xenocrysts, the ages of which included a component at 1923 ± 11 Ma. A biotite–muscovite granodiorite sample from the plug on GLENBURGH (GSWA 142924) yielded an igneous crystallization age of 1827 ± 14 Ma (Nelson, 1999b), together with xenocrysts dated at 1980 ± 15 Ma and older (Nelson, 1999b). A biotite–muscovite granodiorite sheet east of Gregory Bore on GLENBURGH (GSWA 142931) yielded a crystallization age of 1824 ± 9 Ma, and contained 17 xenocrysts with a mean age of 2000 ± 7 Ma (Nelson, 1999a).

Both samples from GLENBURGH were re-examined in 2009 because of their apparently anomalously old ages compared with the rest of the supersuite. The SHRIMP mounts for both were imaged using cathodoluminescence (CL) to examine whether the analysed grains contained rims, and to determine the locations of the analyses in relation to any rims. Zircons from sample GSWA 142924 contained high-U rims that were not identified or analysed in 1999. Most rims are highly enriched in U and common Pb, and only one could be analysed successfully. Although this analysis is 12% reversely discordant, it is retained because the discordance probably reflects sputtering characteristics different to those in the zircon standard, which contains lower U, and does not affect the $^{207}Pb^{*}/^{206}Pb^{*}$ ratio (Nelson, 1999b.). This analysis indicated a date indistinguishable from six other zircon analyses, which together define a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1812 ± 9 Ma. Zircons from sample GSWA 142931 do not contain any obvious rims. Eleven analyses of 11 zircons yield a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1817 ± 11 Ma, interpreted as the igneous crystallization age of the granodiorite (Nelson, 1999a).

References

Nelson, DR 1998, 142900: muscovite–biotite monzogranite, Dewars Bore; Geochronology Record 360: Geological Survey of Western Australia, 4p.

Nelson, DR 1999a, 142931: biotite–muscovite–oligoclase granodiorite dyke, Two Wells; Geochronology Record 318: Geological Survey of Western Australia, 4p.

Nelson, DR 1999b, 142924: biotite–muscovite granodiorite, Two Wells Well; Geochronology Record 328: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-gglb)

Legend narrative

Leucocratic, equigranular biotite granodiorite or monzogranite; biotite forms clots; fine- and medium-grained

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	Mundine Well Dolerite Suite (P_-MW-od)
Underlying units	P_-MO-gge
Primary mineralogy	biotite

Summary

Leucocratic, equigranular biotite granodiorite or monzogranite is a minor unit of the Moorarie Supersuite. The unit forms a series of dykes and veins, characterized by clots of biotite that intrude plutons of the Minnie Creek batholith on northwestern EUDAMULLAH. A sample of the granodiorite selected for SHRIMP U–Pb zircon dating yielded an igneous crystallization age of 1777 ± 8 Ma.

Distribution

Leucocratic, equigranular biotite granodiorite or monzogranite forms a series of east-southeast trending dykes and veins south of Minnie Creek Homestead on EUDAMULLAH over an area about 20 km long and 5 km wide.

Lithology

Leucocratic, equigranular biotite granodiorite or monzogranite forms a series of dykes and veins striking east-southeast, of which the largest dyke is nearly 9 km long and up to 100 m wide. The dykes contain up to a few percent phenocrysts of tabular microcline less than about 4 mm long. Biotite, which comprises about 3% or less of the granodiorite and monzogranite, typically forms clots or, locally, phenocrysts. Round quartz phenocrysts about 4–5 mm in diameter are present in places. Muscovite of probable igneous origin is a very minor constituent of the granodiorite and monzogranite. Examination of plagioclase twinning suggests that it is oligoclase in composition.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname	granodiorite	g
1st qualifier	leuco-	l
2nd qualifier	biotite	b
Rock code		**P_-MO-gglb**

Contact relationships

Leucocratic, equigranular biotite granodiorite or monzogranite forms a series of dykes and veins that intrude equigranular medium-grained biotite(–muscovite) granodiorite (P_-MO-gge) on northwestern EUDAMULLAH. The dyke margins are mostly sharp and planar, but locally they are cuspate and irregular suggesting mingling with the host granodiorite. At Nurunah Hill southwest of Minnie Creek Homestead, leucocratic biotite granodiorite is mingled with mesocratic microgranite.

Geochronology

P_-MO-gglb	*Maximum*	*Minimum*
Age (Ma)	1777 ± 8	1777 ± 8
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Bodorkos et al., 2006	Bodorkos et al., 2006

Leucocratic equigranular biotite granodiorite has been dated on northwestern EUDAMULLAH at 1777 ± 8 Ma. Granodiorite or monzogranite dykes in this area intrude equigranular medium-grained biotite(–muscovite) granodiorite (P_-MO-gge) dated at 1783 ± 5 Ma, of which sample GSWA 88414 is representative.

References

Bodorkos, S, Love, GJ, Nelson, DR and Wingate, MTD 2006, 88415: porphyritic granodiorite dyke, Nurunah Hill; Geochronology Record 613: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-gma)

Legend narrative

Pink, fine-grained equigranular to seriate biotite monzogranite

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-au-sp
Underlying units	P_-LS-mhs; P_-LS-md; P_-LS-mwa

Summary

Pink, fine-grained equigranular to seriate biotite monzogranite is a minor component of the Moorarie Supersuite. Most of the unit comprises a pluton at the eastern end of the Minnie Creek batholith, where it is unconformably overlain by the Mount Augustus Sandstone and Edmund Group.

Distribution

Pink, fine-grained equigranular to seriate biotite monzogranite is mainly confined to an east-trending pluton at least 11 km long and up to 2.5 km wide centred on Bassit Bore on the eastern edge of MOUNT PHILLIPS. The pluton may be larger, but it disappears to the east under the Mount Augustus Sandstone and Edmund Group. Dykes of pink, fine-grained equigranular biotite monzogranite intrude surrounding granites of the Minnie Creek batholith.

Lithology

Pink, fine-grained equigranular to seriate biotite monzogranite is homogeneous, with the exception of the eastern part of the intrusion, which locally is medium grained.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	fine-grained	a
Rock code		**P_-MO-gma**

Contact relationships

Pink, fine-grained equigranular to seriate biotite monzogranite intrudes, and contains rafts of pelitic and psammitic schist (P_-LS-mhs), amphibolite and metadolerite (P_-LS-md), and amphibolite and actinolite–plagioclase schist (P_-LS-mwa) of the Leake Spring Metamorphics. The relationship with enclosing porphyritic biotite monzogranite (P_-MO-gmp) is unknown. Pink, fine-grained equigranular to seriate biotite monzogranite is unconformably overlain by siliciclastic rocks of the ?latest Paleoproterozoic to ?earliest Mesoproterozoic Mount Augustus Sandstone.

Geochronology

P_-MO-gma	*Maximum*	*Minimum*
Age (Ma)	1807	1620
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Kirkland et al., 2009	

Pink, fine-grained equigranular biotite monzogranite has not been dated, but is assumed to be coeval with other granites comprising the Minnie Creek batholith, which are dated at c. 1805–1780 Ma. The monzogranite is unconformably overlain by the Mount Augustus Sandstone, which was deposited at about 1620 Ma.

References

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009, 183205: schistose metatonalite, Mallet Well; Geochronology Record 753: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-gmal)

Legend narrative

Fine-grained, leucocratic biotite monzogranite

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	P_-MO-gmp, P_-MO-gge, P_-LS-mlsm
Primary mineralogy	biotite

Summary

Fine-grained, leucocratic biotite monzogranite forms two very small plugs, as well as numerous veins and dykes that intrude all the main phases of the Minnie Creek batholith. A sample of the monzogranite selected for SHRIMP U–Pb zircon dating yielded an igneous crystallization age of 1794 ± 4 Ma. This age is nominally older than some of the granites in the batholith that the monzogranite intrudes.

Distribution

Fine-grained, leucocratic biotite micromonzogranite is a minor, though widespread, unit of the Moorarie Supersuite. It forms two very small plugs, one in the southwestern corner of MANGAROON, and the other on the western part of MOUNT PHILLIPS, in addition to numerous veins and dykes up to 3 m wide that intrude all the main phases of the Minnie Creek batholith. The largest of the plugs is only about 1 km^2.

Lithology

The leucocratic biotite micromonzogranite is typically a massive, sugary, and equigranular rock almost free of inclusions. Biotite is the sole mafic mineral, and may form fine-grained clots. The micromonzogranite plug centred about 1 km southeast of Christmas Well on the western edge of MOUNT PHILLIPS has pods and segregations of pegmatite in addition to being intruded by pegmatite veins and dykes.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	fine-grained	a
2nd qualifier	leuco-	l
Rock code		**P_-MO-gmal**

Contact relationships

Leucocratic biotite micromonzogranite comprises numerous veins and dykes that intrude all the main phases of the Minnie Creek batholith on EUDAMULLAH, MOUNT PHILLIPS, and southwestern MANGAROON.

Geochronology

P_-MO-gmal	*Maximum*	*Minimum*
Age (Ma)	1794 ± 4	1794 ± 4
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2005a	Nelson, 2005a

A sample (GSWA 178025) of a 2–4 m wide dyke of massive, leucocratic micromonzogranite was collected about 5 km west-southwest of Shearing Shed Bore, on southwestern MANGAROON. The sample yielded a date of 1794 ± 4 Ma, interpreted as the igneous crystallization age of the micromonzogranite (Nelson, 2005a). Dykes of leucocratic micromonzogranite have intruded medium- to coarse-grained tonalite (P_-MO-gti) dated at 1783 ± 5 Ma by Nelson (2005b; GSWA 178024). The age of 1794 ± 4 Ma determined for the dyke appears to contradict the crosscutting relationships between the dyke and the medium- to coarse-grained tonalite. However, the apparent contradiction can be explained if the uncertainties have been underestimated or the dates were derived from units that intruded over several million years (Nelson, 2005b). Alternatively, the zircon dated at 1794 ± 4 Ma may reflect an inherited component in the leucocratic micromonzogranite.

References

Nelson, DR 2005a, 178025: biotite monzogranite dyke, Shearing Shed Bore; Geochronology Record 534: Geological Survey of Western Australia, 4p.

Nelson, DR 2005b, 178024: biotite granodiorite, Minga Well; Geochronology Record 533: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-gmap)

Legend narrative

Leucocratic porphyritic micromonzogranite; locally flow banded

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	P_-MO-gmeb; P_-MO-gmp; P_-MO-gmpi
Primary mineralogy	biotite

Summary

Dykes of leucocratic porphyritic micromonzogranite intrude plutons of the Minnie Creek batholith on Mount Phillips and Mount Augustus. Some of the dykes are flow banded. The dykes have a texture similar to some of the porphyritic monzogranites in the batholith, suggesting that the dykes were feeders to some higher level plutons. A sample of a dyke selected for SHRIMP U–Pb zircon dating yielded an igneous crystallization age of 1782 ± 7 Ma.

Distribution

Leucocratic porphyritic micromonzogranite forms north-northeast to northeast trending dykes that intrude plutons of the Minnie Creek batholith over a wide area on Mount Phillips and Mount Augustus. Most are too small to show on the maps, the exception being a swarm of dykes over an area of about 10 km^2 east of Cattlecamp Well in the southeastern corner of Mount Phillips. The largest of the dykes is more than 3 km long and up to 10 m wide. This unit also forms a plug about 1.5 km east of Calamity Well on western Mount Phillips.

Lithology

Leucocratic porphyritic micromonzogranite forms dykes up to 10 m wide. The micromonzogranite may be flow banded, very fine grained, and aphyric at dyke margins, grading to a fine-grained core with up to about 35% phenocrysts of squat tabular K-feldspar, anhedral quartz and euhedral plagioclase. The rocks are locally schistose, along with the enclosing granites. The plug east of Calamity Well consists of dark grey rhyolite, which is white on weathered surfaces. The rock comprises about 5% phenocrysts of K-feldspar, plagioclase, and quartz about 1 mm in diameter in a microcrystalline groundmass. A weakly schistose dyke at site SXSMTP007292 (Zone 50, MGA 447885E 7304323N) sampled for thin section, shows 1–2 mm euhedral and subhedral phenocrysts of quartz, K-feldspar, and plagioclase in a very fine grained recrystallized groundmass of quartz and feldspar, and sericite. The rock contains minor recrystallized biotite microphenocrysts inside feldspar phenocrysts, some micrographic and microperthitic textures, and extensive secondary sericite, calcite and fluorite. Pseudomorphed microphenocrysts of ?allanite are also present.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	fine-grained	a
2nd qualifier	porphyritic	p
Rock code		**P_-MO-gmap**

Contact relationships

Dykes of leucocratic porphyritic micromonzogranite mainly intrude: medium- and coarse-grained porphyritic biotite monzogranite (P_-MO-gmp); medium- to coarse-grained, equigranular to porphyritic, inclusion-rich mesocratic biotite monzogranite (P_-MO-gmpi); and equigranular, medium- and coarse-grained biotite monzogranite (P_-MO-gmeb). Given that they intrude the equigranular, medium- and coarse-grained biotite monzogranite dated on southwestern Mount Augustus at 1782 ± 5 Ma, the leucocratic porphyritic micromonzogranite dykes are one of the youngest units in the batholith.

Geochronology

P_-MO-gmap	*Maximum*	*Minimum*
Age (Ma)	1782 ± 7	1782 ± 7
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Kirkland et al., 2009	Kirkland et al., 2009

A 10 m-thick dyke of leucocratic porphyritic biotite micromonzogranite about 3 km east of Mount Phillips Homestead (site SXSMTP007231; Zone 50, MGA 432693E 7301516N) was sampled for SHRIMP U–Pb zircon geochronology (GSWA 180933). An igneous crystallization age of 1782 ± 7 Ma is provided by a single group of 30 analyses of 30 zircons (Kirkland et al., 2009). There is also one slightly discordant outlier at 1891 ± 42 Ma interpreted as a xenocryst. This age is one of the youngest obtained from the Minnie Creek batholith, consistent with the field relationships.

References

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009, 180933: monzogranite dyke, Mount Phillips Homestead; Geochronology Record 754: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-gmeb)

Legend narrative

Massive, equigranular to sparsely porphyritic biotite monzogranite; medium- and coarse-grained; minor muscovite in places; includes some granodiorite and minor leucocratic tonalite

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmal, P_-DUdn-gmp, P_-DU-gmvt, P_-DU-mgmb, P_-MO-gmp (intrusive); P_-POb-mxq, P_-POb-mqef, P_-POb-mtef, P_-POs-mtqs, P_-_au-sp (unconformable)
Underlying units	AP_-_ha-mgnl, P_-LS-mlsg, P_-MO-gmp, P_-MO-mgts, P_-MO-xmg-m (intrusive)
Primary mineralogy	biotite

Summary

Equigranular biotite monzogranite is a major component of the Moorarie Supersuite, and was emplaced into the central and southern Gascoyne Province, the Errabiddy Shear Zone, and the Yarlarweelor Gneiss Complex. The monzogranite is typically medium and coarse grained, and reasonably homogeneous with few inclusions. Most of the unit contains less than a few percent tabular K-feldspar phenocrysts, but locally it is moderately porphyritic. The monzogranite may grade to granodiorite in parts. Three samples from the unit selected for SHRIMP U–Pb zircon dating yielded a range of igneous crystallization ages from 1801 ± 7 Ma to 1783 ± 5 Ma.

Distribution

In the Minnie Creek batholith, the equigranular monzogranite forms a very large (>50 km by 20 km) east-southeast trending intrusion in the southeast corner of Mount Phillips and the adjacent southwest corner of Mount Augustus, as well as two smaller, equidimensional intrusions, each about 50 km^2, on Eudamullah and Mount Phillips. Farther south in the Limejuice Zone on Candolle, equigranular monzogranite forms two intrusions, each of which outcrops over ~ 30 km^2. In the Mooloo Zone in the southern part of the Gascoyne Province, medium-grained equigranular biotite(–muscovite) monzogranite forms a large, elongate, southeasterly trending pluton on southern Yinnetharra and northern Glenburgh and as a east-southeasterly trending pluton between Mia Well in the northwestern part of Glenburgh and Burrin Bore in the central part. Elsewhere in the Mooloo Zone, medium-grained biotite(–muscovite) granite forms sheets, veins, and dykes. This unit is much less abundant in the Paradise Zone, forming scattered veins and dykes that are commonly too small to be shown on the map.

In the Errabiddy Shear Zone southwest of Pines Bore on Errabiddy, a pluton of medium-grained biotite–(muscovite) granite intrudes migmatitic pelitic gneiss of the Quartpot Pelite. The pluton is about 10 km long and 5 km wide, and strikes in an easterly direction. In the Yarlarweelor Gneiss Complex on Marquis, equigranular biotite granite forms a large (>60 km^2) crescent-shaped pluton west of Mount Marquis that is exposed as low, rounded, bouldery hills. Equigranular biotite monzogranite also comprises a swarm of dykes that intruded granite gneisses around the Morris Fault on central Marquis. Most of the dykes strike in one of two orientations: between about 90–120° and 150–160°. About 3 km east-northeast of Weedarra Bore (Zone 50, MGA 571140E 7187850N), dykes trending in each of the orientations intruded the other, indicating that they were contemporaneous. Some of the dykes in the 150–160° orientation have a sigmoidal shape, consistent with emplacement during dextral strike-slip faulting. The veins and dykes are mostly less than 2 m wide, but locally dykes may reach 5 m in width.

Lithology

Equigranular, medium- and coarse-grained biotite monzogranite is typically a reasonably homogeneous rock type with few inclusions, although locally it is moderately porphyritic and rich in inclusions of porphyritic or mesocratic microgranite. Most of the unit contains less than a few percent tabular K-feldspar phenocrysts. Biotite, some of which comprises clots up to 7 mm in diameter, constitutes about 10% of the rock. Most equigranular monzogranite is massive, but east and southeast of Mount Phillips Homestead, the monzogranite locally displays flow banding or an igneous layering. This is developed on a scale from a few decimetres to a metre or two, and reflects layers with different grain sizes or presence and absence of K-feldspar phenocrysts.

In places equigranular biotite monzogranite is heterogeneous and inclusion rich. For example SXSMTP007333 (Zone 50, MGA 442354E 7297435N) medium-grained seriate or sparsely porphyritic biotite monzogranite contains numerous screens and inclusions of mesocratic microgranite. The inclusions are round with irregular to cuspate margins, and the inclusions contain xenocrysts of feldspar and quartz identical to those in the host monzogranite. Zones such as these are interpreted to reflect mingling between two separate granite magmas.

Medium-grained equigranular biotite(–muscovite) monzogranite grades to granodiorite, and locally consists of leucocratic tonalite. The textures of the rocks range from massive to distinctly foliated, but all show extensive recrystallization at low-grade conditions. The original igneous mineralogy is quartz, plagioclase, microcline, and biotite, with or without minor muscovite. The micas make up 5–15% of the rock, typically less than 10%. Accessory minerals are magnetite, minor amounts of ilmenite, allanite, and zircon.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	even-grained/even textured/ equigranular	e
2nd qualifier	biotite	b
Rock code		**P_-MO-gmeb**
Additional lithologies	granodiorite	

Contact relationships

In the central Gascoyne Province equigranular biotite monzogranite intrudes various units of the Leake Spring Metamorphics, including pelitic and psammitic schist (P_-LS-mhs; P_-LS-mlsm). Equigranular biotite monzogranite also intrudes at least two other phases of the Minnie Creek batholith namely: interleaved, gneissose to schistose, mesocratic biotite granodiorite to monzogranite and leucocratic muscovite(–biotite) monzogranite (P_-MO-xmg-m); and porphyritic biotite monzogranite (P_-MO-gmp).

The contact between equigranular biotite monzogranite and coarse-grained porphyritic biotite monzogranite (P_-MO-gmp) is exposed at several places on Mount Phillips and Mount Augustus. At two localities about 6 and 6.5 km west-southwest of Samuel Bore on Mount Augustus, medium- to coarse-grained equigranular biotite monzogranite contains rafts or inclusions of coarse-grained strongly porphyritic biotite monzogranite. In the southwest corner of Mount Augustus, the contact between a plug of equigranular biotite monzogranite and enclosing porphyritic monzogranite is well exposed. Locally (Zone 50, MGA 451407E 7296444N) there are inclusions of strongly porphyritic coarse-grained monzogranite with diffuse contacts within equigranular monzogranite. Nearby (Zone 50, MGA 451388E 7296552N) a sharp but locally irregular contact between the two phases is exposed; inclusions of either phase may be found in the other. Collectively, these field relationships suggest that the parent magmas to these two units mingled and are, therefore, coeval. At two localities on Mount Phillips the relationship is more equivocal; medium-grained equigranular biotite monzogranite or granodiorite appears slightly finer grained at the contact, and contains scattered large phenocrysts of quartz and K-feldspar like those in the strongly porphyritic monzogranite. These observations suggest that the equigranular monzogranite is younger than the porphyritic monzogranite.

The contact between medium- to coarse-grained, equigranular biotite monzogranite and schistose, medium-grained, mesocratic biotite granodiorite (P_-MO-mgts) is exposed about 7.5 km west of Samuel Bore on the southwestern part of Mount Augustus; the contact marked by intrusion of leucocratic muscovite–biotite micromonzogranite dykes and a brittle fault, and the relative ages of the two granites cannot be established.

In the Limejuice Zone on central and southern Candolle equigranular biotite monzogranite is unconformably overlain by the Mount Augustus sandstone (P_-_au-sp). The more northerly pluton intrudes foliated metagranodiorites of the Moorarie Supersuite (P_-MO-mgg), contains a raft of Leake Spring Metamorphics calc-silicate rock (P_-LS-mk), is intruded by leucocratic tourmaline-bearing granites (P_-DU-gmvt) of the Durlacher Supersuite and unconformably overlain by sedimentary rocks of the Edmund Group (P_-MEy-st).

In the Paradise and Mooloo Zones in the southern Gascoyne Province, equigranular biotite(–muscovite) granite intrudes the Halfway Gneiss, Moogie Metamorphics, foliated and gneissic granites of the Dalgaringa Supersuite, the Nardoo Granite, and Dumbie Granodiorite. On southern Yinnetharra around Mount Steere, the biotite monzogranite is poorly exposed but is probably intrusive into the basement leucocratic gneisses of the Halfway Gneiss (AP_-_ha-mgnl). The monzogranite is intruded by small stocks of granite from both the Moorarie and Durlacher Supersuites (P_-MO-gmp, P_-DU-mgmb) and unconformably overlain by low grade metasedimentary rocks of the Mount James Subgroup (P_-POb-mxq, P_-POb-mqef, P_-POb-mtef, P_-POs-mtqs). Plutons of medium-grained biotite(–muscovite) monzogranite in the northern part of Glenburgh contain numerous screens or large rafts of country rock.

In the Yarlarweelor Gneiss Complex, medium-grained equigranular monzogranite intruded the granitic gneisses, as well as interleaved amphibolite and metasedimentary rocks, and the Yamagee Granite. Equigranular biotite monzogranite was intruded by the c. 1620 Ma Discretion Granite about 7 km east of Cardingie Bore (Zone 50, MGA 566140E 7210050N) and 3.4 km southwest of Round Yard Bore (Zone 50, MGA 570840E 7206950N) on Marquis.

Geochronology

P_-MO-gmeb	*Maximum*	*Minimum*
Age (Ma)	1801 ± 7	1783 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1998a	Kirkland et al., 2009

Equigranular biotite monzogranite intruded and mingled with coarse-grained strongly porphyritic biotite monzogranite (P_-MO-gmp), which is dated on the southwestern corner of Eudamullah at 1795 ± 8 Ma (Evans et al., 2003). In addition, equigranular biotite monzogranite in the southwestern corner of Mount Augustus has been dated at 1783 ± 5 Ma (GSWA 180938). Equigranular biotite monzogranite is intruded along the eastern edge of Mount Phillips by an undated swarm of dykes of leucocratic porphyritic micromonzogranite (P_-MO-gmlp). In the Yarlarweelor Gneiss Complex on Marquis, a sample of biotite monzogranite (GSWA 142856) from the pluton west of Round Yard Bore (Zone 50, MGA 570440E 7108350N) was dated at 1801 ± 7 Ma (Nelson, 1998a). One of the dykes from the swarm centred on the Morris Fault on Marquis, about 2 km southwest of Dune Bore, was dated at 1797 ± 4 Ma (Nelson, 1998b).

References

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009, 180938: monzogranite, Leake Spring: Geochronology Record 751: Geological Survey of Western Australia, 4p.

Nelson, DR 1998b, 142852: recrystallized monzogranite dyke, Dunes Well; Geochronology Record 368: Geological Survey of Western Australia, 4p.

Nelson, DR 1998a, 142856: monzogranite, west of Round Yard Bore; Geochronology Record 372: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-gml)

Legend narrative

Massive, equigranular, leucocratic biotite monzogranite; medium- and coarse-grained

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-POb-mtef (unconformable), P_-MO-gmal, P_-MW-od (intrusive)
Underlying units	P_-MO-gmp, P_-MO-gge
Primary mineralogy	biotite

Summary

Medium- and coarse-grained, equigranular, leucocratic biotite monzogranite hosts Mo–Cu mineralization at the Minnie Springs prospect near the eastern edge of EUDAMULLAH. The monzogranite comprises a series of plutons, plugs, and dykes along the middle of the Minnie Creek batholith. The sole mafic mineral, biotite, constitutes less than 5% of the rock. The unit is prominent on isotopic images owing to high levels of U, Th, and K. A sample of leucocratic biotite monzogranite yielded an igneous crystallization age of 1786 ± 6 Ma.

Distribution

Equigranular, medium- to coarse-grained, leucocratic biotite monzogranite comprises a discontinuous, east-southeast trending belt of plutons, plugs and dykes along, or close to, a major shear zone down the spine of the Minnie Creek batholith. The unit has been recognized over a distance of about 100 km, from the southwestern corner of MANGAROON to the southeastern edge of MOUNT PHILLPS. By far the largest individual intrusion of this unit is an east-southeast trending pluton over 20 km long and up to 5 km wide, which straddles the boundary between EUDAMULLAH and MOUNT PHILLPS. This unit commonly contains elevated levels of U, Th, and K, and stands out on isotopic images. The unit is resistant, and commonly forms a topographically higher weathered surface relative to more recessive units around it.

Lithology

Equigranular, medium- to coarse-grained, leucocratic biotite monzogranite is an homogeneous unit composed of a single phase, and characterized by a lack of inclusions. Biotite is the sole mafic mineral in the monzogranite, and comprises less than 5% of the rock.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	leuco-	l
Rock code		**P_-MO-gml**

Contact relationships

Equigranular, medium- to coarse-grained, leucocratic biotite monzogranite, along with fine-grained leucocratic biotite monzogranite (P_-MO-gmal), is the youngest recognized phase in the Minnie Creek batholith. On central and eastern MOUNT PHILLPS, a suite of plugs and dykes of leucocratic biotite monzogranite intrude medium- to coarse-grained porphyritic biotite monzogranite (P_-MO-gmp) over a wide area. On western MOUNT PHILLPS at the margin of the large intrusion of leucocratic monzogranite (site SXSEUD6418; Zone 50, MGA 402180E 7320810N), leucocratic biotite monzogranite is finer grained adjacent to coarse-grained porphyritic biotite monzogranite (P_-MO-gmp), suggesting that the leucocratic monzogranite was chilled against the porphyritic unit. On northwestern EUDAMULLAH, southeast of Minnie Creek Homestead, dykes of leucocratic biotite monzogranite intrude equigranular biotite(–muscovite) granodiorite (P_-MO-gge). On the eastern edge of EUDAMULLAH, about 6 km east-southeast of Minnie Springs Well, coarse-grained leucocratic biotite monzogranite is intruded by irregular veins and dykes of fine-grained leucocratic biotite monzogranite (P_-MO-gmal). About 5.5 km north-northwest of Onslow Well, near the boundary between EUDAMULLAH and MOUNT PHILLPS, leucocratic biotite monzogranite is unconformably overlain by an outlier of metamorphosed, well-sorted, coarse-grained quartz–feldspar sandstone and granule sandstone with interbedded phyllite and metamorphosed quartz pebble conglomerate and pebbly sandstone (P_-POb-mtef) of the Pooranoo Metamorphics.

Geochronology

P_-MO-gml	*Maximum*	*Minimum*
Age (Ma)	1792 ± 7	1792 ± 7
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Wingate et al., 2009	Wingate et al., 2009

Medium- to coarse-grained, leucocratic biotite monzogranite was sampled for SHRIMP U–Pb geochronology about 5 km east-southeast of Minnie Springs Well (GSWA 183269), and yielded a crystallization age of 1792 ± 7 Ma (Wingate et al., 2009). An older grain at c. 2027 Ma is interpreted as a xenocryst. Field relationships indicate that leucocratic biotite monzogranite is one of the youngest phases in the Minnie Creek batholith.

References

Wingate, MTD, Kirkland, CL, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183269: leucocratic syenogranite, Minnie Springs; Geochronology Record 773: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-gmlp)

Legend narrative

Coarse-grained leucocratic biotite monzogranite

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	P_-DAna-mgt

Summary

Coarse-grained leucocratic biotite monzogranite forms dykes in the Paradise Zone on LANDOR. The dykes post-date the Glenburgh Orogeny and have been assigned to the Moorarie Supersuite, although the minimum age of the dykes is not known.

Distribution

Dykes of coarse-grained, leucocratic biotite granite intrude the Nardoo Granite in the area southeast of Brockman Well (Zone 50, MGA 460240E 7203040N) in the western part of LANDOR. The dykes are up to 10 m wide. The larger dykes may be traced along strike for up to 3 km.

Lithology

The dykes contain elliptical microcline–microperthite phenocrysts up to 1 cm long, which commonly have small inclusions of subhedral plagioclase and biotite. The rocks are commonly moderately recrystallized. Fine-grained granophyric intergrowths of quartz and microcline are common. Plagioclase (oligoclase) is partly replaced by ?albite, sericite, and epidote.

Age code	Proterozoic	P_-
Stratigraphic cide	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname 1	monzogranite	m
1st qualifier	leuco-	l
2nd qualifier	pegmatitic	p
Rock code		**P_-MO-gmlp**

Contact relationships

Dykes of coarse-grained, leucocratic biotite monzogranite intrude the Nardoo Granite.

Geochronology

P_-MO-gmlp	*Maximum*	*Minimum*
Age (Ma)	1817	1776
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 1999	Nelson, 2002

Dykes of coarse-grained, leucocratic biotite monzogranite have not been directly dated and are only loosely constrained by cross-cutting relationships. The leucocratic dykes intrude the Nardoo Granite, the youngest phase of which has an igneous crystallization age of 1974 ± 4 Ma. The leucocratic granite also post-dates medium-grade metamorphic fabrics in the Nardoo Granite related to the 2005–1950 Ma Glenburgh Orogeny. Although the minimum age of the leucocratic biotite monzogranite is effectively unconstrained it is assumed to be coeval with other granites of the Moorarie Supersuite, which are dated at 1820–1775 Ma.

References

Nelson, DR 1999, 142931: biotite–muscovite–oligoclase granodiorite dyke, Two Wells; Geochronology Record 328: Geological Survey of Western Australia, 4p.

Nelson, DR 2002, 169058: augen orthogneiss, Kanes Gossan Prospect; Geochronology Record 132: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-gmp)

Legend narrative

Massive, medium-grained, porphyritic biotite monzogranite; round phenocrysts of K-feldspar up to 5 cm in diameter; minor fine- to medium-grained, sparsely porphyritic biotite monzogranite

Rank	Formation
Parent	Moorarie Supersuite P_-MO-g
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gml (intrusive), P_-MO-gmal (intrusive), P_-MO-gte (intrusive), P_-POb-mxq (unconformable), P_-PO-mlpc (unconformable), P_-MEk-s (unconformable)
Underlying units	P_-LS-mc (intrusive), P_-LS-mlsm (intrusive), P_-LS-mhs (intrusive), P_-MO-gti (intrusive), P_-MO-mog (intrusive), P_-MO-gmeb (mingled)

Summary

Massive, medium-grained porphyritic biotite monzogranite is the most voluminous unit in the Minnie Creek batholith comprising one very large intrusion, and several smaller plutons. The monzogranite typically contains 10–20% round phenocrysts of K-feldspar 1.5–5 cm in diameter. Parts of the unit are flow banded and layered attesting to the presence of multiple magma batches. Textures suggestive of magma mingling are present at the contact between the porphyritic biotite monzogranite and equigranular to sparsely porphyritic biotite monzogranite (P_-MO-gmeb). Porphyritic biotite monzogranite both intrudes, and is in turn intruded by, several other units of the Minnie Creek batholith. Three samples of the porphyritic biotite monzogranite have yielded igneous crystallization ages within uncertainty of each other at c. 1795 Ma.

Distribution

Medium- and coarse-grained porphyritic biotite monzogranite is the largest individual unit within the Minnie Creek batholith. It forms the bulk of the batholith on MOUNT PHILLIPS, but also extends to the southeast onto MOUNT AUGUSTUS, and to the northwest onto eastern EUDAMULLAH, dominating an area about 75 km long by 25 km wide. Smaller plutons outcrop on northwestern EUDAMULLAH and adjacent southwestern MANGAROON. Pale-grey, massive, medium-grained, porphyritic biotite monzogranite also forms an elongate, southeasterly trending plug, about 4 km long and 1.5 km wide, between Mia Well and Errawarra Well on northwestern GLENBURGH.

Lithology

Porphyritic biotite monzogranite ranges from medium to coarse grained, and typically contains about 10–20% round phenocrysts of K-feldspar 1.5–5 cm in diameter. However, there may be considerable variation in the proportion of phenocrysts, and the monzogranite is not uncommonly sparsely to moderately porphyritic (2–10% oval K-feldspar phenocrysts). Locally, the K-feldspar phenocrysts are tabular and up to 4 cm long. Sparsely porphyritic zones may grade to granodiorite. Biotite is the sole mafic mineral. Most of the porphyritic monzogranite contains around 10% biotite, but this ranges from 5–15%, giving the monzogranite a distinctly lighter or darker appearance. Coarse- to very coarse-grained parts of this unit are characterized by round or oval quartz crystals around 1 cm in diameter. Much of the monzogranite contains partly altered prismatic crystals of allanite about 1 mm long.

Porphyritic biotite monzogranite commonly contains scattered, or locally abundant, round to lenticular inclusions of fine- to medium-grained intermediate to acid granitic rocks 5–30 cm long. Some inclusions contain phenocrysts (?xenocrysts) of quartz which are the same size and shape as those in the host monzogranite.

Porphyritic monzogranite is typically massive, although east and southeast of Mount Phillips Homestead the unit is commonly flow banded or contains an igneous layering that strikes northeast to east-northeast and dips very steeply to the southeast. This orientation is oblique to the axis of the Minnie Creek batholith. Flow banding is defined by variably aligned tabular K-feldspar phenocrysts or biotite-rich schlieren. Igneous layering, which is typically developed on a scale of a few decimetres to metres, may be defined by layers of different grain size or phenocryst content. Contacts between layers are commonly sharp suggesting that plutons have been assembled via multiple intrusion of dyke-like bodies. In and around shear zones, porphyritic monzogranite is variably foliated.

Most of the porphyritic biotite monzogranite is massive or weakly foliated; however, along the northern and southern margins of the Minnie Creek batholith, porphyritic biotite monzogranite is commonly moderately to strongly foliated. Deformation and low-grade metamorphism is marked by the development of green, epidotized plagioclase and pink K-feldspar.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	porphyritic	p
Rock code		**P_-MO-gmp**

Contact relationships

Medium- and coarse-grained porphyritic biotite monzogranite is in contact with a large number of units. Porphyritic biotite monzogranite extensively intrudes pelitic schist (P_-LS-mlsm), interlayered pelitic and psammitic schist (P_-LS-mhs), and metachert (P_-LS-mc) of the Leake Spring Metamorphics. Small inclusions of pelitic and psammitic schists are commonly scattered through the monzogranite. Medium- to coarse-grained porphyritic monzogranite is intruded by several other granite components of the Minnie Creek batholith, as well as being unconformably overlain by low-grade metasedimentary rocks of the Pooranoo Metamorphics and unmetamorphosed to very low-grade metasedimentary rocks of the Edmund Group.

In the far southwest corner of Mangaroon (Zone 50, MGA 348530E 7345970N), dykes of medium- to coarse-grained, strongly porphyritic, biotite monzogranite intrude medium- to coarse-grained tonalite with abundant mafic clots (P_-MO-gti). Medium- to coarse-grained, strongly porphyritic, biotite monzogranite contains scattered inclusions of fine-grained mafic rocks, as well as what are inferred to be rafts. About 4.6 km west-southwest of Government Well on Mount Phillips, a remnant of a layered intrusion is exposed, in which the lithological layering is truncated by the enclosing massive, medium-grained, porphyritic biotite monzogranite.

The contact between coarse-grained porphyritic biotite monzogranite and equigranular biotite monzogranite (P_-MO-gmeb) is exposed at several places on Mount Phillips and Mount Augustus. At two localities about 6 and 6.5 km west-southwest of Samuel Bore on Mount Augustus, medium- to coarse-grained equigranular biotite monzogranite contains rafts or inclusions of coarse-grained, strongly porphyritic biotite monzogranite. In the southwest corner of Mount Augustus, the contact between a plug of equigranular biotite monzogranite and enclosing porphyritic monzogranite is well exposed. Locally (at 451407E 7296444N) there are inclusions of strongly porphyritic coarse-grained monzogranite with diffuse contacts within equigranular monzogranite. Nearby (Zone 50, MGA 451388E 7296552N) a sharp but locally irregular contact between the two phases is exposed; inclusions of either phase may be found in the other. These field relationships suggest that the parent magmas to these two units mingled and are, therefore, coeval. However, about 6 km west-southwest of Samuel Bore in the southwestern corner of Mount Augustus (sites SXSMTA007378; Zone 50, MGA 456845E 7296488N; and SXSMTA007376; Zone 50, MGA 456603E 7296840N) coarse-grained porphyritic biotite monzogranite is intruded by dykes of, or forms inclusions in, equigranular biotite monzogranite. These different field relationships between the two units suggest that both monzogranite phases may consist of several intrusive pulses spanning a considerable time. This conclusion is reinforced by contact relationships on Glenburgh, where medium-grained, porphyritic biotite monzogranite may be transitional to medium-grained biotite(–muscovite) granite (P_-MO-gmeb), but the porphyritic phase locally intrudes the equigranular phase (e.g. about 2 km southeast of Mia Well; Zone 50, MGA 405800E 7218200N).

On central and eastern Mount Phillips, medium- to coarse-grained porphyritic biotite monzogranite is intruded by a suite of plugs and dykes of leucocratic biotite monzogranite intrude (P_-MO-gml) over a wide area. On western Mount Phillips at the margin of a large intrusion of leucocratic monzogranite (site SXSEUD6418; Zone 50, MGA 402180E 7320810N), leucocratic biotite monzogranite is finer grained adjacent to the porphyritic monzogranite, suggesting that the leucocratic monzogranite was chilled against the porphyritic phase. Medium- to coarse-grained biotite monzogranite is intruded over a wide area by dykes of fine-grained leucocratic biotite monzogranite (P_-MO-gmal). Coarse-grained porphyritic biotite monzogranite is intruded by sparsely porphyritic tonalite (P_-MO-gte) around Hatches Soak in the centre of Eudamullush. Southeast of Minnie Springs around the boundary between Eudamullush and Mount Phillips, medium- to coarse-grained porphyritic biotite monzogranite is unconformably overlain by metamorphosed coarse-grained and pebbly quartz–feldspar sandstone (P_-POb-mxq) at the base of the Pooranoo Metamorphics. On the southeastern part of Mount Phillips about 3 km northwest of Cattlecamp Well, coarse-grained porphyritic biotite monzogranite is unconformably overlain by several small outliers of chlorite-rich phyllite with a few metres of metamorphosed quartz sandstone at the base.

Geochronology

P_-MO-gmp	*Maximum*	*Minimum*
Age (Ma)	1795 ± 8	1792 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Bodorkos et al., 2006a; Bodorkos et al., 2006b; Evans et al., 2003	Bodorkos et al., 2006a; Bodorkos et al., 2006b; Evans et al., 2003

Coarse-grained porphyritic biotite monzogranite has been sampled at three localities for SHRIMP U–Pb zircon geochronology; one on southwestern Mangaroon, and two on Mount Phillips. Evans et al. (2003; sample MD02MC) determined an igneous crystallization age of 1795 ± 8 Ma for the monzogranite on southwestern Mangaroon. A sample (GSWA 88405) about 3.5 km northwest of Harvey Well (Bodorkos et al., 2006a) yielded an igneous crystallization age of 1792 ± 5 Ma. A sample (GSWA 88407) taken 3.5 km north-northwest of Dunnise Well has an igneous crystallization age of 1794 ± 8 Ma (Bodorkos et al., 2006b).

References

Bodorkos, S, Love, GJ and Wingate, MTD 2006a, 88405: biotite granodiorite, Harvey Well; Geochronology Record 606: Geological Survey of Western Australia, 4p.

Bodorkos, S, Love, GJ and Wingate, MTD 2006b, 88407: porphyritic monzogranite, Dunnise Well; Geochronology Record 607: Geological Survey of Western Australia, 4p.

Evans, DAD, Sircombe, KN, Wingate, MTD, Doyle, M, McCarthy, M, Pidgeon, RT and Van Nierkerk, HS 2003, Revised geochronology of magmatism in the western Capricorn Orogen at 1805–1785 Ma: Diachroneity of the Pilbara–Yilgarn collision: Australian Journal of Earth Sciences, v. 50, p. 853–864.

Moorarie Supersuite; subunit (P_-MO-gmpi)

Legend narrative

Medium- to coarse-grained, mesocratic biotite monzogranite; equigranular to porphyritic; abundant round inclusions of mesocratic microgranite

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmp, P_MO-gml, P_-MO-gmal, P_-DU-gmvt (intrusive)
Underlying units	P_-LS-mlsm (intrusive)

Summary

Medium- to coarse-grained, mesocratic biotite monzogranite is largely restricted to a single intrusion in the Minnie Creek batholith on southeastern Mount Phillips. The unit resembles equigranular biotite monzogranite (P_-MO-gmeb) and porphyritic biotite monzogranite (P_-MO-gmp), but is distinguished by the presence of abundant mesocratic microgranite inclusions and a higher biotite content (~15%). The unit has not been dated directly, but is some gradational contacts with porphyritic biotite monzogranite (P_-MO-gmp) indicate that it is likely to be c. 1795 Ma in age.

Distribution

Medium- to coarse-grained, equigranular to porphyritic, inclusion-rich mesocratic biotite monzogranite is restricted to an east-northeast trending intrusion about 12 km long and 3.5 km wide, most of which outcrops on the southeastern corner of Mount Phillips, but just extends onto Mount Augustus. This intrusion is bisected by a tongue of coarse-grained porphyritic biotite monzogranite (P_-MO-gmp).

Lithology

Mesocratic, inclusion-rich biotite monzogranite is medium to coarse grained, and ranges from equigranular to porphyritic, the latter with up to 20% tabular K-feldspar phenocrysts 1–2 cm long. In part, the unit resembles equigranular biotite monzogranite (P_-MO-gmeb) and porphyritic biotite monzogranite (P_-MO-gmp), but is distinguished by the presence of abundant, round inclusions of mesocratic microgranite. The mesocratic, inclusion-rich monzogranite also contains more biotite (typically ~15%) than either of the equigranular or porphyritic monzogranites. Locally, equigranular mesocratic monzogranite grades into a granodiorite or tonalite. Most of the unit is massive, but in places flow banding, defined primarily by aligned tabular K-feldspar phenocrysts, is present.

In thin section, even massive samples show evidence of metamorphism and partial static recrystallization; for example, undulose and sutured quartz, fine grained recrystallized aggregates of biotite with granular titanite, plagioclase recrystallized to albite and epidote and sericite, and ilmenite mantled or pseudomorphed by titanite.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	porphyritic	p
2nd qualifier	inclusion- or xenolith-rich	i
Rock code		**P_-MO-gmpi**

Contact relationships

Medium- to coarse-grained, equigranular to porphyritic, inclusion-rich mesocratic biotite monzogranite is enclosed within medium- and coarse-grained equigranular biotite monzogranite (P_-MO-gmeb), but it is commonly difficult to determine their relative ages, in part owing to the apparent gradational nature of some contacts. Mesocratic inclusion-rich biotite monzogranite also may show gradational contacts with coarse-grained porphyritic biotite monzogranite (P_-MO-gmp), marked by a decrease in biotite content and inclusion abundance over a hundred or more metres. At site SXSMTP007245 (Zone 50, MGA 438021E 7301118N) coarse-grained, mesocratic biotite monzogranite is intruded by veins and sheets of paler coloured coarse-grained, porphyritic biotite monzogranite. Mesocratic, inclusion-rich monzogranite is intruded by dykes of leucocratic micromonzogranite (P_MO-gml, P_-MO-gmal). At site RJC3332 (Zone 50, MGA 446420E 7304580N) mesocratic inclusion-rich monzogranite is intruded by a 'peculiar fine-grained tourmaline granite with very little mica and pegmatitic patches of muscovite as well as large well-formed feldspar laths and abundant spots and nodules of small tourmaline crystals' (P_-DU-gmvt). Mesocratic, inclusion-rich biotite monzogranite contains numerous screens and inclusions of muscovite-rich pelitic schist (P_-LS-mlsm).

Geochronology

P_-MO-gmpi	*Maximum*	*Minimum*
Age (Ma)	1795	1783
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Bodorkos et al., 2006a; Bodorkos et al., 2006b; Evans et al., 2003	Kirkland et al., 2009

Mesocratic, inclusion-rich biotite monzogranite has not been dated directly, but it is gradational (at least in part) with both coarse-grained porphyritic biotite monzogranite (P_-MO-gmp) dated at 1795 ± 8 Ma (Evans et al., 2003) and equigranular biotite monzogranite (P_-MO-gmeb) on nearby southwestern Mount Augustus dated at 1783 ± 5 Ma (GSWA 180938). Mesocratic, inclusion-rich monzogranite intrudes the Leake Spring Metamorphics, which places an older limit for intrusion of c. 1842 Ma, based on the maximum depositional age of the Leake Spring Metamorphics (Varvell, 2001; Wingate et al., in prep.).

References

Bodorkos, S, Love, GJ and Wingate, MTD 2006a, 88405: biotite granodiorite, Harvey Well; Geochronology Record 606: Geological Survey of Western Australia, 4p.

Bodorkos, S, Love, GJ and Wingate, MTD 2006b, 88407: porphyritic monzogranite, Dunnise Well; Geochronology Record 607: Geological Survey of Western Australia, 4p.

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Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009, 180938: monzogranite, Leake Spring: Geochronology Record 751: Geological Survey of Western Australia, 4p.

Varvell, CA 2001, Age, structure and metamorphism of a section of the Morrissey Metamorphic Suite, Central Gascoyne Complex, Western Australia: Curtin University of Technology, Perth, BSc. (Hons) thesis (unpublished).

Wingate, MTD, Kirkland, CL, Johnson, SP and Sheppard, S in prep., 190668; metasandstone, Nardoo Well: Geological Survey of Western Australia.

Moorarie Supersuite; subunit (P_-MO-gmvl)

Legend narrative

Medium- to coarse-grained, even-textured, leucocratic biotite-poor muscovite monzogranite; locally foliated and metamorphosed

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	AP_-_ha-mgn, AP_-_ha-mgnl, AP_-_ha-mgnw, P_-MGm-mtsf, P_-MG-mls (intrusive)

Summary

Medium- to coarse-grained, even-textured, leucocratic biotite- and muscovite-poor monzogranite is a very minor component of the Moorarie Supersuite. The unit outcrops as thin sheets and dykes but occasionally are much larger composite sheets. The monzogranite crosscuts gneissic fabrics in the Halfway Gneiss and Moogie Metamorphics and is only rarely weakly to moderately foliated. A single sample of monzogranite was sampled for geochronology but all of the zircons are interpreted to be of inherited origin. Based on the age of these grains and structural setting of the monzogranite sheets, this unit is interpreted to be part of the Moorarie Supersuite.

Distribution

This unit forms a series of thin, almost flat lying, sheet-like intrusions in the Mooloo Zone, in the southwestern corner of Yinnetharra, and the adjacent northwestern edge of Glenburgh. The two largest near-continuous outcrops, directly to the southeast and southwest of Darawonga Well, cover an area of 3.5 km^2 and 2 km^2, but most are thin metre- to decimetre-scale discontinuous sheets and dykes.

Lithology

Medium- to coarse-grained, even-textured, leucocratic biotite- and muscovite-poor monzogranite is a very minor component of the Moorarie Supersuite. It occurs as thin metre to decimetre scale sheets and dykes that intrude both the Halfway Gneiss and Mumba Psammite. The monzogranite is medium to coarse grained but grades locally into very coarse-grained to pegmatitic units. Discrete very coarse-grained to pegmatitic sheets and dykes are also common. The unit is generally event-textured and equigranular although locally can be weakly to moderately foliated. The monzogranite is very leucocratic generally containing quartz–K-feldspar (–plagioclase) with less than 10% muscovite and which can locally contain up to 5% biotite. In hand specimen muscovite content increases with grain size so that in the very coarse-grained to pegmatitic lithologies muscovite can be up to 15–20%, occasionally forming randomly oriented cm-scale tabular books. Discrete sheets up to 5–10 m thick are common but occasionally composite bodies up to 100 m thick are evident (e.g. SPJYIN000615). These composite bodies are made up of numerous sub-parallel metre- to decimetre-scale sheets comprising all variety of grain sizes from medium grained to pegmatitic. The larger scale sheets may contain thin disparate inclusions of Halfway Gneiss or Mumba Psammite.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	muscovite	v
2nd qualifier	leuco-	l
Rock code		**P_-MO-gmvl**

Contact relationships

Medium- to coarse-grained, even-textured, leucocratic biotite- and muscovite-poor monzogranite forms a series of thin, almost flat lying, sheet-like intrusions into the Halfway Gneiss and Mumba Psammite (Moogie Metamorphics). The monzogranite sheets are generally equigranular and crosscut the gneissic fabrics in the Halfway Gneiss. This is best illustrated in a 250 m long traverse along a small creek on southern Yinnetharra (see SPJYIN000311 through to SPJYIN000313). Here there are numerous shallow southwest-dipping sheets of coarse-grained to pegmatitic monzogranite that intrude and crosscut fabrics in a medium grained part of the Halfway Gneiss (AP_-_ha-mgn). A similar relationship is observed with folded and deformed psammitic and pelitic schists of the Mumba Psammite (P_-MGm-mtsf and P_-MGm-mls), see SPJYIN000296 and SPJYIN000297.

Geochronology

P_-MO-gmvl	*Maximum*	*Minimum*
Age (Ma)	1817	1776
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 1999	Nelson, 2002

A single sample (GSWA 185943) of this unit (medium- to coarse-grained, equigranular, leucocratic biotite- and muscovite-poor monzogranites) from southern Yinnetharra was collected for U–Pb zircon SHRIMP geochronology (Wingate et al., 2010). The sample was collected from a composite 100 m thick sheet that is undeformed and intruded close to the contact between the Halfway Gneiss (AP_-_ha-mgn) and psammitic schists of the Mumba Psammite (P-_MGm-mtsf). The sample yielded numerous zircons, most of which consisted of low-U cores surrounded by thick high-U rims. Nearly all grains contained high proportions of common Pb. Seven analyses of seven cores yielded a range of $^{207}Pb*/^{206}Pb*$ dates between 2787 and 2075 Ma. A single analysis was made of a high-U rim and yielded a $^{207}Pb*/^{206}Pb*$ date of 1947 ± 3 Ma. This rim and its counterpart core are both interpreted to have been inherited from the basement into which the monzogranite sheet intrudes (most likely the Mumba Psammite). The date for the rim therefore provides a maximum age for crystallization of the monzogranite. Considering that locally these sheets are weakly to moderately deformed, presumably during the Capricorn Orogeny, they are likely part of the Moorarie Supersuite, which has a crystallization age range of 1820 to 1775 Ma.

References

Nelson, DR 1999, 142931: biotite–muscovite–oligoclase granodiorite dyke, Two Wells; Geochronology Record 318: Geological Survey of Western Australia, 4p.

Nelson, DR 2002, 169058: augen orthogneiss, Kanes Gossan Prospect; Geochronology Record 132: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, Johnson, SP and Sheppard, S 2010, 185943; metatonalite, Caralba Well; Geochronology Record 899: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-gp)

Legend narrative

Porphyritic to equigranular, coarse-grained, biotite- and muscovite-bearing monzogranite, syenogranite, and pegmatite; locally tourmaline bearing

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-POb-mtef, P_-POb-mxq, P_-POb-mhs, P_-MEy-st (unconformable)
Underlying units	AP_-_ha-mgnl, AP_-_ha-mgnw, P_-MGm-mtsf, P_-MGm-mls, P_-MG-mkk, P_-DAna-mgt, P_-DAna-mgtl, P_-CHq-mln, P_-CHp-mk, P_-MOdu-ggp, P_-MO-gmeb, P_-MO-gmp (intrusive)

Summary

Coarse-grained granite and pegmatite dykes and veins intrude most units in the Mooloo and Paradise Zones in the southern part of the Gascoyne Province. Most of the dykes and veins carry biotite(–muscovite) or muscovite(–tourmaline). The deformed and metamorphosed equivalents of the granite and pegmatite (P_-MO-mgp) intrude rocks throughout the Errabiddy Shear Zone and Yarlarweelor Gneiss Complex.

Distribution

Dykes and veins of coarse-grained granite and pegmatite extensively intrude rocks of the Gascoyne Province in the Mooloo Zone, but they also form localized swarms in the Paradise Zone to the south; for example, on the southern part of GLENBURGH, between Dardoo Well and Salt Well and east-northeast of Parrot Bore. The metamorphosed and deformed equivalents of the coarse-grained granite and pegmatite (P_-MO-mgmp), intrude reworked Archean gneiss of the Yarlarweelor Gneiss Complex and metasedimentary rocks of the Camel Hills Metamorphics in the Errabiddy Shear Zone. To a lesser extent, metamorphosed coarse-grained granite and pegmatite intrude rocks along the northern edge of the Yilgarn Craton, where the effects of the Capricorn Orogeny are limited to shear zone reactivation, rather than pervasive reworking.

Lithology

Coarse-grained granite and pegmatite comprises sheets, veins, and dykes of coarse- to very coarse-grained biotite monzogranite and syenogranite, and biotite(–muscovite) pegmatite. Some sheets and dykes show zoning, parallel to their margins, from coarse-grained granite to pegmatite. Biotite is normally the sole mafic mineral in the coarse-grained granite, whereas the pegmatite contains biotite or muscovite (or both). Many of the dykes in the northern part of GLENBURGH are tourmaline bearing. The mineralogy of the sheets and veins is variable, and may be partly dependent on the country rocks. Where they intrude granitic gneiss, the pegmatites commonly contain biotite, with or without muscovite. In contrast, where they intrude migmatitic pelitic gneiss, the bulk of the pegmatites contain muscovite with or without tourmaline and biotite. Many of the pegmatite veins and sheets are hypersolvus — they contain plagioclase crystals with microcline intergrowths. The coarse-grained granite and pegmatite range from massive to weakly foliated.

Age code	Proterozoic	P_-MO-g
Stratigraphic code	Moorarie Supersuite	
Rock type	Igneous granitic	
Lithname	pegmatite	p
Rock code		**P_-MO-gp**
Additional lithologies	pegmatite	

Contact relationships

Coarse-grained granite and pegmatite intrudes a wide variety of rock types, including many units of the 2660–2430 Ma Halfway Gneiss, and 2240–2125 Ma Moogie Metamorphics, as well as some units of the 1820–1775 Ma Moorarie Supersuite (P_-MO-gmeb, P_-MO-gmp).

Geochronology

P_-MO-gp	*Maximum*	*Minimum*
Age (Ma)	1813	1802
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 1998a	Nelson, 1998b

No samples of coarse-grained granite and pegmatite (P_-MO-gp) from the Gascoyne Province have been dated directly. However, a sheet of coarse-grained metagranite and metapegmatite (P_-MO-mgmp) in the Yarlarweelor Gneiss Complex on MARQUIS yielded an igneous crystallization age of 1813 ± 8 Ma (Nelson, 1998a). Five zircons that indicated Archean ages are interpreted as xenocrysts. On ERRABIDDY, coarse-grained metagranite and metapegmatite north of Dewar Bore is intruded by a plug and associated veins of massive, fine- to medium-grained, leucocratic muscovite–biotite granodiorite (P_-MO-ggev) dated at 1802 ± 9 Ma (Nelson, 1998b). On this basis, undeformed coarse-grained granite and pegmatite in the Gascoyne Province is inferred to be about 1810 Ma in age.

References

Nelson, DR 1998a, 142849: foliated coarse-grained monzogranite, northeast of White Well; Geochronology Record 365: Geological Survey of Western Australia, 4p.

Nelson, DR 1998b, 142900: muscovite-biotite monzogranite, Dewars Bore; Geochronology Record 360: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-gte)

Legend narrative

Equigranular to sparsely porphyritic biotite tonalite and granodiorite; medium grained; massive to weakly foliated

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmeb, P_-DU-gmvt (intrusive)
Underlying units	P_-LS-mlsg, P_-LS-mlsm, P_-MO-gmp (intrusive)

Summary

Equigranular to sparsely porphyritic biotite tonalite and granodiorite comprises one large intrusion, and several small plutons, in the Minnie Creek batholith on EUDAMULLAH and MOUNT PHILLIPS. The unit is reasonably homogeneous, with most rocks straddling the tonalite–granodiorite boundary. One sample of a biotite granodiorite taken for SHRIMP U–Pb zircon dating yielded an igneous crystallization age of 1787 ± 5 Ma.

Distribution

Equigranular to sparsely porphyritic biotite tonalite and granodiorite forms an elongate intrusion about 160 km^2 in area, in the central and eastern parts of EUDAMULLAH. It also forms several small intrusions, each less than 10 km^2, farther east on the western part of MOUNT PHILLIPS.

Lithology

Equigranular to sparsely porphyritic biotite tonalite and granodiorite is a reasonably homogeneous unit. The main rock type is medium-grained rock that straddles the tonalite–granodiorite boundary. Rocks are mainly weakly foliated, but locally are moderately foliated or massive. Scattered square K-feldspar phenocrysts up to 1cm in diameter are locally present, and biotite comprises about 15% of the rock. The rocks typically contain a few scattered round inclusions of biotite-rich pelite or, locally, oval and lenticular inclusions 2–30 cm long of fine-grained variably porphyritic biotite quartz diorite to granodiorite. In places, the rocks consist of banded biotite tonalite and granodiorite, with individual layers 0.15 to 20 m or more thick and roughly parallel to the tectonic foliation. This unit is more heterogeneous in the southeastern part of the large intrusion on EUDAMULLAH. Here, coarse-grained porphyritic biotite granodiorite commonly contains screens and inclusions of variably schistose dark grey, medium- to coarse-grained tonalite rich in biotite.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname	tonalite	t
1st qualifier	even-grained/even textured/equigranular	e
Rock code		**P_-MO-gte**
Additional lithologies	granodiorite	

Contact relationships

Equigranular to sparsely porphyritic biotite tonalite and granodiorite intrude pelitic schists of the Leake Spring Metamorphics (P_-LS-mlsg, P_-LS-mlsm) around Mullet Well and Herring Well on the eastern part of EUDAMULLAH. Sparsely porphyritic tonalite intrudes coarse-grained porphyritic biotite monzogranite (P_-MO-gmp) around Hatches Soak in the centre of EUDAMULLAH. The biotite tonalite and granodiorite are in contact with equigranular biotite(–muscovite) granodiorite (P_-MO-gge) over a large distance, but the relative age of these two units could not be established. North of Dunnise Well on western MOUNT PHILLIPS, biotite tonalite and granodiorite are intruded by dykes of equigranular to sparsely porphyritic biotite monzogranite (P_-MO-gmeb).

Geochronology

P_-MO-gte	*Maximum*	*Minimum*
Age (Ma)	1787 ± 5	1787 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Bodorkos et al., 2006	Bodorkos et al., 2006

A 0.5 m diameter boulder of weakly foliated, sparsely porphyritic biotite granodiorite, located about 2 km northwest of Hatches Soak on EUDAMULLAH, was sampled for SHRIMP U–Pb zircon geochronology. The weighted mean date of 1787 ± 5 Ma was interpreted as the age of crystallization (Bodorkos et al., 2006). The relatively high MSWD of 2.1 for this result indicates some dispersion in the data, although the reason for this is unclear.

References

Bodorkos, S, Love, GJ, and Wingate, MTD 2006, 88420: biotite granodiorite, Hatches Soak; Geochronology Record 615: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-gti)

Legend narrative

Medium- to coarse-grained tonalite with abundant mafic clots; lesser medium-grained granodiorite with scattered mafic clots

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmp, P_-MO-gma (intrusive)
Underlying units	P_-MO-gge

Summary

Massive medium- to coarse-grained tonalite and lesser medium-grained granodiorite forms a large intrusion within the Minnie Creek batholith on northwestern EUDAMULLAH and adjacent southwestern MANGAROON. The intrusion continues farther west, where it is yet to be mapped. The main phase is a medium- to coarse-grained, equigranular biotite tonalite with numerous clots of mafic rock and locally abundant rounded inclusions of quartz diorite. The tonalite locally has prominent oval-shaped quartz crystals 5–7 mm in diameter. In parts of the unit, the tonalite grades into lighter coloured granodiorite that has less biotite and fewer mafic inclusions. One specimen of a biotite tonalite sampled for SHRIMP U–Pb zircon dating yielded an igneous crystallization age of 1783 ± 5 Ma.

Distribution

Massive medium- to coarse-grained tonalite outcrops over an area of more than 150 km^2 in the southwestern corner of MANGAROON and northwestern corner of EUDAMULLAH. In addition, there is a plug about 0.6 km^2 in area located 2.5 km south of Mingabaloo Well on MOUNT PHILLIPS. The unit forms low rounded hills covered in boulders and tors, as well as a sandy, gently undulating land surface with boulders and tors. Adjacent to thicker dolerite dykes, the tonalite is hornfelsed and forms long ridges up to approximately 25 m high.

Lithology

The main tonalite phase is a medium- to coarse-grained, even-textured biotite tonalite with numerous clots of mafic rock and locally abundant rounded inclusions of quartz diorite. The tonalite contains about 15–20% biotite, and locally has prominent oval-shaped quartz crystals 5–7 mm in diameter. The northern margin of the intrusion consists of medium-grained tonalite and granodiorite that grade into the coarse-grained tonalite. However, in the area about 5 km west-southwest of Diamond Well (Zone 50, MGA 34890E 7357840N), the tonalite comprises angular blocks within granodiorite. The granodiorite is a lighter coloured rock than the tonalite, and contains much fewer mafic clots and inclusions of quartz diorite. The tonalite and granodiorite are commonly pale green owing to the presence of abundant epidote. Epidote is more abundant near dolerite dykes.

Quartz diorite inclusions are typically 5–30 cm long but may be up to 2 m in diameter. Inclusions are fine or fine to medium grained and typically sparsely to moderately plagioclase porphyritic; phenocrysts commonly have the same shape and texture as plagioclase crystals in the enclosing tonalite.

The igneous texture of the tonalite and quartz diorite are typically well preserved, but thin sections show them to be extensively recrystallized; undulose extinction is present in quartz, plagioclase is pseudomorphed by sodic variety with sericite and granular epidote, biotite is khaki brown with exsolved Fe–Ti-oxide needles, and ilmenite and magnetite wholly replaced by titanite and epidote.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	Igneous granitic	g
Lithname	tonalite	t
1st qualifier	inclusion- or xenolith-rich	i
Rock code		**P_-MO-gti**
Additional lithologies	quartz diorite, granodiorite	

Contact relationships

In the far southwest corner of MANGAROON (Zone 50, MGA 348530E 7345970N), tonalite is intruded by dykes of medium- to coarse-grained strongly porphyritic biotite monzogranite (P_-MO-gmp). The tonalite, as well as other granite plutons in the Minnie Creek batholith, is intruded by numerous dykes of fine-grained, leucocratic biotite granite (P_-MO-gma).

Geochronology

P_-MO-gti	*Maximum*	*Minimum*
Age (Ma)	1783 ± 5	1783 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2004	Nelson, 2004

About 3 km west-southwest of Minga Well (Zone 50, MGA 349960E 7350180N), a sample of coarse-grained tonalite (GSWA 178024) yielded a SHRIMP U–Pb zircon age of 1783 ± 5 Ma (Nelson, 2004).

References

Nelson, DR 2004, 178024: biotite granodiorite, Minga Well; Geochronology Record 533: Geological Survey of Western Australia, 4p.

GOOCHE GNEISS
(P_-MOgo-mgn)

Legend narrative

Strongly foliated, porphyritic metagranodiorite and metamonzogranite, and augen gneiss

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-PO-mtsf (faulted), P_-DUyn-gmv (intrusive)

Summary

The Gooche Gneiss outcrops over a wide area of the Mangaroon Zone, mainly south of the Mangaroon Syncline, as a series of small inliers within the Pooranoo Metamorphics or rafts in granites of the Durlacher Supersuite. The Gooche Gneiss ranges from a foliated porphyritic metagranodiorite or metamonzogranite to augen gneiss. One specimen of augen gneiss sampled for SHRIMP U–Pb zircon dating yielded an igneous crystallization age of 1776 ± 8 Ma, indicating that the Gooche Gneiss is part of the Moorarie Supersuite.

Distribution

The Gooche Gneiss was defined on EDMUND (Martin et al., 2002), where it forms several elongate rafts (each <2 km^2) in the Pimbyana Granite. On MANGAROON the gneiss outcrops over a wide area in the Mangaroon Zone between the Minga Bar Fault and the Mangaroon Syncline as a series of small (<2 km^2 and mostly <1 km^2) inliers amongst pelitic gneiss and granofels (P_-PO-mln) and metamorphosed feldspathic sandstone (P_-PO-mtsf) of the Pooranoo Metamorphics. Gooche Gneiss extends, as two small inliers (<1 km^2), onto the northeastern corner of MOUNT PHILLIPS.

Lithology

The Gooche Gneiss ranges from foliated, porphyritic biotite metagranodiorite or metamonzogranite, to pegmatite-banded augen gneiss. Phenocrysts of K-feldspar are round and up to 3 cm in diameter. The gneiss is typically weathered, but is commonly well exposed as whalebacks and pavements.

Age code	Proterozoic	P_-
Stratigrahic code	Moorarie Supersuite, Gooche Gneiss	MOgo-
Rock type	meta-igneous felsic intrusive	mg
Lithname	granitic gneiss	n
Rock code		**P_-MOgo-mgn**
Additional lithologies	metamonzogranite	

Contact relationships

Contacts between the Gooche Gneiss and rocks of the Pooranoo Metamorphics are tectonic. On northeastern MOUNT PHILLIPS, Gooche Gneiss is intruded by dykes and veins of the c. 1660 Ma Yangibana Granite.

Geochronology

P_-MOgo-mgn	*Maximum*	*Minimum*
Age (Ma)	1776 ± 8	1776 ± 8
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2002	Nelson, 2002

Augen gneiss (GSWA 169058) from the Gooche Gneiss on EDMUND, was sampled for SHRIMP U–Pb zircon geochronology, and yielded a date of 1776 ± 8 Ma, interpreted as the age of igneous crystallization of the precursor granite (Nelson, 2002). The sample is incorrectly described in the petrography as a 'sheared quartzofeldspathic gneiss breccia'.

References

Nelson, DR 2002, 169058: augen orthogneiss, Kanes Gossan Prospect; Geochronology Record 132: Geological Survey of Western Australia, 4p.

MIDDLE SPRING GRANITE; subunit (P_-MOmi-mgmn)

Legend narrative

Pale grey, gneissic to foliated metamonzogranite; derived from a medium-grained equigranular to sparsely porphyritic biotite monzogranite

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MOru-mgm, P_-MO-xmg-m, P_-MO-mgml; P_-DU-gmvt (intrusive); P_-MOmi-mgmy (gradational)
Underlying units	AP_-_ha-mgnw (intrusive); P_-LS-mlsm, P_-LS-mhs; P_-LS-mts (faulted)

Summary

The Middle Spring Granite is a distinctive, pale grey, finely banded, gneissic to foliated metamonzogranite that outcrops on eastern PINK HILLS and western CANDOLLE. Part of the unit is interpreted as a recrystallized mylonitic metamonzogranite (P_-MOmi-mgmy) that was emplaced syntectonically with the Capricorn Orogeny. The protolith to the Middle Spring Granite was an equigranular or sparsely porphyritic monzogranite with about 5% thin tabular K-feldspar phenocrysts 5–10 mm long. The Middle Spring Granite contains inclusions of rock types similar to those comprising the Halfway Gneiss.

Distribution

The Middle Spring Granite forms an easterly trending belt about 10 km wide and 50 km long south of Burringurrah community on the eastern part of PINK HILLS and the adjacent western part of CANDOLLE. The granite forms low undulating country typically with good exposure comprising low outcrops and pavements. Exposure at both ends of the belt is commonly poor, being largely covered by sheetwash or partly consolidated colluvial deposits.

Lithology

Most of the Middle Spring Granite comprises a fine-grained, gneissic metamonzogranite characterized by a 2–3 mm-thick gneissic banding or foliation. This fabric is parallel to the S_{1n} gneissic layering or foliation in metasedimentary rocks of the Leake Spring Metamorphics. The majority of the rocks are pale grey, and contain about 10% biotite or less as the sole mafic mineral. Locally the rocks consist of augen gneiss. Pegmatite veins in within the foliation or banding are rare. This unit also contains narrow horizons of recrystallized mylonitic monzogranite (P_-MOmi-mgmy). Low-strain domains show that the protolith to the Middle Spring Granite was typically equigranular or sparsely porphyritic with about 5% thin tabular K-feldspar phenocrysts 5–10 mm long.

Most of the Middle Spring Granite is homogeneous, but locally (as at SXSPKH008176, 4.5 km northeast of Middle Spring) the metamonzogranite is heterogeneous, comprising banded and schlieric, inclusion-rich varieties. In this area, parts of the unit superficially have the appearance of a diatexite. Inclusions comprise foliated metamonzogranite and metatonalite, calc-silicate gneiss, biotite-rich mesocratic tonalitic gneiss, and rare amphibolite. The host metamonzogranite cuts a gneissic banding in the inclusions. About 6.5 km west-northwest of Middle Spring (at SXSPKH008006) on PINK HILLS, a contact between medium-grained, foliated metamonzogranite with spindly K-feldspar phenocrysts and a raft of gneissic porphyritic biotite metamonzogranite is exposed. The host metamonzogranite truncates the gneissic banding in the raft.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite, Middle Spring Granite	MOmi-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	–	
2nd qualifier	gneissose	n
Rock code		**P_-MOmi-mgmn**

Contact relationships

The Middle Spring Granite is in contact with a wide range of units: it is intruded by various metagranites of the 1820–1775 Ma Moorarie Supersuite and granites of the 1680–1620 Ma Durlacher Supersuite; it is faulted against several units of the Leake Spring Metamorphics; and, it contains inclusions and rafts of gneissic granite of the Halfway Gneiss.

The Middle Spring Granite locally contains inclusions and rafts of gneissic mesocratic tonalite or gneissic porphyritic metagranodiorite, similar in appearance to rock types that make up much of the mesocratic granite unit of the Halfway Gneiss. About 6.5 km west-northwest of Middle Spring (at SXSPKH008006) on PINK HILLS, a contact between medium-grained, foliated metamonzogranite with spindly K-feldspar phenocrysts of the Middle Spring Granite and a raft of gneissic porphyritic biotite metamonzogranite is exposed. The host metamonzogranite truncates the gneissic banding in the raft.

The Middle Spring Granite is intruded by several granitic units of the Moorarie Supersuite, in particular by veins and dykes of variably porphyritic metamonzogranite of the Rubberoid Granite. Irregular veins of leucocratic granite with biotite clots up to 2 cm in diameter intrude the Middle Spring Granite at many localities, as do veins and thin dykes of muscovite–tourmaline granite and pegmatite (P_-DU-gmvt, P_-DU-gpt). Contacts between the Middle Spring Granite and units of the Leake Spring Metamorphics appear to be faulted, and no unequivocal examples of the granite intruding the Leake Spring Metamorphics were noted. The foliation or gneissic banding in the Middle Spring Granite is parallel to the S_{1n} foliation or gneissic banding in the metasedimentary rocks.

Geochronology

P_-MOmi-mgmn	*Maximum*	*Minimum*
Age (Ma)	1788 ± 7	1788 ± 7
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Wingate et al., in prep.	Wingate et al., in prep.

Gneissic metamonzogranite of the Middle Spring Granite was sampled for SHRIMP U–Pb zircon geochronology on the western part of CANDOLLE, and yielded a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1788 ± 7 Ma, interpreted as the igneous crystallization age of the monzogranite precursor (GSWA 190662; Wingate et al., in prep.). Despite the strongly deformed nature of the Middle Spring Granite, it is not significantly older than many of the weakly deformed or undeformed granites in the Minnie Creek batholith. The age of the Middle Spring Granite is within analytical uncertainty of the age of the Rubberoid Granite that intrudes it, and which is substantially less deformed. This suggests that the gneissic fabric in the Middle Spring Granite formed during emplacement of the Minnie Creek batholith.

References

Wingate, MTD, Kirkland, CL, Sheppard, S, and Johnson, SP in prep., 190662: gneissic metamonzogranite, Recovery Well; Geological Survey of Western Australia.

MIDDLE SPRING GRANITE
(P_-MOmi-mgmy)

Legend narrative

Pale grey, recrystallized mylonitic metamonzogranite; derived from a medium-grained equigranular to sparsely porphyritic biotite monzogranite

Rank	Member
Parent	MIDDLE SPRING GRANITE (P_-MOmi-mgmn)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA

Summary

Recrystallized mylonitic Middle Spring Granite forms an easterly trending belt on Pink Hills and Candolle. The unit is heterogeneous, and consists of fine- to medium-grained quartzofeldspathic rock that was previously interpreted as a succession of metamorphosed feldspathic sandstone with minor polymictic conglomerate. Many of the features that resemble graded bedding or cross-bedding are ultramylonites formed during the Capricorn Orogeny but that have been recrystallized during a subsequent medium- to low-grade dynamic metamorphic event.

Distribution

Recrystallized mylonitic Middle Spring Granite forms an easterly trending belt about 2 km wide that bifurcates east of Middle Spring. The western end of the belt on Pink Hills is not well defined, but the eastern end on western Candolle disappears under the unconformity with the overlying Edmund Group. The recrystallized mylonitic granitic member defines much of the faulted southern margin of the Middle Spring Granite. The eastern end of the belt south of Recovery Well is deeply weathered, and in part poorly exposed. The rocks here are assigned to the recrystallized mylonitic member of the Middle Spring Granite partly on the presence of boudinaged inclusions of vein quartz characteristic of this unit.

Lithology

Recrystallized mylonitic monzogranite of the Middle Spring Granite is heterogeneous and fine to medium grained, commonly with a layering defined by changes in composition and grain size. The rocks are best exposed around, and to the southeast of, Middle Spring. This unit was previously mapped as ‘Quartz–feldspar–biotite microgneiss with polymictic conglomerate’ (P_nr) or ‘metamorphosed greywacke’ (P_np) (Williams et al., 1983). Many exposures do contain a layering that looks somewhat like bedding, and low-angle cut-out structures that resemble cross-bedding. Individual layers are about 1–20 cm thick, but are commonly finely banded internally. Layers are typically fine to medium grained, and range from equigranular to porphyritic. Quartz and feldspar porphyroclasts are less than about 6 mm in diameter and comprise up to 15% of individual layers. Most of the porphyroclasts are lens shaped, but some feldspar crystals are tabular. Many layers contain round or lens-shaped inclusions of strongly foliated, coarse-grained porphyritic metamonzogranite, leucocratic metagranite, and fine-grained metatonalite up to 15 cm long, as well as angular inclusions of milky vein quartz. These inclusions typically have a foliation oblique to that in the host rock suggesting rotation of the inclusions. In places, for example at site SXSPKH008204 (Zone 50, MGA 486217E 7266386N), the rocks consist of gneissic metamonzogranite with boudins of leucocratic metagranite, numerous low-angle cut-out structures marked by seams of biotite, ptygmatic quartzofeldspathic veins, and strongly flattened quartz and feldspar porphyroclasts. These features are indicative of very high strain.

Recrystallized mylonitic monzogranite of the Middle Spring Granite was previously interpreted as metamorphosed greywacke, with low-angle cut-out structures interpreted as cross lamination (Williams et al., 1983). These authors considered that metamonzogranite with inclusions of foliated and gneissic granites in the Middle Spring area to consist of metamorphosed boulder conglomerate. However, the contradictory facing evidence indicated by the low-angle cut-out structures, the lack of grading in the layers, the presence of ‘boulders’ of metagranites with sigma and delta tails, and the transitional nature of these outcrops with unequivocally sparsely porphyritic, foliated, and gneissic metamonzogranite collectively indicate that the protoliths were granites rather than sedimentary rocks.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite, Middle Spring Granite	MOmi-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	—	
2nd qualifier	mylonitic	y
Rock code		**P_-MOmi-mgmy**

Contact relationships

Recrystallized mylonitic Middle Spring Granite has a gradational contact with foliated to gneissic metamonzogranite of the Middle Spring Granite (P_-MOmi-mgmn). Near the contact, the latter may contain narrow zones of recrystallized mylonitic metamonzogranite. Contacts between recrystallized mylonitic Middle Spring Granite and units of the Leake Spring Metamorphics are faulted. The Rubberoid Granite (P_-MOru-mgm) of the Moorarie Supersuite is inferred to have intruded the mylonitic Middle Spring Granite at the western end of the belt. Veins and thin dykes of muscovite–tourmaline granite and pegmatite (P_-DU-gmvt, P_-DU-gpt) commonly intrude the recrystallized mylonitic metamonzogranite.

Geochronology

P_-MOmi-mgmy	*Maximum*	*Minimum*
Age (Ma)	1788 ± 7	1788 ± 7
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Wingate et al., in prep.a	Wingate et al., in prep.a

Gneissic metamonzogranite of the Middle Spring Granite (P_-MOmi-mgmn) was sampled for SHRIMP U–Pb zircon geochronology on the western part of CANDOLLE and yielded a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1788 ± 7 Ma, interpreted as the igneous crystallization age of the monzogranite precursor (GSWA 190662; Wingate et al., in prep.a). The magmatic zircons did not contain any metamorphic overgrowths and so the timing of mylonitization and / or subsequent dynamic metamorphism cannot be directly dated. Recrystallized mylonitic Middle Spring Granite is intruded by the weakly to moderately well foliated Rubberoid Granite, which is dated at 1791 ± 4 Ma (Wingate et al., in prep.b). The age of the Middle Spring Granite it is within analytical uncertainty of many of the weakly deformed or undeformed granites in the Minnie Creek batholith. Therefore, the mylonitic fabric in the Middle Spring Granite was coeval with construction of the Minnie Creek batholith.

References

Williams, SJ, Williams, IR, Chin, RJ, Muhling, PC and Hocking, RM 1983, Mount Phillips W.A.: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 29p.

Wingate, MTD, Kirkland, CL, Sheppard, S, and Johnson, SP in prep.a, 190662: gneissic metamonzogranite, Recovery Well: Geological Survey of Western Australia.

Wingate, MTD, Kirkland, CL, Sheppard, S, and Johnson, SP in prep.b, 190660: metamonzogranite: Geological Survey of Western Australia.

RUBBEROID GRANITE
(P_-MOru-mgm)

Legend narrative

Pale-grey, medium- to coarse-grained, seriate to porphyritic metamonzogranite; typically with well-developed igneous layering; commonly with mingled pegmatite veins; minor mesocratic metagranodiorite; locally schistose

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-mgml, P_-DUpi-gmg (intrusive); P_-MEy-s (unconformable)
Underlying units	AP_-_ha-mgnw, P_-MGm-mtq, P_-MOmi-mgmn, P_-MOmi-mgmy, P_-LS-mlsg, P_-LS-mlsm, P_-LS-mhs, P_-LS-mwa (intrusive); P_-MO-xmg-m (gradational)

Summary

The Rubberoid Granite is a voluminous unit of the Moorarie Supersuite that outcrops over a wide area in the Limejuice Zone on Pink Hills and Candolle. The granite forms elongate plutons parallel to the regional structural grain. It is closely related to another large unit of the supersuite (P_-MO-xmg-m), with which it is in gradational contact. The Rubberoid Granite is strongly layered, and the intrusions are composed of hundreds or thousands of individual magma batches. Two samples from the unit yielded indistinguishable SHRIMP U–Pb zircon igneous crystallization ages of 1791 ± 4 Ma and 1786 ± 6 Ma.

Distribution

The Rubberoid Granite outcrops over a large part of northern Pink Hills and on Candolle to the east. The unit forms three large elongate plutons, two of which are greater than 250 km^2 and the remainder about 100 km^2, as well as a number of smaller plutons and plugs. The plutons strike east-southeasterly or easterly and commonly have irregular shapes, with numerous lobes or tongues of metamonzogranite at the ends of the intrusions.

Lithology

The Rubberoid Granite mainly comprises pale grey, medium- to coarse-grained, seriate to porphyritic metamonzogranite, typically with well-developed igneous layering. Most of the rocks contain 5–15% squat tabular to round K-feldspar phenocrysts 1–3 cm long (although in parts they are up to 5 cm long). Macrocrysts of K-feldspar are usually associated with disaggregated veins of coeval, strongly porphyritic metagranite or meta-pegmatite. In these areas, the abundance of phenocrysts/macrocrysts may reach 25%. Many of the rocks contain an igneous layering defined by variations in grain size, and/or abundances of biotite, and/or phenocrysts of K-feldspar. Layering may also be marked by thin seams of biotite-rich schlieren. Locally, K-feldspar phenocrysts define a flow banding parallel to the layering. Individual layers are typically 0.2 – 5 m thick. The metamonzogranite normally contains about 7–10% biotite, with very little or no muscovite; some fine-grained muscovite or sericite is probably of secondary origin. Most of the metamonzogranite is weakly foliated or massive; the foliation is usually parallel to the igneous layering. The low state of strain for the majority of the unit is indicated by equant quartz crystals, the lack of a preferred orientation to the biotite, and the unstrained nature of pelitic inclusions.

Biotite-rich, mesocratic metagranodiorite is a minor, but widespread phase of the Rubberoid Granite. The metagranodiorite is typically medium to coarse grained and equigranular. It forms rafts and inclusions within the metamonzogranite. Rarely, for example at SXSPKH008036 (Zone 50, MGA 462651E 7274128N), the Rubberoid Granite contains zones of layered, mixed metagranites; the metagranites range from fine-grained siliceous metamonzogranite through medium- to coarse-grained seriate metamonzogranite to porphyritic metamonzogranite. There may be abundant inclusions up to 0.5 m long of mesocratic metagranodiorite and psammitic schist.

In thin section the metamonzogranite is a weakly recrystallized medium- to coarse-grained rock. Microcline phenocrysts contain inclusions of subhedral to euhedral zoned plagioclase and biotite, and minor quartz. Myrmekite is developed along the margins of most microcline crystals. Plagioclase has a composition around An_{40} (andesine) and is weakly sericitized. Biotite is dark brown and forms clusters of fine-grained crystals. Most magnetite or titanomagnetite is replaced by epidote, and quartz shows abundant subgrain development. The mesocratic rocks range from weakly recrystallized biotite metagranodiorite to metatonalite. Plagioclase is andesine (about An_{40}) and is weakly sericitized. Quartz has recrystallized to polygonal subgrains, and all opaque minerals have been pseudomorphed by epidote and titanite. Muscovite comprises less than 1% of the rock. Some samples contain large prismatic crystals of hydrated allanite.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite, Rubberoid Granite	MOru-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
Rock code		**P_-MOru-mgm**
Additional lithologies	granodiorite	

Contact relationships

The Rubberoid Granite intrudes several units of the Leake Spring Metamorphics. Inclusions of pelitic and psammitic schist (P_-LS-mhs), amphibolite (P_-LS-mwa), and garnet- or staurolite-bearing pelitic schist and gneiss (P_-LS-mlsg) are widespread in the granite, and may be abundant at the margins of the intrusions. Contacts with mesocratic biotite metagranodiorite to metamonzogranite and pale grey, layered biotite(–muscovite) metamonzogranite

(P_-MO-xmg-m) are commonly transitional, being marked by increasing amounts of metagranodiorite and interlayered metamorphic rocks. The Rubberoid Granite is intruded by veins of leucocratic biotite granite, which are in turn cut by dykes and veins of foliated leucocratic, tourmaline granite and pegmatite. On northwestern Pink Hills, the Rubberoid Granite is intruded by a pluton of megacrystic Pimbyana Granite.

Within the Rubberoid Granite, there are also contacts exposed between the several phases that make up the unit. Although much of the mesocratic metagranodiorite forms slabby inclusions within the metamonzogranite (e.g. site SXSCDL008305; Zone 50, MGA 517759E 7268471N), there are some indications that the two phases are in part coeval. At site SXSPKH007952 (Zone 50, MGA 459215E 7274808N) an irregular and partly lobate contact between fine- to medium-grained biotite-rich metagranodiorite and coarse-grained porphyritic biotite metamonzogranite to south is exposed. At the contact, coarse-grained porphyritic metamonzogranite contains inclusions of the biotite-rich metagranodiorite and forms irregular veins that terminate in clusters of tabular K-feldspar phenocrysts, suggesting mingling between the two precursor magmas. At SXSPKH008036 (Zone 50, MGA 462651E 7274128N) a zone of layered, mixed metagranites is exposed. There are multiple injection events of dykes and veins, all broadly parallel, that give the rocks a banded appearance. The metagranites range from fine-grained siliceous metamonzogranite, through medium- to coarse-grained seriate metamonzogranite to porphyritic metamonzogranite. At site SXSCDL008305 (Zone 50, MGA 517759E 7268471N) deeply weathered porphyritic to megacrystic metamonzogranite is in contact with fine- to medium-grained metamonzogranite about 50 m to the northeast. The contact is marked by an intermingling of each rock type as veins and inclusions, suggesting that the two rock types were coeval. The strongly layered nature of the Rubberoid Granite indicates that the plutons were constructed from multiple injections of magma along an existing tectonic fabric in the surrounding metasedimentary rocks.

Geochronology

P_-MOru-mgm	Maximum	Minimum
Age (Ma)	1791 ± 4	1786 ± 6
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Wingate et al., in prep.a	Wingate et al., in prep.b

Two samples of the Rubberoid Granite on Pink Hills were collected for SHRIMP U–Pb zircon geochronology: GSWA 190660 and 188974. Sample GSWA 190660, a biotite metamonzogranite from northwestern Pink Hills (at SXSPKH007962: Zone 50, MGA 465066E 7280382N) yielded a concordia age of 1791 ± 4 Ma, interpreted as the time of igneous crystallization (Wingate et al., in prep.a). One core analysis yielded a ^{207}Pb*/^{206}Pb* date of 1933 ± 9 Ma, interpreted as the minimum age of an inherited component. Sample GSWA 188974, a weakly foliated, fine- to medium-grained biotite metamonzogranite from southeastern Pink Hills (at SPJPKH000877; Zone 50, MGA 486418E 7249142N) yielded a weighted mean ^{207}Pb*/^{206}Pb* date of 1786 ± 6 Ma (MSWD = 1.7), interpreted to date crystallization of the monzogranite (Wingate et al., in prep.b).

References

Wingate, MTD, Kirkland, CL, Sheppard, S, and Johnson, SP in prep.a, 190660: metamonzogranite, Midway Bore: Geological Survey of Western Australia.

Wingate, MTD, Kirkland, CL, Johnson, SP, and Sheppard, S in prep.b, 188974: metamonzogranite, No. 1 Bore: Geological Survey of Western Australia.

Moorarie Supersuite; subunit (P_-MO-mgg)

Legend narrative

Fine- to medium-grained, foliated metagranodiorite; locally porphyritic

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-xmg-m, P_-DU-gmvt, P_-MO-gmeb (intrusive), P_-MEy-st (unconformable)
Underlying units	P_-LS-mlsg, P_-LS-mlsm, P_-LS-mhs, P_-MO-mog (intrusive)

Summary

Fine- to medium-grained, foliated metagranodiorite outcrops in the Mutherbukin Zone, and is a minor component of the Moorarie Supersuite. The foliated metagranodiorite outcrops at the eastern end of the Limejuice Zone on PINK HILLS and CANDOLLE where it intrudes several units of the Leake Spring Metamorphics and metagabbros of the Moorarie Supersuite, and is itself intruded by numerous components of the Moorarie Supersuite. Foliated metagranodiorite is a heterogeneous, fine- to medium-grained unit commonly including dykes of leucocratic metamonzogranite or metasyenogranite and, in places, zones of mixed metagranites. The most abundant and widespread rock type is an equigranular to porphyritic (up to 20% tabular and round K-feldspar phenocrysts) metagranodiorite usually with variably flattened inclusions of fine-grained metatonalite.

Distribution

Fine- to medium-grained, foliated metagranodiorite outcrops at the eastern end of the Limejuice Zone on PINK HILLS and CANDOLLE. The largest intrusion covers about 60 km^2 on northwestern PINK HILLS, with smaller exposures scattered amongst more voluminous units of the Moorarie Supersuite on southwestern CANDOLLE. The unit typically outcrops as rounded boulders amongst sheetwash and colluvium, but on CANDOLLE close to the unconformity with the overlying Edmund Group, the exposures are strongly weathered or silicified.

Lithology

Fine- to medium-grained, foliated metagranodiorite is a heterogeneous unit commonly including dykes of leucocratic metamonzogranite or metasyenogranite and, in places, zones of mixed metagranites. The most abundant and widespread rock type is an equigranular to porphyritic (up to 20% tabular and round K-feldspar phenocrysts) metagranodiorite usually with variably flattened inclusions of fine-grained metatonalite. Some very coarse-grained phenocrysts are pegmatitic and may be derived from intrusion of coeval pegmatite veins. Parts of the metagranodiorite contain prominent allanite crystals. The metagranodiorite contains about 10–15% biotite, and rocks grading to metatonalite commonly have pitted weathering surfaces. Most of the rocks are weakly foliated, with narrow higher-strain zones of strongly foliated rock. Locally, the metagranodiorite contains abundant subangular to subrounded inclusions of pelitic schist, amphibolite and metatonalite or metamorphosed quartz-diorite. In places, for example, at SXSPKH008163 (497316E 7258420N), the unit comprises a mixture of up to five different granite types dominated by coarse-grained porphyritic biotite-rich metagranodiorite. The metagranodiorite contains numerous inclusions and screens of mesocratic metatonalite, with both phases intruded by dykes of pale grey, fine- to medium-grained equigranular biotite metamonzogranite and medium- to coarse-grained, seriate biotite metamonzogranite.

In thin section, the metagranodiorite shows evidence of largely static recrystallization. The rocks are now composed of andesine (An_{35}), quartz, brown biotite, epidote, and microcline. The cores to some larger zoned plagioclase crystals are strongly sericitized and epidotized, and prismatic epidote crystals (some zoned) are intergrown with biotite and appear to have replaced magnetite. Quartz crystals have recrystallized to subgrains with sutured boundaries and undulose extinction.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metagranodiorite	g
Rock code		**P_-MO-mgg**

Contact relationships

Fine- to medium-grained, foliated metagranodiorite intrudes several units of the Leake Spring Metamorphics. Around Medalia Pool on northwestern PINK HILLS, metagranodiorite intrudes metagabbro of the Moorarie Supersuite. In the same area, the metagranodiorite is intruded by pale grey, foliated biotite(–muscovite) metamonzogranite that constitutes much of the unit of mesocratic biotite metagranodiorite to metamonzogranite and pale grey, layered biotite(–muscovite) metamonzogranite (P_-MO-xmg-m). To the north of Gaffney Bore on CANDOLLE foliated metagranodiorite occurs as decimetre-scale inclusions and rafts, the largest being nearly 500m across, within leucocratic, muscovite–tourmaline(–biotite) monzogranite of the Durlacher Supersuite (P_-DU-gmvt) and as discrete intrusions some 4 km^2 and 14 km^2 that are intruded by biotite monzogranite of the Moorarie Supersuite (P_-MO-gmeb and P_-MO-xmg-m) and leucocratic granite of the Durlacher Supersuite (P_-DU-gmvt) . Near Gaffney Bore and K 17 Well on CANDOLLE, fine- to medium-grained, foliated metagranodiorite intrudes into schists of the Leake Spring Formation (P_-LS-mlsm) and is unconformably overlain by the Yilgatherra Formation at the base of the Edmund Group.

Geochronology

P_-MO-mgg	Maximum	Minimum
Age (Ma)	1817	1776
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 1999	Nelson, 2002

This fine- to medium-grained, foliated metagranodiorite has not been dated. The metagranodiorite intrudes metasedimentary rocks of the Leake Spring Metamorphics, which have a maximum depositional age of 1842 ± 5 Ma (Wingate et al., in prep.). The metagranodiorite is intruded by mesocratic biotite metagranodiorite to metamonzogranite and pale grey, layered biotite(–muscovite) metamonzogranite (P_-MO-xmg-m), which is in turn intruded by coarse-grained equigranular biotite monzogranite (P_-MO-gmeb) dated at 1783 ± 5 Ma (Kirkland et al., 2009). Therefore, the metagranodiorite falls within the age range for the 1820–1775 Ma Moorarie Supersuite.

References

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009, 180938: monzogranite, Leake Spring: Geochronology Record 751: Geological Survey of Western Australia, 4p.

Nelson, DR 1999, 142931: biotite–muscovite–oligoclase granodiorite dyke, Two Wells; Geochronology Record 318: Geological Survey of Western Australia, 4p.

Nelson, DR 2002, 169058: augen orthogneiss, Kanes Gossan Prospect; Geochronology Record 132: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, Johnson, SP and Sheppard, S in prep., 190668; metasandstone, Nardoo Well: Geological Survey of Western Australia.

Moorarie Supersuite; subunit (P_-MO-mggn)

Legend narrative

Foliated and gneissic metagranodiorite and metatonalite; weakly pegmatite banded

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-md, P_-DU-gmv (intrusive); P_-MEy-s, P_-MEi-k (unconformable)
Underlying units	P_-LS-mhs, P_-LS-mk, P_-LS-mi, P_-MO-mgmn (faulted)

Summary

Foliated and gneissic metagranodiorite and metatonalite comprises the bulk of the Boora Boora Zone on Maroonah, and probably extends farther to the west on Towera, where it was mapped as meta-greywacke during the first edition mapping (Hocking et al., 1985). The most common rock type is a weakly pegmatite-banded, medium- to fine-grained, grey, foliated or gneissic metagranodiorite. The unit is tectonically interleaved with foliated and gneissic metamonzogranite (P_-MO-mgmn), and with various metasedimentary units of the Leake Spring Metamorphics. A low-strain metagranodiorite and a metamonzogranite dyke were both sampled for SHRIMP U–Pb zircon geochronology. The two samples yielded igneous crystallization ages of, respectively, 1794 ± 9 Ma and 1784 ± 5 Ma.

Distribution

Foliated and gneissic metagranodiorite and metatonalite comprises the bulk of the Boora Boora Zone on Maroonah. The foliated and gneissic metagranodiorite and metatonalite outcrops as low rounded hills covered in boulders and tors, with some pavements. In the northern part of the zone on Maroonah the rocks are commonly fresh, but farther south, closer to the unconformity with the overlying Edmund Group, the rocks are ferruginous and strongly weathered. Here they can be difficult to distinguish from metasedimentary rocks — particularly high-grade metamorphosed feldspathic sandstone (P_-PO-mtsf) — of the Pooranoo Metamorphics.

Lithology

The most common rock type is a medium- to fine-grained grey foliated or gneissic metagranodiorite. Most rocks are weakly pegmatite banded, but locally they are strongly pegmatite banded. The metagranodiorite is interleaved with lesser amounts of foliated to gneissic fine-grained, dark-grey metatonalite, and foliated and gneissic metamonzogranite (P_-MO-mgmn). The unit also includes dykes of pale-grey biotite metamonzogranite that intrude the gneissic layering at a low angle, but which are also deformed. The dykes are widespread, although not abundant, and up to 2 m wide.

Low-strain areas of the metagranodiorite comprise a medium- to coarse-grained rock that is equigranular to weakly porphyritic. In places the metagranodiorite contains inclusions of biotite metatonalite (Zone 50, MGA 349400E 7443890N) or fine-grained metamonzogranite (Zone 50, MGA 349850E 7444390N). Where little affected by low-grade metamorphism, the metagranodiorite has an anhedral granular or amoeboid texture with mafic minerals consisting of biotite, or biotite and minor muscovite. Microcline or microperthite is a minor component. Accessory minerals include zircon, apatite, and allanite. The metatonalite differs from the metagranodiorite in containing less K-feldspar and more biotite. There is no evidence of igneous hornblende in the metagranodiorite or metatonalite.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metagranodiorite	g
1st qualifier	–	
2nd qualifier	gneissose	n
Rock code		**P_-MO-mggn**
Additional lithologies	metatonalite	

Contact relationships

Foliated and gneissic metagranodiorite and metatonalite is tectonically interleaved with foliated and gneissic metamonzogranite (P_-MO-mgmn), and with various metasedimentary units of the Leake Spring Metamorphics. In a creek pavement about 6 km east-southeast of Mundong Well (Zone 50, MGA 361310E 7438650N) foliated and gneissic metagranodiorite is intruded by fine-grained amphibolite layers less than 0.5 m thick. Foliated and gneissic metagranodiorite and metatonalite is intruded by a large pluton of muscovite–biotite granodiorite (P_-DU-gmv) of the 1680–1620 Ma Durlacher Supersuite, and is unconformably overlain by the basal units of the Mesoproterozoic Edmund Group (P_-MEy-s, P_-MEi-k).

Geochronology

P_-MO-mggn	*Maximum*	*Minimum*
Age (Ma)	1794 ± 9	1784 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2004a	Nelson, 2004b

Foliated, equigranular to porphyritic, biotite metagranodiorite with sparse pegmatite veins was sampled 6 km west-northwest of Minga Springs for SHRIMP U–Pb zircon geochronology. The sample (GSWA 169087) is from a low-strain domain and is representative of the main rock type comprising the unit. The sample yielded a weighted mean date of 1794 ± 9 Ma, interpreted as the igneous crystallization age (Nelson, 2004a). In addition, eight xenocrysts yielded dates between c. 2280 and

c. 1850 Ma. A monzogranite dyke about 5 km northwest of Boora Boora Bore was also sampled for SHRIMP U–Pb geochronology (GSWA 169086). The dyke has an igneous foliation, and cuts gneissic layering (S_1) in the gneissic granodiorite, and intrudes an F_2 fold along the axial surface. The dyke has an igneous crystallization age of 1784 ± 5 Ma (Nelson, 2004b).

References

Hocking, RM, Williams, SJ, Lavaring, IH and Moore, PS 1985, Winning Pool–Minilya, W.A.: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 36p.

Nelson, DR 2004a, 169087: foliated biotite granodiorite, Minga Springs; Geochronology Record 44: Geological Survey of Western Australia, 4p.

Nelson, DR 2004b, 169086: biotite monzogranite, Boora Boora Bore; Geochronology Record 117: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-mgml)

Legend narrative

Leucocratic, equigranular muscovite(–biotite) metamonzogranite; fine- to medium-grained; weakly foliated

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-xmg-m (gradational); P_-POb-mxq, P_-POb-mqef, P_-POb-mtef, P_-MEy-st (unconformity).
Underlying units	P_-MOmi-mgmn, P_-LS-mhs, P_-LS-mlsm, P_-MO-mgms (intrusive); P_-MO-xmg-m (gradational)

Summary

Leucocratic, equigranular muscovite(–biotite) metamonzogranite is a minor component of the Moorarie Supersuite. The unit comprises two small intrusions in the Minnie Creek batholith on southeastern Mount Phillips and southwestern Mount Augustus and four small intrusions on Pink Hills. The metamonzogranite is fine to medium grained, typically with a weak to moderate foliation, and locally contains abundant phenocrysts of K-feldspar that may reach 30 mm in diameter.

Distribution

Leucocratic, equigranular muscovite(–biotite) metamonzogranite forms two irregular-shaped intrusions in the southeast corner of Mount Phillips and adjacent southwest corner of Mount Augustus. The main western intrusion is about 6 km long and less than 1 km wide. The smaller eastern intrusion comprises two sheets both less than 1 km long, that are probably contiguous at depth. There are also three small plugs in the area around Bentley Well on northeastern Eudamullah. The plugs are partly covered by colluvium, but each is probably less than 1 km^2 in size. Leucocratic, equigranular muscovite(–biotite) metamonzogranite also forms dykes that intrude rock types in the surrounding region. Minor outcrops of leucocratic, equigranular muscovite(–biotite) metamonzogranite are also found on southern and central Pink Hills. The most southerly outcrop is the most extensive, forming an elongate inlier some 8 km long by 2 km wide. The inlier is unconformably overlain by low grade sedimentary rocks of the Mount James Subgroup and Yilgatherra Formation of the Edmund Group. In the central part of Pink Hills the leucocratic metamonzogranite forms three small, discrete intrusions, all less than 2 km^2 that intrude parts of the Leake Spring Metamorphics and Middle Spring Granite.

Lithology

Leucocratic, equigranular muscovite(-biotite) metamonzogranite is mostly a homogeneous unit. The metamonzogranite is fine to medium grained, typically with a weak to moderate foliation. Phenocrysts of K-feldspar are locally present, and may reach 30 mm in diameter, but are usually less than 15 mm. There are a few zones of more mesocratic metagranite with a diffuse layering defined by concentrations of biotite. Inclusions of mesocratic, seriate to porphyritic biotite metamonzogranite (P_-MO-mgms) are sparse.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	–	
2nd qualifier	leucocratic	l
Rock code		**P_-MO-mgml**

Contact relationships

Leucocratic, weakly foliated, equigranular muscovite(–biotite) monzogranite intrudes interlayered pelitic and psammitic schist (P_-LS-mhs) and pelitic muscovite-rich schist (P_-LS-mlsm) of the Leake Spring Metamorphics, as well as gneissic to foliated metamonzogranites of the Middle Spring Granite (P_-MOmi-mgmn) and mesocratic, seriate to porphyritic biotite metamonzogranite (P_-MO-mgms). On this basis the monzogranite could belong to either the 1820–1775 Ma Moorarie Supersuite or the 1680–1620 Ma Durlacher Supersuite. At site TRFMP658 (Zone 50, MGA 445068E 7295298N), the monzogranite, along with psammitic schist, contains an early differentiated tectonic fabric that is cut by massive granites of the Minnie Creek batholith. Therefore, the leucocratic, weakly foliated, equigranular muscovite (–biotite) monzogranite is assigned to the Moorarie Supersuite. Leucocratic, fine- to medium-grained, weakly foliated, equigranular muscovite(–biotite) monzogranite grades, with increasing amounts of mesocratic biotite granodiorite and interleaved schist, into gneissose to schistose, mesocratic biotite granodiorite to monzogranite and leucocratic muscovite(–biotite) monzogranite (P_MO-xmgn-m). On southern Pink Hills leucocratic, weakly foliated, equigranular muscovite(–biotite) monzogranite is unconformably overlain by, and locally in faulted contact with low grade sedimentary rocks of the Mount James Subgroup (P_-POb-mxq, P_-POb-mqef, P_-POb-mtef) and Yilgatherra Formation (P_-MEy-st).

Geochronology

P_-MO-mgml	Maximum	Minimum
Age (Ma)	1795 ± 10	1782 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Bodorkos et al., 2006; Kirkland et al., 2009a	Kirkland et al., 2009b

Leucocratic, weakly foliated, equigranular muscovite (–biotite) metamonzogranite has not been dated directly, but is considered to be part of the Moorarie Supersuite. The metamonzogranite intrudes pelitic and psammitic schist of the Leake Spring Metamorphics (P_-LS-mhs) with a maximum depositional age of 1961 Ma (Kirkland et al., 2009a). The leucocratic metamonzogranite intrudes seriate to porphyritic biotite metamonzogranite (P_-MO-mgmp) dated at 1795 ± 10 Ma (Bodorkos et al., 2006), thus providing a maximum age for intrusion of the leucocratic metamonzogranite. Tectonic fabrics in the leucocratic, weakly foliated metamonzogranite are cut by massive coarse-grained equigranular biotite monzogranite (P_-MO-gmeb) dated at 1782 ± 5 Ma (Kirkland et al., 2009b), thus providing a minimum age for intrusion of the leucocratic metamonzogranite.

References

Bodorkos, S, Love, GJ, Nelson, DR and Wingate, MTD 2006, 88411: biotite granodiorite, Bentley Well; Geochronology Record 610: Geological Survey of Western Australia, 4p.

Kirkland, CL, Wingate, MTD, Bodorkos, S and Farrell, TR 2009a, 180935: psammitic schist, Leake Spring; Geochronology Record 749: Geological Survey of Western Australia, 5p.

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009b, 180938: monzogranite, Leake Spring; Geochronology Record 751: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-mgmn)

Legend narrative

Pale grey, foliated and gneissic metamonzogranite

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-mggn (faulted); P_-DU-gmv (intrusive); P_-MEy-s, P_-MEi-k (unconformable)
Underlying units	P_-LS-mhs, P_-LS-mk, P_-LSmi (faulted)

Summary

Pale-grey, foliated and gneissic metamonzogranite is interleaved with foliated and gneissic metagranodiorite and metatonalite (P_-MO-mggn) over much of the Boora Boora Zone on Maroonah. In low-strain zones, the metamonzogranite is medium grained and equigranular. A specimen of foliated metamonzogranite that was sampled for SHRIMP U–Pb zircon geochronology yielded an igneous crystallization age of 1806 ± 7 Ma.

Distribution

Pale-grey, foliated and gneissic metamonzogranite is tectonically interleaved with foliated and gneissic metagranodiorite and metatonalite (P_-MO-mggn) over a wide area on northwestern Maroonah. However, it is predominant only in the area southwest of Boora Boora Bore. Here it forms a layer, which is probably folded, up to 700 m thick and more than 9 km long that extends onto the Towera 1:100 000 sheet area to the west.

Lithology

Low-strain areas consist of a medium-grained, equigranular biotite metamonzogranite with minor pegmatite veining. In places the metamonzogranite contains up to 10% oval-shaped K-feldspar phenocrysts about 1 cm in diameter. In places (e.g. Zone 50, MGA 349670E 7453520N) the metamonzogranite contains lenticular inclusions of fine-grained, dark-grey quartz diorite or tonalite.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	–	
2nd qualifier	gneissose	n
Rock code		**P_-MO-mgmn**

Contact relationships

Foliated and gneissic metamonzogranite is tectonically interleaved with foliated and gneissic metagranodiorite and metatonalite (P_-MO-mggn), and with various metasedimentary units of the Leake Spring Metamorphics. Foliated and gneissic metamonzogranite is intruded by a large pluton of muscovite–biotite granodiorite (P_-DU-gmv) of the 1680–1620 Ma Durlacher Supersuite, and is unconformably overlain by the basal units of the Mesoproterozoic Edmund Group (P_-MEy-s, P_-MEi-k).

Geochronology

P_-MO-mgmn	*Maximum*	*Minimum*
Age (Ma)	1806 ± 7	1806 ± 7
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2004	Nelson, 2004

Foliated, grey, equigranular metamonzogranite was sampled from pavements in the Telfer River at Mundong Well on Maroonah for SHRIMP U–Pb zircon geochronology (GSWA 169088). The sample yielded a weighted mean date of 1806 ± 7 Ma (Nelson, 2004), interpreted as the igneous crystallization age of the granite precursor.

References

Nelson, DR 2004, 169088: foliated biotite monzogranite, Mundong Well; Geochronology Record 45: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-mgmp)

Legend narrative

Porphyritic to equigranular, medium- to very coarse-grained metagranite and pegmatite; leucocratic; massive to strongly foliated; locally gneissic

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DUdn-gmp
Underlying units	AP_-mgnl-YNAY, AP_-mgnw-YNAY, A-mwa-YNA, A-mwax-YNA, A-moa-YNA, A-mat-YNA, A-max-YNA, A-mkq-YNA, A-mkqx-YNA, A-mtq-YNA, A-mi-YNA, A-gge-YNA, A-mgnl-YNA, A-mngw-YNA, P_-CHq-mli, P_-CHp-mk, P_-BBya-mgm, P_-BBya-mgmu (intrusive)

Summary

Porphyritic to equigranular, medium- to very coarse-grained metagranite and pegmatite comprises dykes, veins, and some sheets that intrude a wide range of rock units in the Yarlarweelor Gneiss Complex and Errabiddy Shear Zone. Undeformed equivalents of the metagranite and pegmatite (P_-MO-gp) intrude the southern part of the Gascoyne Province. The metagranite and pegmatite display a range of textures from gneissic to massive, consistent with variable states of deformation. The metagranite and pegmatite typically contain biotite as the main or sole mafic mineral, but the mineralogy may vary according to the nature of the country rock. A sheet of coarse-grained metapegmatite from the Yarlarweelor Gneiss Complex on the western edge of MARQUIS yielded an igneous crystallization age of 1813 ± 8 Ma.

Distribution

Sheets and veins of metamorphosed and deformed coarse-grained granite and pegmatite (P_-MO-mgmp) intrude reworked Archean gneiss of the Yarlarweelor Gneiss Complex, and metasedimentary rocks of the Camel Hills Metamorphics in the Errabiddy Shear Zone. To a lesser extent, metamorphosed coarse-grained granite and pegmatite intrude rocks along the northern edge of the Yilgarn Craton, where the effects of the Capricorn Orogeny are limited to shear zone reactivation, rather than pervasive reworking. In the Yarlarweelor Gneiss Complex, metamorphosed coarse-grained granite and pegmatite mostly form bodies ranging in width from about a centimetre to several metres, but sheets or lenses up to 200 m thick and 4 km long are also present. Large sheets are particularly abundant in the southwestern corner of MARQUIS. In the Errabiddy Shear Zone east of Vince Bore and south of Pines Bore on eastern ERRABIDDY, pegmatite commonly forms east-southeasterly or southeasterly trending dykes. In addition, metamorphosed medium- to coarse-grained biotite–muscovite granite and pegmatite form an elongate, northeasterly trending pluton about 15 km long and 5 km wide north of Dewar Bore on southeastern ERRABIDDY.

On the southeastern part of ERRABIDDY, sheets of coarse-grained biotite monzogranite to granodiorite, up to 1.5 km thick, intrude reworked leucocratic granitic gneiss (AP_-mgnl-YNAY). This part of ERRABIDDYis close to the tectonic boundary between the Yilgarn Craton and Yarlarweelor Gneiss Complex, and the abundance of the coarse-grained granite sheets in this zone may represent magmatic ‘stitching’ of this faulted contact.

Lithology

Most of the metamorphosed coarse-grained granites and some of the pegmatites contain plagioclase and microcline, but many of the pegmatites contain only plagioclase with microcline intergrowths. Biotite is commonly the main mafic mineral, but the mineralogy of the pegmatites is variable and may be partly dependent on the country rocks. The pegmatites commonly contain biotite, with or without muscovite, where they intrude granitic gneiss. In contrast, where they intrude migmatitic pelitic gneiss in the Errabiddy Shear Zone, the bulk of the pegmatites contain muscovite with or without tourmaline and biotite. On ERRABIDDY, both the pluton north of Dewar Bore and the granites that intruded the migmatitic pelitic gneiss consist of biotite–muscovite tonalite and trondhjemite. In the Yarlarweelor Gneiss Complex on MARQUIS, the pegmatites commonly contain tremolite where they intruded calc-silicate gneiss, and magnetite is common in the pegmatites where iron-formation is locally abundant.

Also included within this unit are dykes of foliated, medium-grained, weakly porphyritic monzogranite in the Yarlarweelor Gneiss Complex on southern MARQUIS. The dykes are widespread through the granitic gneisses, but never abundant.

The metamorphosed coarse-grained granites and pegmatites display a range of textures consistent with their variable states of deformation. Some preserve coarse-grained igneous textures, but most show evidence of moderate dynamic or static recrystallization. In the Yarlarweelor Gneiss Complex some granites and pegmatites have medium-grained amoeboid and polygonal granoblastic textures indicative of recrystallization at medium to high metamorphic grade. Where strongly deformed, the sheets are gneissic and may contain layers up to a few centimetres thick of idioblastic almandine garnet crystals. Unaltered plagioclase crystals are andesine, but most crystals show some recrystallization to albite–oligoclase with fine-grained sericite and minor clinozoisite. Quartz is recrystallized to finer grained, sutured crystals.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	–	
2nd qualifier	pegmatitic	p
Rock code		**P_-MO-mgmp**

Contact relationships

Sheets, dykes, and veins of metamorphosed and deformed coarse-grained granite and pegmatite intrude a wide range of rock types, including reworked Archean granites and gneisses and interleaved supracrustal rocks and the Yamagee Granite in the Yarlarweelor Gneiss Complex, and metasedimentary and meta-igneous rocks of the Camel Hills Metamorphics and Archean granitic rocks in the Errabiddy Shear Zone. The sheets and some veins are concordant with, or slightly discordant to, the gneissic layering, but dykes and many veins are strongly discordant to the gneissic layering. The granite and pegmatite are folded and deformed by D_{1n} structures, but they are also deformed about D_{1n} folds — therefore, they were intruded during D_{1n} (see Capricorn Orogeny). Metamorphosed coarse-grained granite and pegmatite are intruded by porphyritic monzogranite of the Discretion Granite (P_-DUdn-gmp).

Geochronology

P_-MO-mgmp	Maximum	Minimum
Age (Ma)	1813 ± 8	1802
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Inferred
References	Nelson, 1998a; Nelson, 1998b	Nelson, 1998c

A sheet of metamorphosed coarse-grained granite and pegmatite in the Yarlarweelor Gneiss Complex on MARQUIS was sampled for SHRIMP U–Pb zircon geochronology. The sample (GSWA 142849) yielded a weighted mean $^{207}Pb^*/^{206}Pb^*$ date of 1813 ± 8 Ma, interpreted as the igneous crystallization age (Nelson, 1998a). Five concordant zircons with dates >2500 Ma are interpreted to be xenocrysts. A sample (GSWA 142854) of a foliated granite dyke about 4 km east-northeast of Jubilee Bore on southern MARQUIS yielded an igneous crystallization age of 1811 ± 9 Ma (Nelson, 1998b). This result is indistinguishable from the date of the sample of the pegmatitic granite sheet discussed above. On ERRABIDDY, metamorphosed coarse-grained metagranite and metapegmatite north of Dewar Bore is intruded by a plug and associated veins of massive, fine- to medium-grained, leucocratic muscovite–biotite granodiorite (P_-MO-ggev) dated at 1802 ± 9 Ma (GSWA 142900; Nelson, 1998c).

References

Nelson, DR 1998a, 142849: foliated coarse-grained monzogranite, northeast of White Well; Geochronology Record 365: Geological Survey of Western Australia, 4p.

Nelson, DR 1998b, 142854: foliated granite dyke, east-northeast of Jubilee Well; Geochronology Record 370: Geological Survey of Western Australia, 4p.

Nelson, DR 1998c, 142900: muscovite-biotite monzogranite, Dewars Bore; Geochronology Record 360: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-mgms)

Legend narrative

Mesocratic, seriate-textured to porphyritic biotite metamonzogranite; medium- to coarse-grained; commonly strongly foliated

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-mgmz
Underlying units	P_-LS-mlsm

Summary

Mesocratic, seriate to porphyritic biotite metamonzogranite forms two east-southeast-trending, sheet-like intrusions along the northern edge of the Minnie Creek batholith on northeastern EUDAMULLAH. The metamonzogranite is typically strongly foliated, and commonly has a layering defined by porphyritic and seriate textured layers. Two samples of the unit that were taken for SHRIMP U–Pb zircon geochronology yielded igneous crystallization ages of c. 1800 and c. 1795 Ma.

Distribution

Mesocratic, seriate to porphyritic biotite metamonzogranite is confined to two east-southeast-trending intrusions on northeastern EUDAMULLAH between 17 Mile Outcamp Well and West Minnie Bore. The larger of the intrusions is about 15 km long and 3 km wide; the smaller intrusion is about 6 km long and 1.5 km wide. These intrusions outcrop within a series of shear zones that mark the boundary between the Minnie Creek batholith and the Mangaroon Zone to the north.

Lithology

Mesocratic, seriate to porphyritic biotite metamonzogranite is typically strongly foliated. The unit ranges from an homogeneous mesocratic, seriate to porphyritic metamonzogranite, to outcrops of layered mesocratic porphyritic and seriate metamonzogranites, some with layers or dykes of weakly foliated fine- to medium-grained leucocratic granite. Biotite commonly forms clots. K-feldspar phenocrysts range from 5–50 mm in diameter, are anhedral to euhedral, and have simple twinning.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	–	
2nd qualifier	schistose	s
Rock code		**P_-MO-mgms**

Contact relationships

Mesocratic, seriate to porphyritic biotite metamonzogranite is intruded by east-southeast trending dykes of leucocratic, sparsely porphyritic biotite metamonzogranite (P_-MO-mgmz); in high-strain zones the contacts are faulted and the relative ages cannot be determined. Mesocratic, seriate to porphyritic biotite metamonzogranite intrudes muscovite-rich pelitic schist of the Leake Spring Metamorphics (P_-LS-mlsm), and locally contains scattered inclusions of schist up to 0.8 m long.

Geochronology

P_-MO-mgms	*Maximum*	*Minimum*
Age (Ma)	1801 ± 5	1795 ± 10
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Bodorkos et al., 2006a	Bodorkos et al., 2006b

Mesocratic, seriate to porphyritic biotite metamonzogranite was sampled at two localities for SHRIMP U–Pb zircon geochronology. A strongly foliated, K-feldspar porphyritic monzogranite (GSWA 88412), which contains fine-grained biotite-rich inclusions and abundant biotite schlieren, has an igneous crystallization age of 1801 ± 5 Ma (MSWD = 0.89) defined by 29 analysed zircons. A mesocratic, seriate biotite monzogranite with scattered K-feldspar phenocrysts up to 25 mm diameter (GSWA 88411) has an igneous crystallization age of 1795 ± 10 Ma (MSWD = 1.2) defined by 23 concordant to moderately discordant analyses of 22 zircons.

References

Bodorkos, S, Love, GJ and Wingate, MTD 2006a, 88412: foliated porphyritic monzogranite, Bentley Well; Geochronology Record 611: Geological Survey of Western Australia, 4p.

Bodorkos, S, Love, GJ, Nelson, DR and Wingate, MTD 2006b, 88411: biotite granodiorite, Bentley Well; Geochronology Record 610: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-mgmu)

Legend narrative

Strongly porphyritic, foliated biotite metamonzogranite with coarse, round, or tabular phenocrysts of K-feldspar; abundant inclusions of biotite-rich mafic rock; locally comprises augen gneiss

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmeb
Underlying units	P_-CHq-mli, P_-CHp-mk (intrusive)

Summary

Strongly porphyritic, foliated metamonzogranite has an identical appearance to Archean augen gneiss and porphyritic granite (A-mgmu-YNAY), but the Archean unit is intruded by late Archean granite (A-gme-YNA), whereas the strongly porphyritic, foliated granite intruded migmatitic pelitic gneiss (P_-CHq-mli) of the Camel Hills Metamorphics. The Paleoproterozoic, strongly porphyritic, foliated granite commonly contains abundant biotite-rich inclusions and mafic schlieren, features absent from the Archean unit.

Distribution

Strongly porphyritic, foliated metamonzogranite forms several sheets that intrude migmatitic pelitic gneiss in the Errabiddy Shear Zone on the eastern edge of ERRABIDDY. Foliated, strongly porphyritic biotite metamonzogranite also forms a series of exposures between the Gascoyne River and the Landor–Dalgety Downs Road in the western half of LANDOR.

Lithology

The bulk of the strongly porphyritic, foliated metamonzogranite is moderately to strongly foliated, and contains about 30–40% round phenocrysts or porphyroclasts of microcline in a medium-grained (2–3 mm) groundmass. The porphyroclasts typically display deformation lamellae and chequerboard microperthite textures. Small inclusions of round quartz and subhedral plagioclase are preserved in many phenocrysts. The groundmass consists of extensively recrystallized quartz, microcline, plagioclase, and biotite, with accessory zircon, apatite, and monazite. Igneous plagioclase is typically recrystallized to fine-grained sericite, epidote, and ?albite–oligoclase. Locally the unit is an augen gneiss.

On LANDOR the metamonzogranite contains tabular phenocrysts of microcline up to 3 cm long in a grey, medium-grained groundmass. Thin sections show the metamonzogranite to have a metamorphic overprint; quartz and biotite are largely recrystallized, granophyric intergrowths of microcline and quartz are abundant, and plagioclase is strongly recrystallized to sericite, epidote, and ?albite.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	–	
2nd qualifier	augen	u
Rock code		**P_-MO-mgmu**

Contact relationships

Strongly porphyritic, foliated metamonzogranite on ERRABIDDY intrudes the Quartpot Pelite (P_-CHq-mli) and Petter Calc-Silicate (P_-CHp-mk) of the Camel Hills Metamorphics. On LANDOR, strongly porphyritic, foliated metamonzogranite is veined by medium-grained, equigranular biotite monzogranite (P_-MO-gmeb).

Geochronology

P_-MO-mgmu	*Maximum*	*Minimum*
Age (Ma)	1817	1801
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 1999	Nelson, 1998

This strongly porphyritic, foliated metamonzogranite has not been dated directly. The metamonzogranite intrudes the Camel Hills Metamorphics, and must, therefore, be younger than about 2000 Ma, the maximum depositional age of the Quartpot Pelite. On LANDOR, strongly porphyritic, foliated metamonzogranite is intruded by medium-grained equigranular biotite monzogranite (P_-MO-gmeb), which is dated at 1801 ± 7 Ma on MARQUIS (GSWA 142856; Nelson, 1998). As this unit is assumed to be coeval with other granites of the Moorarie Supersuite, but younger than that of P_-MO_gmeb at c. 1800 Ma it must have an age between c. 1820 and 1800 Ma.

References

Nelson, DR 1998, 142856: monzogranite, west of Round Yard Bore; Geochronology Record 372: Geological Survey of Western Australia, 4p.

Nelson, DR 1999, 142931: biotite–muscovite–oligoclase granodiorite dyke, Two Wells; Geochronology Record 318: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-mgmz)

Legend narrative

Altered granite; consists of quartz–sericite–pyrite; locally foliated

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MEy-st
Underlying units	P_-MO-gmeb

Summary

Altered granite consisting of quartz–sericite–pyrite forms a single exposure on northeastern GLENBURGH. The precursor to the altered granite was most likely a medium-grained, equigranular biotite(–muscovite) granite (P_-MO-gmeb).

Distribution

Altered granite is exposed over about 8 km^2 west-northwest of Mount Puckford on the northeastern part of GLENBURGH.

Lithology

The altered granite is medium grained and equigranular, and comprises quartz–sericite–pyrite(–hematite). The mineralogy reflects pervasive alteration. The rocks are locally well foliated.

Age code	Proterozoic	P_-
Stratigraphic cod	Moorarie Supersuite	MO-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	–	
2nd qualifier	altered composition; metasomatized	z
Rock code		**P_-MO-mgmz**

Contact relationships

Altered granite probably has a gradational contact with medium-grained, equigranular biotite(–muscovite) granite (P_-MO-gmeb) and is unconformably overlain by low grade sedimentary rocks of the Yilgatherra Formation (P_-MEy-st) of the Edmund Group.

Geochronology

P_-MO-mgmz	*Maximum*	*Minimum*
Age (Ma)	1801	1783
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 1998	Kirkland et al., 2009

Altered granite has not been dated directly, but given that the likely precursor to the rock was medium-grained, equigranular biotite(–muscovite) granite (P_-MO-gmeb), then the altered granite is likely to be 1801–1783 Ma in age.

References

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009, 180938: monzogranite, Leake Spring; Geochronology Record 751: Geological Survey of Western Australia, 4p.

Nelson, DR 1998, 142852: recrystallized monzogranite dyke, Dunes Well; Geochronology Record 368: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-mgn)

Legend narrative

Pegmatite-banded gneissic and foliated granite; protoliths include mesocratic metamonzogranite to metagranodiorite, foliated porphyritic metamonzogranite, and minor foliated leucocratic garnet metagranite and metapegmatite

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-mgmp (intrusive)
Underlying units	P_-LS-mhs, P_-LS-mk (intrusive); AP_-_ha-mgnl (faulted)

Summary

Pegmatite-banded gneissic and foliated granites comprise a heterogeneous unit on the eastern part of YINNETHARRA, marked by the presence of refolded folds. These folds distinguish the granitic rocks from foliated and gneissic granites of the Durlacher Supersuite, which contain only one tectonic fabric. A specimen of low-strain metamonzogranite sampled for SHRIMP U–Pb zircon geochronology yielded an igneous crystallization age of 1799 ± 5 Ma.

Distribution

Pegmatite-banded gneissic and foliated granites of the Moorarie Supersuite (P_-MO-mgn) are restricted to an easterly-trending belt, about 13 km long and up to 5 km wide on the eastern edge of YINNETHARRA, which extends eastwards on to PINK HILLS. The unit underlies low hills covered with boulders and tors, and scattered weathered pavements.

Lithology

Pegmatite-banded gneissic and foliated granites (P_-MO-mgn) is a heterogeneous unit comprising at least three granite protoliths; these protoliths include (1) gneissic, mesocratic biotite-rich monzogranite to granodiorite, (2) foliated porphyritic, medium-grained metamonzogranite, and (3) minor foliated leucocratic garnet granite and pegmatite. Mesocratic granitic gneiss or gneissic monzogranite is both widespread and abundant. It is commonly intruded by veins and dykes of foliated porphyritic, medium-grained metamonzogranite, which cut the gneissic layering. Locally this metamonzogranite is the most abundant phase, and contains rafts of the mesocratic gneissic phase. Both of these rock types are intruded in places by veins and sheets of foliated leucocratic garnet granite and pegmatite. The mesocratic gneissic granites contain minor interleaved horizons or pods less than 2 m thick of quartz-rich psammitic gneiss, pelitic gneiss, and calc-silicate gneiss.

Mesocratic granitic gneisses sampled for thin section are quartz–biotite–plagioclase–titanomagnetite(–garnet) and quartz–biotite–plagioclase–epidote–titanomagnetite(–microcline) rocks with abundant accessory zircon, allanite, and monazite, some of which is prismatic. Biotite comprises about 20% or more of the rocks. Plagioclase is very fresh and has only simple twinning. Plagioclase is commonly difficult to distinguish from quartz, and it may comprise considerably more of the rocks than the 15–20% estimated. The protolith was probably a tonalite.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	meta-igneous felsic intrusive	mg
Lithname	granitic gneiss	n
Rock code		**P_-MO-mgn**
Additional lithologies	metasyenogranite, metamonzogranite	

Contact relationships

Pegmatite-banded gneissic and foliated granites (P_-MO-mgn) contain widespread, if not abundant, horizons and pods of interlayered pelitic and psammitic gneiss (P_-LS-mhs) and calc-silicate gneiss (P_-LS-mk) of the Leake Spring Metamorphics. Contact relationships between these horizons and pods, and the host gneissic and foliated granites are commonly difficult to identify; it is not altogether clear as to whether the contacts are intrusive, as well as faulted. The pegmatite-banded gneissic and foliated granites are in contact with leucocratic granitic gneiss and foliated leucocratic granite of the Halfway Gneiss (AP_-_ha-mgnl) over a considerable strike extent, but the contact appears to be faulted.

Geochronology

P_-MO-mgn	*Maximum*	*Minimum*
Age (Ma)	1799 ± 5	1799 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Wingate et al., 2010	Wingate et al., 2010

Pegmatite-banded gneissic and foliated granites were sampled for SHRIMP U–Pb zircon geochronology about 5 km north of Daly Bore on eastern YINNETHARRA. The sample (GSWA 185952) is a medium grained recrystallized metamonzogranite with biotite-rich schlieren and inclusions, and yielded subhedral to euhedral, equant to elongate zircons, most with oscillatory growth zoning. Sixteen analyses of 16 zircons define a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1799 ± 5 Ma, which is interpreted as the igneous crystallization age (Wingate et al., 2010).

References

Wingate, MTD, Kirkland, CL, Sheppard, S and Johnson, SP 2010, 185952: gneissic monzogranite, Salt Well; Geochronology Record 905: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-mgnl)

Legend narrative

Leucocratic granitic gneiss and foliated leucocratic metagranite; derived from biotite monzogranite and granodiorite

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-mgm, P_-DU-mgmb, P_-_mod-GA (intrusive)
Underlying units	AP_-_ha-mgnw, P_-MGm-mtq, P_-MGm-mk, P_-LS-mhs, P_-MO-mgn (faulted)

Summary

Leucocratic granitic gneiss and foliated leucocratic metagranite is a minor component of the Moorarie Supersuite, being restricted to the Mutherbukin Zone on eastern YINNETHARRA and western PINK HILLS. The unit is undated, but is inferred to belong to the Moorarie Supersuite on the basis of its field relationships with dated units.

Distribution

Leucocratic granitic gneiss and foliated leucocratic metagranite outcrops in an easterly to southeasterly trending belt about 2 km wide on the eastern edge of YINNETHARRA and adjacent western edge of PINK HILLS. The eastern and southern ends of the belt are truncated by faults.

Lithology

Leucocratic granitic gneiss and foliated leucocratic metagranite commonly contains minor biotite-rich schlieren and inclusions, as well as some mesocratic granitic gneiss layers. The gneisses are commonly folded about upright east-southeast trending F_2 folds. The leucocratic rocks are typically medium to coarse grained, equigranular to sparsely porphyritic (4–8 mm porphyroclasts of feldspar), locally pegmatitic, with banding in part defined by pegmatite veins. These veins may be folded about small-scale intrafolial folds or isoclinal folds 2–20 cm in wavelength within the gneissic layering. In places the leucocratic gneisses contain small idioblastic garnet porphyroblasts. In lower strain areas the rocks are foliated leucocratic metagranites. In addition to the leucocratic rocks, the unit contains pale-grey, fine- to medium-grained, sparsely porphyritic metamonzogranite and fine-grained, mesocratic, biotite-rich metagranodiorite, or their gneissic and schistose equivalents.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	meta-igneous felsic intrusive	mg
Lithname	granitic gneiss	n
1st qualifier	–	
2nd qualifier	leucocratic	l
Rock code		**P_-MO-mgnl**
Additional lithologies	metagranodiorite	

Contact relationships

Leucocratic granitic gneiss and foliated leucocratic metagranite is both faulted against and tectonically interleaved with mesocratic granitic gneiss of the Halfway Gneiss, units of the Moogie Metamorphics, and pegmatite-banded gneissic and foliated granites (P_-MO-mgn). The leucocratic gneiss contains slivers of interlayered pelitic and psammitic schist of the Leake Spring Metamorphics, but it is unclear as to whether or not the original relationship was intrusive. The gneiss is intruded by foliated equigranular and porphyritic biotite metamonzogranite of the Durlacher Supersuite (P_-DU-mgm, P_-DU-mgmb), and by dykes of metadolerite and amphibolite (P_-_mod-GA).

Geochronology

P_-MO-mgnl	*Maximum*	*Minimum*
Age (Ma)	1817	1776
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 1999	Nelson, 2002

Leucocratic granitic gneiss and foliated leucocratic metagranite has not been dated directly. Nevertheless, the rocks have the same structural history as the pegmatite-banded gneissic and foliated granites (P_-MO-mgn), a sample of which has an igneous crystallization age of 1799 ± 5 Ma. If the protoliths to the leucocratic gneiss intruded the Leake Spring Metamorphics, this would indicate a maximum age of c. 1842 Ma for the unit. The leucocratic gneiss and metagranite is intruded by units of the 1680–1620 Ma Durlacher Supersuite, which contain only a single foliation. For these reasons, the leucocratic granitic gneiss and foliated leucocratic metagranite are assigned to the Moorarie Supersuite, which has an age range of c. 1820 to 1775 Ma.

References

Nelson, DR 1999, 142931; biotite–muscovite–oligoclase granodiorite dyke, Two Wells: Geochronology Record 318: Geological Survey of Western Australia, 4p.

Nelson, DR 2002, 169058: augen orthogneiss, Kanes Gossan Prospect; Geochronology Record 132: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-mgsl)

Legend narrative

Schistose, leucocratic muscovite(–biotite) metamonzogranite

Rank	Formation
Parent	Moorarie Supersuite P_-MO-g
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-POs-mtqs, P_-POb-mxq (faulted/unconformable); P_-DUda-mgmu, P_-TT-gmlt, P_-MW-od (intrusive)
Underlying units	P_-LS-mlst, P_-LS-mwa (intrusive)

Summary

Schistose, leucocratic muscovite(–biotite) metamonzogranite is confined to a strip near the northern edge of the Mutherbukin Zone on Mount Phillips. The main outcrop forms a southeast-trending belt less than 1 km wide that separates the Pooranoo Metamorphics from the Leake Spring Metamorphics in the Nardoo Hills area on the southern edge of Mount Phillips. Schistose, leucocratic muscovite(–biotite) metamonzogranite is typically fine to medium grained, with roughly equal amounts of muscovite and biotite, is typically strongly foliated, and locally contains feldspar porphyroclasts up to about 15 mm in diameter. A sample of the metamonzogranite yielded a SHRIMP U–Pb zircon age of 1795 ± 7 Ma.

Distribution

Schistose, leucocratic muscovite(–biotite) metamonzogranite outcrops as a southeast-trending belt less than 1 km wide that separates the Pooranoo Metamorphics from the Morrissey Metamorphics in the Nardoo Hills area on the southern edge of Mount Phillips. There is also a 1 km^2 exposure of the same metamonzogranite a little farther to the east.

Lithology

Schistose, leucocratic muscovite(–biotite) metamonzogranite is typically fine to medium grained, with roughly equal amounts of muscovite and biotite. The metamonzogranite is typically strongly foliated, and locally contains feldspar porphyroclasts up to about 15 mm in diameter. The metamonzogranite is layered in places, with 5–30 cm-thick layers defined by variations in grain size and colour. Many parts of the unit have drawn out quartzofeldspathic ribbons implying relatively high strain. There are a few layers of quartzite and scattered inclusions and layers of pelitic schist and amphibolite.

In thin section, the metamonzogranite comprises quartz, microcline, plagioclase, biotite, muscovite, with accessory tourmaline, apatite and zircon, and trace secondary calcite. Quartz forms elongate strips suggesting gneissic fabric.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	meta-igneous felsic intrusive	mg
Lithname	granitic schist	s
1st qualifier	–	
2nd qualifier	leucocratic	l
Rock code		**P_-MO-mgsl**

Contact relationships

At the western end of the main sheet, a crenulation in pelitic schist (P_-LS-mlst) is parallel to a lineation in the schistose, leucocratic muscovite(–biotite) metamonzogranite, implying that the metamonzogranite is younger. There are also scattered rafts and layers of schist and amphibolite of the Leake Spring Metamorphics (P_-LS-mlst, P_-LS-mwa) in the leucocratic metamonzogranite. The contact between the leucocratic metamonzogranite and metasedimentary rocks of the Pooranoo Metamorphics is inferred to have originally been an unconformity, but is now faulted. The leucocratic metamonzogranite is intruded by the Davey Well Granite (P_-DUda-mgmu) and by leucocratic tourmaline-bearing granite of the Thirty Three Supersuite (P_-TT-gmlt). Dykes belonging to the Mundine Well Dolerite Suite also intrude the leucocratic metamonzogranite.

Geochronology

P_-MO-mgsl	*Maximum*	*Minimum*
Age (Ma)	1792 ± 6	1792 ± 6
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Wingate et al., 2009	Wingate et al., 2009

Schistose, leucocratic muscovite(–biotite) metamonzogranite was sampled for SHRIMP U–Pb zircon geochronology about 4 km northwest of Nardoo Well, on southwestern Mount Phillips (Zone 50, MGA 405118E 7296088N). Twenty five zircons separated from the sample, GSWA 191995, were analysed, of which five are characterized by moderate discordance and high common Pb. Ten analyses of 10 zircons yield a weighted mean $^{207}Pb^*/^{206}Pb^*$ date of 1792 ± 6 Ma, interpreted as the age of igneous crystallization of the monzogranite precursor (Wingate et al., 2009). Nine analyses of nine older grains, interpreted as xenocrysts, yield ages between 2538 Ma and 1885 Ma.

References

Wingate, MTD, Kirkland, CL, Bodorkos, S, Farrell, TR and Sheppard, S 2009, 191995: foliated leucocratic metamonzogranite, White Well; Geochronology Record 776: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-mgts)

Legend narrative

Mesocratic, equigranular to sparsely porphyritic biotite metatonalite and metamorphosed quartz-diorite; medium- to coarse-grained; schistose

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmeb, P_-DU-gmv, P_-DU-gmvt, P_-DUda-mgmu
Underlying units	P_-LS-mlsg

Summary

Mesocratic, equigranular to sparsely porphyritic biotite metatonalite and metamorphosed quartz-diorite outcrops along the southern edge of the Minnie Creek batholith on EUDAMULLAH and MOUNT AUGUSTUS. The unit is commonly schistose. The metatonalite and metamorphosed quartz-diorite contains numerous inclusions of pelitic schist of the Leake Spring Metamorphics, and is intruded by more silicic granites of the Minnie Creek batholith. A specimen of metatonalite sampled for SHRIMP U–Pb zircon geochronology yielded an igneous crystallization age of 1807 ± 3 Ma, which is amongst the oldest in the Minnie Creek batholith.

Distribution

Mesocratic, equigranular to sparsely porphyritic biotite metatonalite and metamorphosed quartz-diorite is restricted to two areas; the first, a strip about 8 km long and 2 – 2.5 km wide along the southern edge of the Minnie Creek batholith centred on Granite Well on eastern EUDAMULLAH, and the second, the remnants of two intrusions each less than about 7 km^2 near the southern edge of the Minnie Creek batholith in the southwestern corner of MOUNT AUGUSTUS. Similar rock types also form inclusions within many phases of the Minnie Creek batholith.

Lithology

Mesocratic, equigranular to sparsely porphyritic biotite metatonalite and metamorphosed quartz-diorite are schistose, medium- to coarse-grained rocks. The metamorphosed quartz-diorite usually forms lenticular or slabby inclusions up to 1 m long within the metatonalite. Inclusions of amphibolite are also common in the metatonalite. Metatonalite commonly outcrops poorly relative to the silicic granites that intrude it; parts of this unit contain abundant veins and dykes of foliated, fine- to medium-grained biotite–muscovite or muscovite–tourmaline granite (P_-DU-gmv, P_-DU-gmvt) with screens of metatonalite, particularly in the area around Granite Well on EUDAMULLAH. Metatonalite and metamorphosed quartz-diorite are strongly recrystallized, to assemblages of oligoclase, brown biotite, epidote, quartz, and titanite. Biotite is the sole mafic mineral.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metatonalite	t
1st qualifier	–	
2nd qualifier	schistose	s
Rock code		**P_-MO-mgts**
Additional lithologies	metadiorite	

Contact relationships

Mesocratic, equigranular to sparsely porphyritic biotite metatonalite and metamorphosed quartz-diorite contains numerous inclusions and rafts of garnet- or staurolite-bearing pelitic schist and gneiss of the Leake Spring Metamorphics northwest of Granite Well. At numerous localities northwest and east of Granite Well, metatonalite and metamorphosed quartz-diorite is intruded by medium- to coarse-grained, equigranular biotite monzogranite (P_-MO-gmeb), as well as dykes and veins of fine- to medium-grained biotite–muscovite granodiorite and monzogranite (P_-DU-gmv) and muscovite–tourmaline(–biotite) monzogranite (P_-DU-gmvt). At site SXSEUD6629 (Zone 50, MGA 386588E 7310870N) screens of mesocratic metatonalite and metamorphosed quartz-diorite are present within coarse grained porphyritic monzogranite of the Davey Well Granite (P_-DUda-mgmu).

Geochronology

P_-MO-mgts	*Maximum*	*Minimum*
Age (Ma)	1807 ± 3	1807 ± 3
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Kirkland et al., 2009	Kirkland et al., 2009

About 4 km south-southwest of Mallet Well on southeastern EUDAMULLAH, at site SXSEUD6628 (Zone 50, MGA 386327E 7310931N) screens of metatonalite with metamorphosed quartz-diorite inclusions are present within equigranular biotite monzogranite (P_-MO-gmeb), coarse-grained porphyritic biotite monzogranite (P_-DUda-mgmu), and muscovite–biotite monzogranite (P_-DU-gmv). The metatonalite was sampled here for SHRIMP U–Pb zircon geochronology (Kirkland et al., 2009). Twenty-two analyses of 20 zircons define a single group with an age of 1807 ± 3 Ma, with two xenocrysts at c. 1830 Ma. This date indicates that the mesocratic biotite metatonalite and metamorphosed quartz-diorite is one of the oldest phases in the Minnie Creek batholith.

References

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009, 183205: schistose metatonalite, Mallet Well: Geochronology Record 753: Geological Survey of Western Australia, 4p.

Moorarie Supersuite; subunit (P_-MO-mog)

Legend narrative

Massive, subophitic metagabbro; medium grained; amphibolite; minor hornblende schist

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmp, P_-MO-gmpi, P_-MO-gmeb, P_-MO-gmal (intrusive); P_-MO-gge (mingled)
Underlying units	P_-MO-gmp

Summary

Metagabbro comprises rafts and inclusions within most of the granites of the Minnie Creek batholith; the remainder of the Moorarie Supersuite contains no exposed metagabbro. Preliminary results from two gravity traverses are consistent with the presence of some 1–2 km-thick mafic bodies at depth in the Minnie Creek batholith, but overall, the metagabbro is a minor component of the Moorarie Supersuite. The metagabbro has not been dated directly, but field relationships with dated granite intrusions suggest that metagabbro may have been emplaced over at least 10 Ma.

Distribution

Metagabbro forms rafts and inclusions within granites along the mapped extent of the Minnie Creek batholith. The largest rafts, each 0.3 – 1 km^2 in extent, outcrop southeast of Minnie Creek Homestead on Eudamullah. However, most of the rafts are <0.1 km^2 in area. Two gravity traverses were carried out to test the hypothesis that positive regional gravity anomalies in the Minnie Creek batholith reflect the presence of large mafic intrusions at depth: the first along the Gascoyne Junction – Ullawarra Road, and the second along the Dairy Creek – Cobra Road. Modelling along the two traverses suggests that the anomalies can be explained by mafic bodies 1–2 km thick at a depth of about 2–4 km (GSWA, unpublished data). In addition, a detailed traverse was conducted over an outcrop of metagabbro roughly 300 m in diameter about 1.4 km west-northwest of Roadside Well on Mount Phillips. Modelling along the detailed traverse shows the metagabbro is probably only about 100 m thick (GSWA, unpublished data).

In the northwestern corner of Maroonah, in the Boora Boora Zone, composite layers of metagabbro and amphibolite up to 100 m thick and 3 km long are exposed. These mafic rocks have been included within the Moorarie Supersuite rather than in the Morrissey Metamorphics, because field relationships suggest that some of the mafic rocks intruded foliated and gneissic granites of the Moorarie Supersuite, but were deformed along with them.

Lithology

In the Limejuice Zone metagabbro mainly consists of medium- to coarse-grained rocks with a subophitic or poikilitic texture. Weathered surfaces may be pitted owing to weathering of relict clinopyroxene oikocrysts. Primary phases include plagioclase, magnetite, and quartz, with pyroxene commonly entirely replaced by amphibole. Locally, metagabbro contains layering reflecting varying proportions of feldspar to pyroxene (amphibole). About 8.5 km north of Mount Phillips Homestead there is a raft of a metamorphosed layered intrusion comprising massive, medium-grained metagabbro with hornblende oikocrysts up to 1 cm long after pyroxene, metamorphosed leucogabbro, and massive coarse-grained metamorphosed olivine websterite. All three rock types have been thoroughly recrystallized during low- to medium-grade metamorphism. The metamorphosed gabbro and leucogabbro consist of actinolite–plagioclase–hornblende–epidote–titanite–sericite and actinolite–epidote/clinozoisite–sericite–quartz(–?albitic plagioclase). The metamorphosed olivine websterite consists of large crystals of actinolite (after clinopyroxene) and talc (after orthopyroxene) that contain numerous small euhedral and subhedral inclusions of serpentine and fine-grained granular opaques (after olivine).

In the Boora Boora Zone metagabbro and amphibolite typically consists of fine- to medium-grained epidote amphibolite or actinolite gneiss with a granoblastic texture. Typically, the rocks comprise bluish-green actinolite or green actinolitic hornblende, clinozoisite, and quartz, with minor titanite. In the area about 6 km northeast of Boora Boora Bore (Zone 50, MGA 357080E 7455280N), layered metagabbro, including porphyritic metaleucogabbro, with a relict igneous texture is exposed. Porphyritic metaleucogabbro contains plagioclase phenocrysts up to 1 cm in diameter pseudomorphed by granular clinozoisite, sericite, and sodic plagioclase, with interstitial actinolitic hornblende, clinozoisite, and sericite.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Rock type	meta-igneous mafic intrusive	mo
Lithname	metagabbro	g
Rock code		**P_-MO-mog**
Additional lithologies	amphibolite derived from intrusive rock	

Contact relationships

Metagabbro is intruded by, and included within, a number of granite units in the Minnie Creek batholith. South of Minnie Creek Homestead, equigranular to sparsely porphyritic, medium-grained biotite(–muscovite) granodiorite (P_-MO-gge) veins rafts of metagabbro. However, locally, the irregular nature of the veins and the presence of cuspate contacts between the two rock types suggests that the granodiorite and gabbro magmas mingled. Igneous layering within a remnant of a layered intrusion about 8.5 km north of Mount Phillips Homestead is truncated by surrounding coarse-grained porphyritic biotite monzogranite (P_-MO-gmp). Several rafts of metagabbro are intruded by dykes of pale pink leucocratic microsyenogranite (P_-MO-gmal), along with the enclosing granite. About 7 km east of Calamity Well in the centre of Mount Phillips, massive, medium- to coarse-grained metagabbro reportedly intrudes cataclastically foliated granite (site SJW220; Zone 50, MGA 416630E 7315390N. The presence of some large quartz and K-feldspar crystals reported by Steve Williams in the metagabbro suggest it may have mingled with the surrounding porphyritic biotite monzogranite (P_-MO-gmp). Metagabbro is not in contact with the Leake Spring Metamorphics, but the relationship is inferred to be intrusive given that some metagabbro is mingled with granite in the Minnie Creek batholith.

In the Boora Boora Zone it is difficult to determine an intrusive or extrusive origin for many of the mafic rocks, as contacts are not exposed or they are faulted. In the area about 6 km northeast of Boora Boora Bore (Zone 50, MGA 357080E 7455280N), layered metagabbro, including porphyritic metaleucogabbro, is exposed. The contact with the enclosing granitic gneiss is faulted, but the coarse porphyritic and fractionated nature of some metagabbro layers suggests that they may be intrusive. In a creek pavement about 6 km east-southeast of Mundong Well (Zone 50, MGA 361310E 7438650N) fine-grained amphibolite layers less than 0.5 m thick truncate gneissic layering in granitic gneiss at a low angle. Amphibolite also contains rare inclusions of granitic gneiss attesting to an intrusive origin.

Geochronology

P_-MO-mog	*Maximum*	*Minimum*
Age (Ma)	1806 ±	1776
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2004	Nelson, 2002

No intrusions of metagabbro have been dated directly. A sample of leucogabbro from the layered intrusion 8.5 km north of Mount Phillips Homestead was processed for SHRIMP U–Pb geochronology, but no zircons were recovered from the sample. If metagabbro intruded the Leake Spring Metamorphics, then this places an older limit for intrusion of c. 1842 Ma, based on the maximum depositional age of the Leake Spring Metamorphics (Varvell, 2001; Wingate et al., 2009). Metagabbro has been intruded by granites dated at 1795 ± 8 Ma (P_-MO-gmp), 1792 ± 5 Ma (P_-MO-gmeb), and 1794 ± 4 Ma (P_-MO-gmal) suggesting that the metagabbro is one of the older components of the batholith. However, metagabbro south of Minnie Creek Homestead is mingled with granodiorite (P_-MO-gge) dated at 1777 ± 8 Ma (Bodorkos et al., 2006), implying that intrusion of the metagabbro may span 10 million years or more.

In the Boora Boora Zone, a creek pavement about 6 km east-southeast of Mundong Well (Zone 50, MGA 361310E 7438650N) exposes fine-grained amphibolite layers less than 0.5 m thick that truncate gneissic layering in granitic gneiss at a low angle, and contain rare inclusions of granitic gneiss. This older granitic unit (P_-MO-mgmn) has been dated at 1806 ± 7 Ma (Nelson, 2004), and thus provides a maximum age for the amphibolite and metadolerite, the minimum age being defined by the youngest phases in the Moorarie Supersuite at c. 1775 Ma.

References

Bodorkos, S, Love, GJ, Nelson, DR and Wingate, MTD 2006, 88415: porphyritic granodiorite dyke, Nurunah Hill; Geochronology Record 613: Geological Survey of Western Australia, 4p.

Nelson, DR 2002, 169058: augen orthogneiss, Kanes Gossan Prospect; Geochronology Record 132: Geological Survey of Western Australia, 4p.

Nelson, DR 2004, 169088: foliated biotite monzogranite, Mundong Well; Geochronology Record 45: Geological Survey of Western Australia, 4p.

Varvell, CA 2001, Age, structure and metamorphism of a section of the Morrissey Metamorphic Suite, Central Gascoyne Complex, Western Australia: Curtin University of Technology, Perth, BSc (Hons) thesis (unpublished)

Wingate, MTD, Kirkland, CL, Johnson, SP and Sheppard, S in prep., 190668; metasandstone, Nardoo Well: Geological Survey of Western Australia.

Moorarie Supersuite; subunit (P_-MO-xmg-m)

Legend narrative

Mesocratic biotite metagranodiorite to metamonzogranite and pale-grey, layered biotite(–muscovite) metamonzogranite; commonly schistose; includes rafts of schist, amphibolite, calc-silicate rock, and quartzite

Rank	Formation
Parent	Moorarie Supersuite (P_-MO-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MO-gmeb (intrusive); P_-MO-mgml P_-MOru-mgm (gradational); P_-MGm-mtsf (faulted); P_-MEy-s (unconformable)
Underlying units	AP_-_ha-mgnw, P_-MGm-mtq, P_-MOmi-mgmn, P_-MOmi-mgmy, P_-LS-mhs, P_-LS-mlsm, P_-LS-mwa, P_-LS-mus, P_-LS-mk (intrusive); P_-MO-mgml (gradational)

Summary

Mesocratic biotite metagranodiorite to metamonzogranite and pale-grey biotite(–muscovite) metamonzogranite is a voluminous unit at the southeastern end of the Limejuice Zone. The mesocratic biotite metagranodiorite to metamonzogranite is a heterogeneous unit, comprising two main granite phases along with variable amounts of interleaved country rock. The pale grey metamonzogranite component is mainly medium grained, but is locally coarse grained and may contain scattered pegmatite zones. The metamonzogranite is porphyritic, with up to 20% tabular phenocrysts of K-feldspar to 3 cm long. A crude layering, defined by wispy biotite-rich streaks and an alignment of slightly coarser biotite-poor zones, is present in places. Multiple intrusive phases are common. Interleaved country rocks are varied, ranging from mesocratic basement gneisses of the Halfway Gneiss, schists of the Moogie Metamorphics and Leake Spring Metamorphics as well as amphibolite metamorphosed ultramafic rock and calc-silicate gneiss and schist. A single sample of a metatonalitic portion to the unit was sampled for U–Pb zircon SHRIMP analysis and yielded a precise age of 1804 ± 4 Ma which is interpreted as the igneous crystallization age of the tonalite precursor.

Distribution

Mesocratic biotite metagranodiorite to metamonzogranite and pale-grey biotite(–muscovite) metamonzogranite is a voluminous unit at the southeastern end of the Limejuice Zone but also forms two restricted plutons some 25 km^2 and 8 km^2 in area, that outcrop on the northwestern edge of Mount Phillips and just extend onto Eudamullah to the west. In the southern part of the Limejuice Zone the unit forms an irregular belt nearly 80 km long and 250 km^2 in area trending east-southeast from the southeastern corner of Mount Phillips across the northern part of Pink Hills and Candolle. Another series of irregular shaped intrusions forms an easterly trending belt across eastern Yinnetharra, southeastern Pink Hills and southern Candolle. Mesocratic biotite metagranodiorite to metamonzogranite and pale-grey biotite(–muscovite) metamonzogranite also forms two intrusions about 30 km^2 and 7 km^2 along the northern edge of the Minnie Creek batholith on northwestern Pink Hills.

Lithology

Mesocratic biotite metagranodiorite to metamonzogranite and pale-grey biotite(–muscovite) metamonzogranite is a heterogeneous unit, comprising two main granite phases along with variable amounts of interleaved country rock. The pale grey metamonzogranite component is mainly medium grained, but is locally coarse grained and may contain scattered pegmatite zones. The metamonzogranite contains up to 20% tabular phenocrysts of K-feldspar to 3 cm long. A crude layering, defined by wispy biotite-rich streaks and an alignment of slightly coarser biotite-poor zones, is present in places. Multiple intrusive phases are common. The pale grey metamonzogranite is interleaved with, or veins, a medium-grained, mesocratic metagranodiorite to metamonzogranite, which locally has small clots of biotite up to 2 cm in diameter. This mesocratic phase is typically equigranular or sparsely porphyritic. At TRFMP687 (Zone 50, MGA 448338E 7291437N) contacts between the two phases are locally gradational or are crenulated, suggesting that they are coeval. Both granite phases are weakly to moderately foliated.

Mesocratic biotite metagranodiorite to metamonzogranite and pale-grey biotite(–muscovite) metamonzogranite are commonly intruded by dykes and veins of leucocratic blotchy metasyenogranite and pegmatite-banded metamonzogranite, parallel to the igneous layering in the unit. Both of the latter rock types are also layered, with the layering defined by schlieren of pelitic schist, and in the metamonzogranite by pegmatite veins and trains of pegmatite-derived xenocrysts. All of the rock types are usually only weakly deformed, as tails on porphyroclasts and quartz flattening fabrics are not widely developed.

Mesocratic biotite metagranodiorite to metamonzogranite and pale-grey biotite(–muscovite) metamonzogranite contain numerous rafts and screens of semi-pelitic schist, amphibolite, mesocratic gneiss, calc-silicate rock, ultramafic rock, and quartzite. There is commonly a range from mainly leucocratic metamonzogranite, via leucocratic metamonzogranite with blocks of schist, through to schist with a network of veins and pods of leucocratic metamonzogranite, particularly at the margins of the intrusions. In places the rocks have the appearance of a diatexite owing to the presence of numerous lenticular pelite inclusions.

Age code	Proterozoic	P_-
Stratigraphic code	Moorarie Supersuite	MO-
Mixed or xenolith-bearing	Mixed	x
Rock type 1	meta-igneous felsic intrusive	mg
Lithname 1	metagranitic rock	mg
Rock type 2	metamorphic	-m
Rock code		**P_-MO-xmg-m**
Additional lithologies	pelitic schist, amphibolite, calc-silicate rock, meta-monzogranite, metatonalite	

Contact relationships

Mesocratic biotite metagranodiorite to metamonzogranite and pale-grey biotite(–muscovite) metamonzogranite veins and contains rafts of a range of units, including the Halfway Gneiss (AP_-_ha-mgnw) and Moogie Metamorphics (P_-MGm-mtq) in the Mount James Homestead area, the Middle Spring Granite (P_-MOmi-mgnm, P_-MOmi-mgny) northwest of Middle Spring, and the Leake Spring Metamorphics, including pelitic and psammitic schist (P_-LS-mhs), muscovite-rich pelitic schist (P_-LS-mlsm), amphibolite (P_-LS-mwa), metamorphosed ultramafic rock (P_-LS-mus), and calc-silicate gneiss and schist (P_-LS-mk) over a wide area. In places, for example at TRFMP671 (Zone 50, MGA 447026E 7293845N) and TRFMP682 (Zone 50, MGA 447364E 7291934N), both the mesocratic and pale grey metagranite phases, along with the metasedimentary schists, contain an intersection rodding reflecting the presence of two tectonic fabrics. However, locally, pale grey metamonzogranite veins have intruded along or across the early fabric in the schists. The interleaved mesocratic metagranodiorite to metamonzogranite and pale grey metamonzogranite is intruded by medium- to coarse-grained equigranular biotite monzogranite (P_-MO-gmeb) of the Minnie Creek batholith. Collectively, these field relationships indicate that the mesocratic and pale grey metagranites were emplaced during and after the first deformation in the Leake Spring Metamorphics, but before the main mass of the Minnie Creek batholith. Therefore, the mesocratic metagranodiorite to metamonzogranite and pale grey metamonzogranite probably represent the early stages of the Moorarie Supersuite. Consistent with this interpretation, mesocratic biotite metagranodiorite to metamonzogranite and pale-grey biotite(–muscovite) metamonzogranite grades, with decreasing amounts of of mesocratic biotite metagranodiorite and interleaved schist, into the Rubberoid Granite (P_-MOru-mgm).

Geochronology

P_-MO-xmg-m	*Maximum*	*Minimum*
Age (Ma)	1804 ± 4	1792
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Inferred
References	Kirkland and Wingate, 2009	Wingate et al., 2009

Mesocratic biotite metagranodiorite to metamonzogranite and pale-grey biotite(–muscovite) metamonzogranite was sampled for SHRIMP U–Pb zircon dating in the southeast corner of Mount Phillips. The sample, GSWA 180947, is of a metatonalite and provided crystallization age of 1804 ± 4 Ma (Kirkland and Wingate, 2009). Two distinctly younger analyses that yield a concordia age of 1076 ± 25 Ma are probably derived from thin cross-cutting leucogranite veins that were two small to separate from the sample.

The igneous crystallization age for the metatonalite is consistent with maximum and minimum age constraints from underlying and overlying units. The metamonzogranite intrudes pelitic and psammitic schist of the Leake Spring Metamorphics (P_-LS-mhs), which has a maximum depositional age of c. 1842 Ma. Tectonic fabrics in the pale-grey, weakly foliated monzogranite are cut by massive coarse-grained equigranular biotite monzogranite (P_-MO-gmeb) dated at 1782 ± 5 Ma. In the northern part of the Limejuice Zone, mesocratic biotite metagranodiorite to metamonzogranite is mingled with coarse-grained, strongly porphyritic biotite monzogranite (P_-MO-gmp), a sample of which has been dated at 1794 ± 8 Ma (Bodorkos et al., 2006) about 3.5 km north-northwest of Dunnise Well on the northwestern part of Mount Phillips. This age may also be regarded as approximating the emplacement age of the mesocratic biotite metagranodiorite to metamonzogranite and is within uncertainty of the crystallization age obtained for the metatonalitic part of the unit farther south. The unit is also intruded by medium- to coarse-grained, leucocratic biotite monzogranite (P_-MO-gml). A sample from the latter taken about 5 km east-southeast of Minnie Springs on northeastern Eudamullah was dated at 1792 ± 7 Ma (Wingate et al., 2009), and provides a minimum age for the mesocratic biotite metagranodiorite to metamonzogranite in this area.

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Capricorn Orogeny

Event type	deformation: transpressional
Parent event	Top of Event list (TOL)
Child events	D_{1a}, D_{2a}, D_{3a}, D_{1n}, D_{2n}, D_{3n}
Tectonic units affected	Gascoyne Province, Ashburton Basin
Tectonic setting	orogen: intracratonic orogen
Metamorphic facies from	greenschist facies: chlorite zone
Metamorphic facies to	amphibolite facies: sillimanite zone

Summary

The 1820–1770 Ma Capricorn Orogeny is widely regarded as recording the convergence and collision of the Archean Pilbara and Yilgarn Cratons. However, a recent program of regional mapping, sensitive high resolution ion microprobe (SHRIMP) U–Pb zircon dating and whole-rock geochemistry, has not identified evidence either of subduction-related magmatism, or of a suture that could be related to the Capricorn Orogeny within the province. Instead, the orogeny is more likely to record intracontinental reworking (Sheppard et al., 2010). Deformation and regional metamorphism assigned to the Capricorn Orogeny started at c. 1820 Ma and continued until c. 1770 Ma. Three main tectonothermal events are recognized during the Capricorn Orogeny: D_{1n}/M_{1n}, D_2n/M_{2n}, and D_{3n}/M_{3n}, although it is not entirely clear as to whether these are separate 'events' or encompass progressive deformation. Metamorphism associated with the orogeny appears to have been a thermal response to the intrusion of stocks, sheets and batholiths of the Moorarie Supersuite, many of which were synchronous with each of the main deformation events.

The age range of the Capricorn Orogeny is taken to include the Moorarie Supersuite, with the younger age limit defined by the timing of growth of metamorphic zircon (c. 1770 Ma) in a sample of quartzite from the Moogie Metamorphics in the Mutherbukin Zone. The age of the supersuite was previously considered to be 1830–1780 Ma, but more recent geochronology, along with reinterpretation of earlier dating, indicates that the supersuite has an range of 1820–1775 Ma, defining the Capricorn Orogeny as being 1820–1770 Ma in age.

Distribution

The effects of the Capricorn Orogeny are recognized across the Gascoyne Province, and in adjacent tectonic units such as the Yarlarweelor Gneiss Complex and Errabiddy Shear Zone to the south, the Ashburton Basin to the north, and the Bryah, Padbury, and Yerrida Basins to the east. Deformed rocks of the Ashburton Basin, and structurally reworked Paleoproterozoic and Archean rocks on the southern margin of the Pilbara Craton are referred to as the Ashburton Fold Belt. Owing to the uncertainty in correlating structures in the Ashburton Fold Belt with those in the Gascoyne Province, the deformation and metamorphic events in the fold belt are described separately.

Description

In the Yarlarweelor Gneiss Complex, Errabiddy Shear Zone, Paradise Zone, southern part of the Mooloo Zone, and Bryah and Padbury Basins, D_{1n} is represented by upright, close to isoclinal folds. The accompanying regional metamorphic grade is typically greenschist facies, with the exception of the Yarlarweelor Gneiss Complex, in which amphibolite facies metamorphism was widespread at this time. Upright, close to isoclinal folds in the southern part of the Mooloo Zone are also assigned to D_{1n}. Similar structures and mineral assemblages were formed during D_{1a} in the Boora Boora Zone at the northern end of the Gascoyne Province; however, age constraints on both D_{1a} and D_{2a} suggest they are coeval with the D_{2n} event present further south. D_{1n} appears to be restricted entirely to the southern part of the province.

The second tectonic fabric that can be attributed to the Capricorn Orogeny is referred to as D_{2n}, and the corresponding mineral assemblage, M_{2n}. This fabric is recognized across most of the southern part of the province and is the principle tectonothermal episode in the northern Mooloo, Mutherbukin, and Limejuice Zones. This event is also recognized in the Errabiddy Shear Zone, the Yarlarweelor Gneiss Complex, and several metasedimentary basins within the Capricorn Orogen. In the Yarlarweelor Gneiss Complex D_{2n} structures mainly consist of conjugate ductile shear zones and faults. The same may be true of the Errabiddy Shear Zone, although it is difficult to rule out younger orogenic events as the cause of these structures. In the Limejuice Zone, D_{2n} produced a strong foliation or gneissic layering subparallel to compositional layering within schists of the Leake Spring Metamorphics and within syn-tectonic granite batholiths of the Minnie Creek batholith, such as the Middle Spring Granite. Deformation was associated with amphibolite facies metamorphism at low pressure, as indicated by assemblages containing andalusite, cordierite, and fibrolite within the pelitic schists. All traces of D_{2n}/M_{2n} structures and mineral assemblages in the Mutherbukin and Mangaroon Zones, if they were originally present, have been obliterated by younger orogenic events. In the Boora Boora Zone at the northern end of the Gascoyne Province (and in the Ashburton Formation to the north), corresponding D_{2a} structures comprise close to isoclinal, upright, non-cylindrical folds at various scales, and associated faults. However, the age constraints for D_{1a} suggest that both D_{1a} and D_{2a} correlate with the D_{2n} event that is present throughout much of the Gascoyne Province.

The pressures and temperatures attained during the D_{2n} episode of the Capricorn Orogeny are difficult to determine owing to multiple overprinting tectonothermal events and to the variable intensity of deformation and metamorphic grade in different zones or tectonic units. In the Limejuice Zone, pelitic and psammitic schist comprise inclusions and rafts within granites of the Minnie Creek batholith. An early gneissic layering or schistosity (S_{2n}) is crenulated by an upright schistosity (S_{3n}) associated with growth of muscovite and chlorite (M_{3n}) and patches of felted sericite 4–7 mm in diameter (after ?andalusite). The M_{2n} assemblages in pelitic rocks are wholly retrogressed, but probably consisted of muscovite–biotite–quartz–andalusite. In the Limejuice Zone on Pink Hills and Candolle a D_{2n}/M_{2n} gneissic layering in pelitic rocks is preserved in widely scattered localities marked by low-D_{3n} strain. Even in most of these localities, the M_{2n} assemblages are strongly retrogressed, but in places relict domains of M_{2n} assemblages persist; for example in the Pink Hills (site SXSPKH008182; Zone 50, MGA 492473E 7276916N) pelitic gneiss or granofels comprises andalusite, cordierite, biotite, muscovite, and quartz.

The final fabric forming event in the Capricorn Orogen, D_{3n}, is only recognized in the Limejuice Zone where D_{2n} gneissic fabrics and foliations are folded into upright, close to tight local- and regional-scale folds. This folding event also produced a crenulation schistosity parallel to the axial surfaces of the folds. D_{3a} strike-slip faults in the Asburton Fold Belt may correlate with D_{3n} further south; however, their age is poorly constrained and may be part of a different orogenic or tectonic event.

Geochronology

Capricorn Orogeny	*Maximum*	*Minimum*
Age (Ma)	1813 ± 8 Ma	1772 ± 6
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1998a	Wingate et al., 2010a

Geochronological constraints on the age of D_{1n}–D_{3n} vary according to the tectonic unit in which the structures occur, as well as the structural domain or zone within a given tectonic unit. Although each dated fabric is the earliest within a given area attributable to the Capricorn Orogeny, it is possible that with variations in imposed strain, the earliest fabric in a given area may be diachronous across the orogen. With this caveat in mind, the constraints on the Capricorn Orogney are as follows.

The D_{1n} episode is constrained in the Yarlarweelor Gneiss Complex and southern part of the Glenburgh Terrane by cross-cutting relationships. In the Yarlarweelor Gneiss Complex, the oldest deformed intrusions are c. 1815 Ma and the S_{1n} fabrics that they contain are cut by the undeformed Kerba Granite dated at c. 1810 Ma (GSWA 142851; Nelson, 1998b). In the Glenburgh Terrane, the oldest dated deformed rocks are part of the Dumbie Granodiorite dated between 1804 and 1800 Ma. These are cross-cut by undeformed massive granite of the Scrubber Granite, the oldest intrusion of which is dated at c. 1800 Ma. Thes relationships demonstrate that D_{1n} was diachronous from the Yarlarweelor Gneiss Complex into the southern part of the Glenburgh Terrane.

In the Yarlarweelor Gneiss Complex, the youngest granite cut by D_{2n} structures is the Kerba Granite, dated at c. 1810 Ma, providing a maximum age for the deformation. Dykes of medium-grained monzogranite are widely emplaced into D_{2n} faults and display a range of textures from massive to foliated, implying that their intrusion was coeval with D_{2n}. One of these dykes on Marquis has been dated at 1797 ± 4 Ma (GSWA 142852; Nelson, 1998c; Sheppard and Swager, 1999). Farther north in the Limejuice Zone, folded and crenulated metasedimentary rocks of the Leake Spring Metamorphics on Eudamullah are intruded by granites as old as c. 1810 and as young as c. 1785 Ma. The Middle Spring Granite on Pink Hills and Candolle contains a gneissic fabric parallel to that in the Leake Spring Metamorphics. The granite has an igneous crystallization age of 1788 ± 7 Ma (GSWA 190662; Wingate et al., in prep.a), and is intruded by the undeformed Rubberoid Granite. This unit has crystallization ages of 1791 ± 4 Ma (GSWA 190660; Wingate et al., in prep.b) and 1786 ± 6 Ma (GSWA 188974; Wingate et al., in prep.c), providing a minimum age for D_{2n}/M_{2n}. A preliminary U–Pb monazite age of c. 1785 Ma from schist sampled along the northern margin of the Minnie Creek batholith (GSWA, unpublished data) confirms the presence of Capricorn Orogeny-aged deformation and metamorphism. A psammitic schist (GSWA 184160; Wingate et al., in prep.d) from the northern part of the Mooloo Zone yielded a single metamorphic zircon rim grown around older detrital cores. This rim was dated at 1788 ± 12 Ma (1σ; Wingate et al., 2010b) and is within error of the other ages for D_{2n}/M_{2n} obtained here.

There are no direct age constraints on the timing of D_{3n} deformation and metamorphism. In the Limejuice Zone, D_{2n} gneissic fabrics and foliations within both the Middle Spring Granite and schists of the Leake Spring Metamorphics are folded around F_{3n} folds, indicating that F_3 folding occurred after c. 1785 Ma (the minimum age constraint for D_{2n}). Metamorphic zircon rims on detrital grains from a quartzite (GSWA 187403), sampled from northwestern Yinnetharra in the Mutherbukin Zone, have been dated at 1772 ± 6 Ma (Wingate et al., 2010a). This age is considerably younger than that obtained for the D_{2n} episode and so it is possible that it records deformation associated with D_{3n}; however, no structures can be confidently linked to this period of metamorphic zircon growth.

Tectonic setting

The Capricorn Orogeny is widely, although not universally, attributed to oblique collision of the Archean Yilgarn and Pilbara Cratons following the model of Tyler and Thorne (1990) and Thorne and Seymour (1991). Since this interpretation was published, it has been recognized that some structures previously attributed to the Capricorn Orogeny belong to the older Ophthalmian and Glenburgh Orogenies (Powell and Horwitz, 1994; Occhipinti and Sheppard, 2001), although modifications of the earlier interpretation prevail (e.g. Evans et al., 2003). Krapež (1999) and Krapež and Martin (1999) considered that the Capricorn Orogeny reflected deformation along a sinistral transcurrent megashear, although little evidence was advanced to support this interpretation. Some objections to the interpretation of the Capricorn Orogeny as reflecting oblique collision of the Yilgarn and Pilbara Cratons were raised by Sheppard (2004, 2005) and Sheppard et al (2010), who interpreted the orogeny as reactivation in an intracontinental setting.

One of the difficulties in advancing our understanding of the Capricorn Orogeny is the extensive nature of later Paleoproterozoic and Neoproterozoic reworking of the orogen. These reworking events have obliterated many of the fabrics, kinematic indicators, and mineral assemblages that formed during the Capricorn Orogeny. In the Errabiddy Shear Zone, Occhipinti et al. (2004) and Reddy and Occhipinti (2004) have shown that deformation related to the Capricorn Orogeny probably reflects dextral transpression. Along the northern margin of the Capricorn Orogen, Thorne and Seymour (1991) interpreted the Ashburton Basin as a foreland basin to collision between the Yilgarn and Pilbara Cratons, with uplift of the Gascoyne Province and thrust stacking to the south of the basin. This model was based in large part on the sedimentology of the Ashburton Formation and, even if the orogeny does not reflect continent–continent collision, it clearly involved substantial compression and uplift of the Gascoyne Province.

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Ashburton Fold Belt D_{1a}/M_{1a}

Event type	deformation: transpressional, metamorphic: regional
Parent event	Capricorn Orogeny
Tectonic units affected	Ashburton Basin
Tectonic setting	orogen: intracratonic orogen
Metamorphic texture/ tectonic feature	cleaved, gneissose, folded, schistose
Metamorphic facies from	greenschist facies: chlorite zone
Metamorphic facies to	amphibolite facies: green hornblende

Summary

The Ashburton Fold Belt formed in response to the Capricorn Orogeny and includes the deformed Wyloo and Capricorn Groups, as well as structurally reworked Archean and Paleoproterozoic rocks on the southern margin of the Pilbara Craton. The structural history of the Ashburton Fold Belt has been given by Tyler and Thorne (1990) and Thorne and Seymour (1991) who described two major deformation events, D_{1a} and D_{2a}. In addition, a third deformation event (D_{3a}) was recognized by Martin et al. (2005). The earliest deformation, D_{1a}, took place after deposition of the Ashburton Formation (upper Wyloo Group) but prior to deposition of the Capricorn Group. This deformation was accompanied, or slightly post-dated, by a regional metamorphic event (M_{1a}). The second and third events (D_{2a}/M_{2a} and D_{3a}) took place after deposition of the Capricorn Group and following intrusion of the Boolaloo Granodiorite, but before deposition of the Edmund Group. On the basis of these relationships the timing of D_{1a}/M_{1a} was between about 1805 and 1790 Ma, whereas D_{2a} and D_{3a} took place between c. 1790 and c. 1620 Ma.

Throughout most of the Ashburton Basin, metamorphic grade is low, characterized by the mineral assemblage quartz–chlorite–muscovite(–sericite) in pelitic and psammitic rocks (Thorne and Seymour, 1991). However, there is a gradual increase in grade and schistosity towards the west and southwest into the Gascoyne Province: on northern Ullawarra, medium-grade metamorphosed equivalents of the Ashburton Formation are represented by quartz–muscovite–biotite–cordierite–andalusite–garnet schist. Metasedimentary rocks in the Boora Boora Zone show a considerable range in M_{1a} metamorphic grade from chlorite–sericite grade, through muscovite–biotite–garnet–andalusite–quartz to, locally, mats of fibrolitic sillimanite preserved in muscovite.

Distribution

Thorne and Seymour (1991) recognized three structural zones within the Ashburton Fold Belt based on the geometry of the D_{2a} structures and the preservation of D_{1a} structures. Zone A is dominated by large-scale open to tight folds and dextral wrench faults. Zones B and C are recognized on northeastern Ullawarra and Capricorn.

Zone B is developed in the Ashburton Formation, northeast of the interpreted fault striking west-northwest from about 1.2 km north of the Hearns Find Au prospect (MGA 500000E 7440000N) on Capricorn. It represents a relatively high-strain zone formed during D_{2a}. As a result of this, the recognition of D_{1a} structures within Zone B is generally difficult because strong overprinting by D_{2a} has resulted in the early cleavage (S_{1a}) being coaxial, and often coplanar with the later fabric (S_{2a}).

Zone C occupies the remainder of the Ashburton Fold Belt on Ullawarra and Ullawarra, between the southwestern boundary of Zone B and the Edmund Group unconformity. It is distinguished from Zone B by its generally lower level of D_{2a} strain leading to the better preservation of D_{1a} structures and also by the presence of large-scale F_{2a} folds and dextral wrench faults. Zone C also preserves evidence of D_{3a} structures in the western Capricorn Range.

The supracrustal rocks in the Boora Boora Zone, and the granites that intrude them, were deformed and metamorphosed during the 1820–1770 Ma Capricorn Orogeny. Although fabrics and mineral assemblages related to the Capricorn Orogeny are present across the width of the Capricorn Orogen, it is not clear how the fabrics in the Boora Boora Zone relate to D_{1n} and D_{2n} fabrics in the southern part of the orogen (Occhipinti et al., 1998; Occhipinti and Sheppard, 2001). However, geochronological work undertaken during remapping indicates that D_1 and D_2 structures in the Boora Boora Zone are comparable in age with D_{1a} and D_{2a} in the Ashburton Fold Belt (Thorne and Seymour, 1991), with which they are correlated.

Description

Most of the evidence for the D_{1a} deformation comes from Zone C and is based on the widespread S_{1a} foliation, the marked angular unconformity between the Ashburton Formation and the Capricorn Group, and rare F_{1a} folds. In many outcrops, evidence for D_{1a} is present in the form of an early S_{1a} cleavage developed subparallel to bedding. This cleavage is often crenulated by S_{2a}, and with the increase in metamorphic grade in southwestern parts of the fold belt, it develops into a metamorphic schistosity. In the Capricorn Range (e.g. localities around Zone 50, MGA 493300E 7412000N), the marked angular unconformity at the base of the Bywash Formation provides clear evidence that the Ashburton Formation was folded prior to deposition of the Capricorn Group. In addition, the Ashburton Formation may show a well-developed S_{1a} penetrative cleavage that is not developed in the overlying Capricorn Group (Thorne and Seymour, 1991). At Mount Blair, on adjacent Turee Creek, the basal unconformity of the Capricorn Group dips north at 50° as a result of D_{2a} folding. The S_{1a} cleavage in the underlying Ashburton Formation dips 15–45° south, while bedding dips (and youngs) southward at 0–30°. Rotation of bedding and S_{1a}, to their pre-D_{2a} orientation indicates that the tight F_{1a} fold was characterized by a steeply southward-dipping axial surface. An example of F_{1a} minor folds that have been refolded during D_{2a} is preserved north of Koonong Pool (at site AMT556; Zone 50, MGA 492918E 7418481N). Here, a pair of small-scale F_{1a} folds with 'S' and 'Z' vergence are preserved on the southern and northern limbs respectively of a westerly plunging, downward facing F_{2a} anticline.

Throughout most of the Ashburton Basin, metamorphic grade is low; there is, however, a gradual increase in grade and schistosity towards the west and southwest. Northeast of the Edmund Group unconformity the nature of the transition is such that it suggests that many psammites and pelites represent metamorphosed Ashburton Formation rocks.

Thorne and Seymour (1991) note that much of the Ashburton Basin is characterized by the mineral assemblage quartz–chlorite–muscovite(–sericite) in pelitic and psammitic rocks. On northern Ullawarra, medium-grade metamorphosed equivalents of the Ashburton Formation are represented by quartz–muscovite–biotite–cordierite–andalusite–garnet schist (P_WYa-mh), that indicate medium-grade metamorphic conditions. Textural evidence suggests that porphyroblastic minerals (biotite, andalusite, cordierite, and garnet) grew during and after the D_{1a} deformation event, overgrowing a quartz, muscovite, and chlorite groundmass. The metamorphic schistosity (S_{1a}) is typically deformed by F_{2a} folds and crenulation cleavage.

The oldest fabric in the metamorphic rocks of the Boora Boora Zone is a regionally extensive foliation or gneissic layering (S_{1a}). This fabric is parallel or subparallel to lithological layering. The gneissic layering is commonly accentuated by minor pegmatite banding. Associated with the gneissic layering are widespread, small-scale isoclinal folds (F_{1a}) that are best developed in the foliated and gneissic granodiorite and tonalite (P_-MO-mggn). These are locally refolded by upright F_{2a} folds to form type 3 fold interference structures (Ramsay, 1967). Around the Monte Carlo mine (Zone 50, MGA 351370E 7450100N), a megascopic, isoclinal F_{1a} fold is refolded about a megascopic F_{2a} fold to form a type 3 interference structure.

The grade of M_{1a} in the Boora Boora Zone is difficult to estimate because most of the metamorphosed rocks are granitic in composition, and because of widespread overprinting by M_{2a} assemblages. Granitic gneisses have locally preserved anhedral granular and amoeboid textures suggesting medium- to high-grade metamorphism. Calc-silicate rocks are composed of augite/diopside, zoisite, titanite, plagioclase, and quartz. Mafic rocks on northern Maroonah with only a weakly developed S_{2a} fabric, have assemblages of blue–green hornblende, plagioclase and minor quartz, accompanied by polygonal textures. Locally, mafic rocks are epidote amphibolites with plagioclase of oligoclase composition, and no chlorite. Collectively, these assemblages are consistent with amphibolite or epidote–amphibolite facies metamorphic conditions during M_{1a}.

Metasedimentary rocks in the Boora Boora Zone show a considerable range in M_{1a} metamorphic grade. Metasedimentary rocks at the southern end of a very large pluton of muscovite–biotite granite on Maroonah show no evidence of having been metamorphosed at more than low or very low grade. However, along strike to the northwest, metasedimentary rocks around the Laura prospect (Zone 50, MGA 361387E 7424532N) contain the M_{1a} assemblage of muscovite, biotite, garnet, ?andalusite, and quartz. Textures indicate that porphyroblasts of garnet and ?andalusite grew at the same time or after S_{1a}, and were partly or wholly replaced by chlorite and sericite during M_{2a}. The M_{1a} assemblages here are consistent with lower amphibolite-facies metamorphic conditions (Spear, 1993). Farther to the northwest, about 8 km northwest of Horse Well (Zone 50, MGA 348340E 7432470N), pelitic rocks contain small domains of biotite, quartz, and muscovite with mats of fibrolite (sillimanite) in the muscovite, implying upper amphibolite-facies conditions (Spear, 1993). The increase in grade to the northwest suggests that the metamorphic isograds are perpendicular to the dominant D_{2a} structural grain, and that the isograds are likely to have been folded.

Geochronology

Ashburton Fold Belt D_{1a}	*Maximum*	*Minimum*
Age (Ma)	1794 ± 9	1784 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2004a;	Nelson, 2004b

A maximum age for D_{1a} in the Boora Boora Zone is constrained by the igneous crystallization age of the youngest deformed intrusion dated at 1794 ± 9 Ma (P_-MO-mggn; Nelson, 2004b; GSWA 169087) for a foliated metagranodiorite. A minimum age for D_{1a} is provided by an age of 1784 ± 5 Ma for an undeformed monzogranite dyke (P_-MO-mgmn; Nelson, 2004b; GSWA 169086) that cuts S_{1a}. In the Ashburton Basin to the north, the minimum age for D_{1a} is provided by a date of 1786 ± 5 Ma for the Boolaloo Granodiorite (Krapež and McNaughton, 1999). In comparison, the D_{1n} fabric in the Yarlarweelor Gneiss Complex and southern part of the Glenburgh Terrane is dated between 1813 and 1800 Ma, (Nelson, 1998a, Nelson 2001), whereas the D_{2n} fabric recorded throughout much of the southern part of the province is dated between 1808-1786 Ma (Nelson, 1998b and Wingate et al., in prep.). This suggests that D_{1a} in the Asburton Basin may correlate with D_{2n} further south.

Tectonic setting

See **Capricorn Orogeny**

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Ashburton Fold Belt D_{2a}/M_{2a}

Event type	deformation: transpressional
Parent event	Capricorn Orogeny
Tectonic units affected	Ashburton Basin
Tectonic setting	orogen: intracratonic orogen
Metamorphic texture/ tectonic feature	Faulted, folded, schistose, retrogressed
Metamorphic facies from	greenschist facies: chlorite zone
Metamorphic facies to	greenschist facies: chlorite zone

Summary

In the Ashburton Fold Belt, and Boora Boora Zone to the south, most of the obvious folding and faulting is attributed to the second deformation event, D_{2a}. In Zone B of the Ashburton Fold Belt, D_{2a} deformation produced tight to isoclinal, non-cylindrical folds and associated strike-slip faults. To the south in Zone C, deformation is less intense: D_{2a} folds are larger, typically open to close (rather than isoclinal), with an array of en echelon strike-slip faults. Low-grade metamorphism accompanied D_{2a} and caused the retrogression of biotite to chlorite and andalusite to sericite and growth of porphyroblastic muscovite.

Distribution

Thorne and Seymour (1991) recognized three structural zones within the Ashburton Fold Belt based on the geometry of the D_{2a} structures and the preservation of D_{1a} structures. Zone B represents a relatively high-strain zone formed during D_{2a}, in which the recognition of D_{1a} structures is generally difficult because strong overprinting by D_{2a} has resulted in the early cleavage (S_{1a}) being coaxial, and often coplanar with the later fabric (S_{2a}). Zone C to the south occupies the remainder of the Ashburton Fold Belt on ULLAWARRA and CAPRICORN, between the southwestern boundary of Zone B and the Edmund Group unconformity. It is distinguished from Zone B by its generally lower level of D_{2a} strain leading to the better preservation of D_{1a} structures and also by the presence of large-scale F_{2a} folds and dextral wrench faults.

Description

Most of the obvious folding and faulting in the Ashburton Fold Belt results from the second deformation event, D_{2a}. Within Zone B, D_{2a} deformation has resulted in tight to isoclinal, non-cylindrical F_{2a} folds with wavelengths of 5–200 m. Folds trend west to northwest and are associated with a pronounced axial-plane cleavage (S_{2a}) which typically dips 60–90° to the southwest or northeast. Within the main body of Ashburton Formation rocks, faults are generally associated with subparallel quartz veins and are frequently observed to cut out all or part of the northern limb of the F_{2a} folds. This fact, coupled with lack of marker horizons in the Ashburton Formation, and the tight to isoclinal folding, creates a false impression of a simple stratigraphy and southwesterly dipping beds throughout much of Zone B. In such cases, evidence for F_{2a} folding comes from local reversals in younging direction and the presence of isolated F_{2a} fold closures within the otherwise uniformly dipping Ashburton Formation.

F_{2a} folds in Zone C are large (100–6000 m wavelength), non-cylindrical, and trend west to northwest. Most plunge 10–40° (up to 80° locally) to the southeast or northwest. Axial planes dip steeply to the southwest or northeast. Close to the northern margin of Zone C, folds are open to tight (or locally isoclinal), but are generally more open in central and southwestern parts of the fold belt. S_{2a} is a penetrative slaty cleavage in the more easterly outcrops, but is present as a crenulation cleavage farther west.

Numerous west-northwest- to north-northwest-trending wrench faults parallel the F_{2a} fold axes or cross-cut them at a shallow angle. Locally, a dextral displacement of up to 3 km can be measured. In general, however, lack of marker horizons within the Ashburton Formation makes it difficult to assess accurately the amount of relative movement. The northern margin of the Capricorn Range is marked locally by a steep, southward-dipping fracture. Many faults are marked by a line of en echelon quartz veins, dipping 30–90° northeast or southwest. Locally they are associated with a second suite of steeply dipping veins that trend between north-northwest and north-northeast. Most veins consist of equant to prismatic, subhedral to anhedral quartz with irregular goethite vugs (after sulfide). Locally, quartz crystals are kinked as a result of progressive fault movement. Most copper, gold, lead, and silver mineralization discovered to date in the Ashburton Fold Belt is associated with D_{2a} faults and quartz veins.

Low-grade metamorphism accompanied D_{2a} in the Ashburton Fold Belt, and caused the retrogression of biotite to chlorite, and andalusite to sericite, and growth of porphyroblastic muscovite.

The map patterns in the Boora Boora Zone are primarily a function of structures formed during D_{2a}. Metre-scale upright, close to tight folds are developed throughout the zone and mostly plunge to the northwest. These fold the S_{1a} foliation or gneissic layering and are associated with an axial planar foliation of variable intensity. An intersection lineation (S_{1a}/S_{2a}) that plunges parallel to the F_{2a} fold axes is extensively developed. The vergence of metre-scale folds in the northwestern corner of MAROONAH can be used to define a megascopic, northwesterly plunging synform.

The S_{2a} fabric on MAROONAH is primarily defined by the widespread development in the granitic rocks of chlorite (after biotite) and sericite. All rock compositions are marked by replacement of plagioclase formed during M_{1a} by albite–oligoclase, sericite, and clinozoisite. In mafic rocks, magnetite and ilmenite have been pseudomorphed by epidote and titanite, respectively, in association with plagioclase recrystallization. Pelitic rocks show extensive replacement of garnet by chlorite and pseudomorphs of very fine grained sericite after andalusite. Biotite and muscovite formed during M_{1a} are largely recrystallized to chlorite and sericite. Collectively, these assemblages suggest greenschist facies conditions during M_{2a}.

Geochronology

Ashburton Fold Belt D_{2a}	*Maximum*	*Minimum*
Age (Ma)	1786 ± 5	1784 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Krapež and McNaughton, 1999	Nelson, 2004

In the Ashburton Fold Belt to the north, a date of 1786 ± 5 Ma for the Boolaloo Granodiorite (Krapež and McNaughton, 1999) provides a maximum age for S_{2a}, which cuts the pluton (Thorne and Seymour, 1991).The minimum age of D_{2a}/M_{2a} is constrained by a SHRIMP U–Pb zircon date on a monzogranite dyke (Nelson, 2004) that intruded parallel to the axial surface of an F_{2a} fold, and truncates S_{1a}. The dyke has an igneous foliation parallel to S_{2a}, and it was probably intruded during or after D_{2a}; therefore, the date of 1784 ± 5 Ma for this dyke provides an estimate for the age of D_{2a}.

Tectonic setting

See **Capricorn Orogeny**

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Ashburton Fold Belt D_{3a}

Event type	deformation: strike-slip
Parent event	Capricorn Orogeny
Tectonic units affected	Ashburton Basin
Tectonic setting	orogen: intracratonic orogen
Metamorphic texture/ tectonic feature	spaced cleavage, faulted

Summary

In the Ashburton Fold Belt D_{3a} is a localized event, possibly reflecting reactivation of strike-slip faults in the western Capricorn Range with the production of a spaced cleavage. The age of D_{3a} is poorly constrained and it is possible that it correlates with deformation and metamorphism associated with the 1680–1620 Ma Mangaroon Orogeny.

Distribution

Evidence of D_{3a} structures is only preserved in Zone C of the Ashburton Fold Belt, in the western Capricorn Range.

Description

In the western Capricorn Range (around Zone 50, MGA 467200E 7425600N), the traces of F_{2a} folds in the Capricorn Group are folded such that the regional west-northwest trend swings firstly southwest and then west-northwest again near Irregully Creek (around Zone 50, MGA 449200E 7423200N). Locally the fold limbs are cut by a steep southwesterly dipping fracture cleavage (S_{3a}). The geometry of the F_{3a} fold structure suggests it may have formed in response to a localized late-stage sinistral movement on a pair of wrench faults that occur along the northern margin of the Capricorn Range and beneath the northern edge of the Edmund Group outcrop.

Geochronology

Ashburton Fold Belt D_{3a}	*Maximum*	*Minimum*
Age (Ma)	1784	1650
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2004	Sheppard et al., 2006

There are no direct age constraints on the timing of D_{3n} deformation and/or faulting. However, because the S_{3a} fracture cleavage cuts F_{2a} folds, the older age limit is defined as the younger age limit for D_{2a}. The younger age constraint for D_{3n} is defined by the age of the Edmund Group, which lies unconformably across F_{3a} folds and faults. The Edmund Group has a maximum depositional age of c. 1620 Ma. However, the best estimate for D_{3a}, may be the age obtained from sinistral transfer faults that cut the Sylvania Inlier to the east. These faults can possibly correlated with the D_{3a} faults in the Ashburton Fold Belt, both of which appear to have controlled the deposition of the Bresnahan Basin. An $^{40}Ar/^{39}Ar$ muscovite date of c. 1650 Ma has been obtained from one of these faults/shear zones in the Sylvania Inlier (Sheppard et al., 2006). If this result does date the shearing, then D_{3a} would correlate with the Mangaroon Orogeny rather than the Capricorn Orogeny.

Tectonic setting

See **Capricorn Orogeny**

References

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Capricorn Orogeny D_{1n}/M_{1n}

Event type	deformation: transpressional, metamorphic: regional
Parent event	Capricorn Orogeny
Tectonic units affected	Gascoyne Province
Tectonic setting	orogen: intracratonic orogen
Metamorphic texture/ tectonic feature	foliated, gneissose, folded, schistose
Metamorphic facies from	greenschist facies: chlorite zone
Metamorphic facies to	amphibolite facies: sillimanite zone

Summary

The oldest tectonic fabric that can be attributed to the Capricorn Orogeny is referred to as D_{1n} (and the corresponding mineral assemblage, M_{1n}), and is recognized in several structural and metamorphic zones in the Gascoyne Province (southern Mooloo Zone, Paradise Zone, the Errabiddy Shear Zone, the Yarlarweelor Gneiss Complex and several metasedimentary basins within the Capricorn Orogen). D_{1n} structures in the Yarlarweelor Gneiss Complex were referred to as D_{2n} structures by Occhipinti and Myers (1999) and Sheppard and Swager (1999). These authors regarded an earlier flat fabric in rocks of the Bryah Group, which they correlated with their 'D_{2n}' in the Yarlarweelor Gneiss Complex, as belonging to the Capricorn Orogeny. However, it is now considered likely that this early fabric formed during the Glenburgh Orogeny (e.g. Pirajno et al., 2000).

In most instances, the kinematics of D_{1n} structures and precise pressure and temperature conditions of M_{1n} are difficult to obtain, owing to multiple overprinting tectonothermal events. In the Yarlarweelor Gneiss Complex, Errabiddy Shear Zone, and Bryah and Padbury Basins, D_{1n} is represented by upright, close to isoclinal folds. The same types of structures are also assigned to D_{1n} in the southern part of the Mooloo Zone and the Paradise Zone. The accompanying regional metamorphic grade is greenschist facies in these units, with the exception of the Yarlarweelor Gneiss Complex where amphibolite facies metamorphism was widespread at this time. Similar structures and mineral assemblages were formed during D_{1a} in the Boora Boora Zone at the northern end of the Gascoyne Province at the same time.

Distribution

Structures that formed during the Capricorn Orogeny are present across the width of the Capricorn Orogen (up to 300–350 km) in several tectonic units. The earliest deformation (D_{1n}) is recognized along the southern part of the province in the southern part of the Mooloo Zone, the Paradise Zone and the Yarlarweelor Gneiss Complex, and correlates with large-scale upright folds, along with a pervasive schistosity, and faults and shear zones, in the Bryah and Padbury Basins to the east and southeast of the province (Occhipinti and Myers, 1999; Pirajno et al., 2000). These structures fold a layer-parallel foliation in metavolcanic rocks of the Bryah Basin that is regarded as having formed during the Glenburgh Orogeny (Pirajno et al., 2000). Pervasive upright F_{1n} folds are developed throughout the Yarlarweelor Gneiss Complex, the Errabiddy Shear Zone and Paradise and Mooloo Zones. At the northern end of the Gascoyne Province (Boora Boora Zone) and in the Ashburton Basin, the first deformation related to the Capricorn Orogeny — labelled as D_{1a} (Ashburton Fold Belt) — may be the equivalent of D_{1n} elsewhere in the Gascoyne Province.

Description

In the Paleoproterozoic Bryah and Padbury Basins large-scale, upright, tight to isoclinal prominent folds, including the Robinson Syncline and Livingstone Synform, are assigned to D_{1n}. Locally, a well-developed S_{1n} crenulation cleavage is present in mafic and ultramafic schist of the Narracoota Formation and metasedimentary rocks of the Millidie Creek Formation. Pirajno et al. (2000) record that M_{1n} (their M_2) involved retrogression, metasomatism, and local hydrothermal alteration. Mineral assemblages formed during M_{1n} were mainly noted in high-strain zones where the S_{1n} schistosity is well developed. These include D_{1n} shear zones south of the Robinson Syncline, where pervasive retrogression of metabasalts to actinolite–chlorite schist is observed (Pirajno et al., 1995a). In addition, in the Mount Pleasant open-cut mine, Pirajno et al. (2000) reported growth of albite porphyroblasts and the development of chlorite at the expense of biotite and epidote during M_{1n}. Mafic and ultramafic rocks of the Narracoota Formation in the Bryah Basin typically comprise actinolite–tremolite(–talc–chlorite) assemblages indicative of greenschist facies metamorphism (Occhipinti and Myers, 1999). Higher grade metamorphism in M_{1n} is recorded along the western edges of the Bryah and Padbury Basins adjacent to the Yarlarweelor Gneiss Complex (Pirajno et al., 2000). There, staurolite–andalusite–biotite–muscovite–q3

al, subhorizontal to shallowly plunging folds in the granitic gneisses that are interpreted to have developed during the Archean are widespread.

In the Yarlarweelor Gneiss Complex amphibolite layers cutting late Archean fabrics in the granitic gneisses, and coarse-grained metagranite and metapegmatite sheets emplaced during D_{1n}, contain mineral assemblages and textures indicative of medium- to high-grade metamorphism. Most of the amphibolites are characterized by the assemblages green hornblende–andesine or green hornblende–andesine–clinopyroxene, both with minor quartz and titanite. These assemblages are typical of regional metamorphism at middle to upper amphibolite facies (Bucher and Frey, 2002). Amphibolite gneisses from the area between Red Peak Bore, Morris Bore, and Jubilee Bore along the southern edge of Marquis have a polygonal or amoeboid granoblastic texture, and assemblages of brown hornblende–labradorite–clinopyroxene–iron-oxide minerals, or clinopyroxene–labradorite–green-hornblende–iron-oxide minerals (Sheppard and Swager, 1999). The assemblages and textures are consistent with local higher grade metamorphism, at the transition between amphibolite and granulite facies (Bucher and Frey, 2002). Sheets of coarse-grained granite and pegmatite that are folded about F_{1n} may show gneissic fabrics, with development of almandine garnet and domains of feldspar and quartz with amoeboid and granoblastic polygonal textures implying medium- to high-grade metamorphism. Granitic and calc-silicate gneisses of the complex have mineral assemblages and textures indicative of medium- to high-grade metamorphism, but it is not always possible to confidently separate the effects of late Archean metamorphism from those of M_{1n}.

Within the Errabiddy Shear Zone, Archean granitic gneisses of the Yarlarweelor Gneiss Complex and metasedimentary rocks of the Camel Hills Metamorphics are folded about upright F_{1n} folds. The F1n structures fold the migmatitic pelitic gneisses, including the leucosomes and diatexite melts of the Quartpot Pelite. These F_{1n} folds were the dominant structures developed during D_{1n} in the Errabiddy Shear Zone. The F_{1n} folds range from close (in areas of moderate D_{1n} strain) to isoclinal (in zones of high D_{1n} strain). Pelitic schist and gneiss at the northern end of the outcrop of Quartpot Pelite on ERRABIDDY commonly contain a steeply dipping crenulation cleavage, which plunges parallel to the F_{1n} folds. The plunge of F_{1n} folds ranges from shallow to steep to the east-northeast to northeast or west-southwest to southwest. The limbs of F_{1n} folds are commonly marked by a strong foliation, or in some places, by a gneissic banding. Thicker layers of calc-silicate gneiss and amphibolite in the northeastern part of ERRABIDDY commonly define fold hinges with amplitudes of up to 200 m. In the southwestern corner of ERRABIDDY and the southeastern corner of LANDOR, east-northeasterly trending shear zones with associated tight to isoclinal, mesoscopic upright folds deform the Narryer Terrane. These folds are correlated with pervasive F_{1n} folds in the Yarlarweelor Gneiss Complex and Camel Hills Metamorphics. Northeasterly plunging folds commonly have a ‘Z’ sense of asymmetry consistent with a dextral sense of shear (i.e. north block to the east-northeast). Locally, an intersection lineation plunges parallel to the F_{1n} folds. Porphyroclasts show reversals in sense of shear around some F1n fold axes indicating that an early lineation has been folded. Small-scale, type 2 refolded fold structures (Ramsay, 1967) produced by interference between Archean F_2 and F_{1n} are widespread.

In the Errabiddy Shear Zone on southeastern LANDOR and southwestern ERRABIDDY, Sheppard and Occhipinti (2000) recorded steeply dipping shear zones that they interpreted as part of D_{1n}. Within these shear zones amphibolites comprise green hornblende–andesine–quartz–ilmenite, consistent with metamorphism in the amphibolite facies (Bucher and Frey, 2002). However, at that stage, the 2005–1960 Ma Glenburgh Orogeny had not been identified. More recent work on northern ERONG and southern LANDOR by Occhipinti and Reddy (2004) and Occhipinti (2004) indicates that D_{1n} fabrics in pelitic rocks were accompanied by widespread development of greenschist facies mineral assemblages; namely, muscovite and chlorite after sillimanite and biotite, and chlorite or chloritoid replacement of garnet.

In the Glenburgh Terrane in the southern part of the Gascoyne Province, the most widespread D_{1n} structures are upright, open to close, shallowly to moderately plunging folds, and a pervasive easterly trending foliation. These mesoscopic folds are common in the Halfway Gneiss and the Mumba Psammite in the southern part of the Mooloo Zone, but also include macroscopic folds south of Dunnawah Well in the Paradise Zone. In the Paradise Zone, the D_{1n} foliation is typically subparallel to the regional structural trend (D_{1g}) established during the Glenburgh Orogeny. A c. 1810 Ma biotite–muscovite granite plug in the central-eastern part of GLENBURGH contains a weak foliation, as do sheets of a similar granite to the north (dated at c. 1820 Ma) that intruded subparallel to ?D_{2g} fold-axial surfaces locally developed in the Dalgaringa Supersuite. Northerly trending Glenburgh Orogeny fabrics (D_{1g} and D_{2g}) dated at 2005–1950 Ma in the Carrandibby Inlier on DAURIE CREEK suggest that in the southwestern corner of GLENBURGH, the main effect of the Capricorn Orogeny was to rotate earlier fabrics developed during the Glenburgh Orogeny into easterly trending structures.

In the southern part of the Mooloo Zone, the Halfway Gneiss forms an elongate easterly trending dome that is interpreted as a regional-scale D_{1n} antiform refolded about a northerly trending axis. In the Mumba Psammite, in the central-northern part of GLENBURGH and just north of the Dalgety Fault (Paradise, well developed small-scale D_{1n} folds and S_{1n} crenulations deform an earlier S_{2g} bedding-parallel fabric. The S_{1n} foliation is well developed in the southern part of the Mooloo Zone on GLENBURGH, particularly in sheets of the 1810–1805 Ma Dumbie Granodiorite, which commonly contain a pervasive L–S or L-tectonite fabric, but are only rarely folded. Many of the rocks show evidence of recrystallization under greenschist facies conditions. This low-grade metamorphic overprint is more pervasive (and dynamic) in the Mooloo Zone compared with the Paradise Zone (Occhipinti and Sheppard, 2001). Higher grade assemblages formed during the Glenburgh Orogeny in the Moogie Metamorphics are partially or wholly overprinted by greenschist-facies assemblages. The Mumba Psammite now comprises chloritoid-bearing schist, quartzofeldspathic schist, and quartzite. Quartzofeldspathic schist consists mostly of sericite and quartz, with minor amounts of biotite and feldspar. Chloritoid-bearing schist consists of a variety of assemblages, including quartz–sericite–chloritoid(–chlorite) schist, quartz–magnetite–sericite–chloritoid(–chlorite) schist, and chloritoid–quartz–sericite schist. Chloritoid-bearing schist locally contains relict porphyroblasts of garnet. Accessory minerals commonly include opaque minerals and tourmaline. Sericite commonly forms fine-grained aggregates with minor quartz, which may represent pseudomorphs of a higher grade mineral. Chloritoid, although sometimes aligned in the foliation of the rock, typically forms clumps and splays and exhibits ‘bow-tie’ texture. The chloritoid ranges from colourless to pale green or bright blue. Of the calc-silicate gneisses, the amphibole- and diopside-rich gneisses are partly or wholly replaced by assemblages of actinolite–tremolite, epidote, albite, calcite, and titanite. Forsterite and clinohumite are commonly partly serpentinized in the marbles.

Geochronology

Capricorn Orogeny D_{1n}	*Maximum*	*Minimum*
Age (Ma)	1813 ± 8 Ma	1800 ± 7 Ma
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1998a	Nelson, 2001

Geochronological constraints on the age of D_{1n} vary according to the tectonic unit, as well as the structural domain or zone within a given tectonic unit, in which the structures occur. Although each dated fabric is the earliest attributable to the Capricorn Orogeny within a given area, it is possible that with variations in imposed strain, the earliest fabric in a given area may be diachronous across the orogen. With this caveat in mind, the constraints on D_{1n} are as follows.

In the Bryah Basin, there are effectively no geochronological controls on the age of D_{1n}. In the Yarlarweelor Gneiss Complex, intrusions of coarse-grained metagranite and metapegmatite (P_-MO-mgmp), one of which was dated at 1813 ± 8 Ma (Nelson, 1998a), were interpreted by Occhipinti et al. (1998), Occhipinti and Myers (1999), and Sheppard and Swager (1999) as having intruded during D_{1n} because the granite and pegmatite cut D_{1n} structures but are also deformed by D1n. A younger limit for D_{1n} is provided by a U–Pb SHRIMP zircon date of 1808 ± 6 Ma (GSWA 142851; Nelson, 1998b) on the Kerba Granite, which is discordant to D_{1n} structures (Sheppard and Swager, 1999).

In the Glenburgh Terrane of the southern Gascoyne Province, the only effective constraints on the age of D_{1n} come from the southern part of the Mooloo Zone. Here foliated and deformed Dumbie Granodiorite, which is dated at 1811 ± 6 Ma, 1810 ± 9 Ma, and 1804 ± 5 Ma (Nelson 1998a,b and Wingate et al., in prep.), are cut by undeformed, massive plutons and dykes of the Scrubber Granite, the oldest of which is dated at 1800 ± 7 Ma (Nelson, 2001). At one locality on southern PINK HILLS (SPJPKH000927), medium-grained, seriate to porphyritic Dumbie Granodiorite is locally strongly deformed with the production of gneissic fabrics. This rock is included as rafts and inclusions within fine-grained slightly porphyritic and only weakly deformed Dumbie Granodiorite. A lower-strain portion of the medium-grained granodiorite gneiss (Wingate et al., in prep.) has been dated at 1804 ± 5 Ma, and the intrusive finer-grained undformed granodiorite (Nelson 2000) at 1810 ± 9 Ma. These age and field relationships suggest that parts of the Dumbie Granodiorite, at least in the southern part of the Mooloo Zone, were syn-tectonic with respect to the D_{1n} event.

Tectonic setting

See **Capricorn Orogeny**

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Capricorn Orogeny D_{2n}/M_{2n}

Event type	deformation: undivided, metamorphic: regional
Parent event	Capricorn Orogeny
Tectonic units affected	Gascoyne Province
Tectonic setting	orogen: intracratonic orogen
Metamorphic texture/ tectonic feature	crenulated, faulted, schistose, sheared, retrogressed
Metamorphic facies from	greenschist facies: chlorite zone
Metamorphic facies to	amphibolite facies: sillimanite zone

Summary

The second tectonic fabric that can be attributed to the Capricorn Orogeny is referred to as D_{2n}, and the corresponding mineral assemblage, M_{2n}. This fabric is recognized in several structural and metamorphic zones in the Gascoyne Province, in the Errabiddy Shear Zone, as well as in the Yarlarweelor Gneiss Complex and several metasedimentary basins within the Capricorn Orogen. D_{2n} structures in the Yarlarweelor Gneiss Complex were referred to as D_{3n} structures by Occhipinti and Myers (1999) and Sheppard and Swager (1999). These authors regarded an earlier flat fabric in rocks of the Bryah Group, which they correlated with their 'D_{2n}' in the Yarlarweelor Gneiss Complex, as belonging to the Capricorn Orogeny. However, it is now considered likely that this early fabric formed during the Glenburgh Orogeny (e.g. Pirajno et al., 2000).

In the Yarlarweelor Gneiss Complex, D_{2n} structures mainly comprise conjugate ductile shear zone and faults. The same may be true of the Errabiddy Shear Zone, although it is difficult to rule out younger orogenic events as the cause of these structures. In the Limejuice Zone, D_{2n} produced a strong foliation or gneissic layering subparallel to compositional layering within schists of the Leake Spring Metamorphics and within syn-tectonic granite batholiths of the Minnie Creek batholith, such as the Middle Spring Granite. Deformation was associated with amphibolite facies metamorphism at low pressure, as indicated by assemblages containing andalusite, cordierite, and fibrolite within the pelitic schists. In the Boora Boora Zone at the northern end of the Gascoyne Province (and in the Ashburton Formation to the north), corresponding D_{2a} structures comprise close to isoclinal, upright, non-cylindrical folds at various scales, and associated faults. All traces of D_{2n}/M_{2n} structures and mineral assemblages in the Mutherbukin and Mangaroon Zones, if they were originally present, have been obliterated by younger orogenic events.

Distribution

Structures that formed during the Capricorn Orogeny are present across the width of the Capricorn Orogen (up to 300–350 km) in several tectonic units. The second deformation recognized in the Yarlarweelor Gneiss Complex (D_{2n}), correlates with northerly trending folds, faults, and, locally, an upright foliation ('D_3' and 'S_3' of Occhipinti and Myers, 1999; Pirajno et al., 2000) in the Bryah and Padbury Basins to the east and southeast of the complex. In the Yarlarweelor Gneiss Complex, D_{2n} structures consist of conjugate east- to east-southeast striking and southeast- to south-southeast striking shear zones and faults ('D_{3n}' of Sheppard and Swager, 1999; Occhipinti and Myers, 1999).

Further north in the Glenburgh Terrane, namely the northern part of the Mooloo Zone, the Mutherbukin and Limejuice Zones, only one period of deformation and metamorphism is recognizable. In the southern part of the Mooloo Zone and the Paradise Zone where D_{1n} is prevalent, D_{2n} is most likely represented as a composite S_{1n}–S_{2n} low-grade schistosity to foliation. In the Limejuice Zone metasedimentary schists of the Leake Spring Metamorphics were deformed during intrusion by granites of the Minnie Creek batholith and preserve an S_{2n} gneissic fabric that is invariably folded around F_{3n} folds.

At the northern end of the Gascoyne Province (Boora Boora Zone) and in the Ashburton Basin, the second deformation related to the Capricorn Orogeny — labelled as D_{2a} (Ashburton Fold Belt) — may be the equivalent of D_{2n} elsewhere in the Gascoyne Province.

Description

In the Bryah and Padbury Basins adjacent to the Yarlarweelor Gneiss Complex, D_{2n} structures consist of northerly trending folds, faults and an upright foliation. The Kinders Fault and Billara Fault are interpreted to be D_{2n} structures. The effects of D_{2n} decrease eastward away from the gneiss complex. The D_{2n} event was also responsible for the doubly plunging nature of the Robinson Syncline and Peak Hill Anticline (Pirajno et al., 2000; their D_3). Pirajno et al. (2000) interpreted D_{1n} and D_{2n} as a continuum, with a single recognizable metamorphic event (M_{1n}; their M_2).

In the Yarlarweelor Gneiss Complex, D_{2n} structures consist mainly of conjugate ductile shear zones and faults in two orientations: 080–110° and 140–170°. The largest of these structures is the Morris Fault, which is a splay off the Errabiddy Shear Zone. Dykes of medium-grained monzogranite (P_-MO-gmeb), one of which is dated at 1797 ± 4 Ma, are widely intruded into conjugate D_{2n} faults. These faults are associated with small, upright, open to tight folds. The Kerba and Seabrook Faults may be D_{2n} structures, at least in part (Occhipinti and Myers, 1999). In the granitic gneisses and Moorarie Supersuite granites of the Yarlarweelor Gneiss Complex, the M_{2n} overprint consists of recrystallized quartz and biotite, partial replacement of plagioclase by albite, sericite, and clinozoisite, and retrogression of microcline to albite and sericite. Ilmenite crystals are commonly rimmed by titanite. In both the Archean and Paleoproterozoic amphibolites, mineral growth during M_{2n} consists of titanite replacement of ilmenite and partial replacement of andesine by epidote, untwinned plagioclase, and calcite. In addition, hornblende is commonly partly replaced by finer grained actinolite. In the Archean and Paleoproterozoic calc-silicate gneisses, epidote, green hornblende, albite, and titanite partly or largely replace high-grade assemblages.

Farther west, rocks in the Errabiddy Shear Zone are cut by numerous subvertical, brittle–ductile shear zones and faults that trend east or east-southeast and have been assigned to D_{2n}. These structures range from shear zones a few metres wide, up to zones about one hundred metres wide marked by upright, open to close folds and a foliation of variable intensity. Fold plunges range from shallow to nearly vertical towards the southeast. In strongly sheared granitic gneisses and interlayered amphibolite and metamorphosed ultramafic rock, D_{2n} structures may consist of a crenulation cleavage, the axis of which typically plunges steeply to the southeast. Most of the faults and shears are marked by a dextral offset ranging from a centimetre up to a few hundred metres. In places, shallowly plunging, east-northeasterly trending F_{1n} folds were rotated into steeply plunging, east-southeasterly trending folds, probably during D_{2n}.

In the Errabiddy Shear Zone, medium- and high-grade assemblages formed during the Glenburgh Orogeny (M_{2g}) in pelitic rocks of the Quartpot Pelite are variably overprinted by a lower grade metamorphic event. However, it is unclear as to how much, if any, of this retrogression belongs to M_{2n}, rather than younger tectonothermal events (Mangaroon and Edmundian Orogenies). Plagioclase is moderately to extensively replaced by fine-grained sericite, epidote, and albite, and garnet is partly altered to fine-grained biotite and muscovite. Sillimanite is entirely replaced by fine-grained mats of sericite. K-feldspar is partly replaced by sericite, quartz, and albite. Accompanying these mineralogical changes are recrystallization of quartz and biotite, and the development of granophyric and myrmekitic textures.

In the Glenburgh Terrane, only one set of structures has been identified that could be attributed to the Capricorn Orogeny. In the southern part of the Mooloo Zone and in the Paradise Zone, this fabric is likely to represent a composite S_{1n}–S_{2n} fabric and further north in the northern part of the Mooloo Zone most likely represents the S_{2n} fabric only. The main difference between the two areas appears to be the grade of metamorphism which was slightly higher to the south, resulting in the retrogression of peak amphibolite M_{2g} assemblages to upper greenschist facies with the pseudomorphing of garnet with chloritoid. In the northern part of the Mooloo Zone, garnet has been retrogressed to mats of white mica–sericite-chlorite, indicating the lower greenschist facies.

In the central part of the Gascoyne Province, in particular the Mutherbukin Zone, it is commonly difficult to identify any structures related to the Capricorn Orogeny because of the effects of late Paleoproterozoic to early Neoproterozoic reworking. Indications of medium- to high-grade metamorphism in the Mutherbukin Zone are provided by 1772 ± 6 Ma metamorphic rims on detrital grains from a quartzite (GSWA 187403) sampled from northwestern YINNETHARRA, but no structures can be confidently linked to this metamorphism. It is equally possible that these metamorphic zircon rims grew during the D_{3n} event.

In the Limejuice Zone, pelitic and psammitic schist comprise inclusions and rafts within granites of the Minnie Creek batholith. An early gneissic layering or schistosity (S_{2n}) is crenulated by an upright schistosity (S_{3n}) associated with growth of muscovite and chlorite (M_{3n}) and patches of felted sericite 4–7mm in diameter (after ?andalusite). The M_{2n} assemblages in pelitic rocks are wholly retrogressed, but probably consisted of muscovite–biotite–quartz–andalusite. In the Limejuice Zone on PINK HILLS and CANDOLLE a D_{2n}/M_{2n} gneissic layering in pelitic rocks is preserved in widely scattered localities marked by low-D_{3n} strain. Even in most of these localities, the M_{2n} assemblages are strongly retrogressed, but in places relict domains of M_{2n} assemblages persist: in the Pink Hills, for example at site SXSPKH008182 (Zone 50, MGA 492473E 7276916N), pelitic gneiss or granofels comprises andalusite, cordierite, biotite, muscovite, and quartz. The mafic rocks in the Limejuice Zone commonly preserve M2n assemblages (along with a D_{2n}/M_{2n} gneissic fabric) much better than the pelites. The mafic rocks are now amphibolites with a fine-grained polygonal texture, and comprise hornblende (straw-yellow–green–dark-green), plagioclase, quartz, titanomagnetite, and minor biotite. The Middle Spring Granite in the Limejuice Zone on PINK HILLS also contains a D_{2n} fabric parallel to that in the pelites and amphibolites.

Geochronology

Capricorn Orogeny

D_{2n}	*Maximum*	*Minimum*
Age (Ma)	1808 ± 6	1786 ± 6
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 1998a	Wingate et al., in prep. a

Geochronological constraints on the age of D_{2n} come from the Yarlarweelor Gneiss Complex and in the Limejuice Zone; elsewhere, the absolute ages of D_{2n} fabrics are poorly known. In the Yarlarweelor Gneiss Complex, the youngest granite cut by D_{2n} structures is the Kerba Granite dated at 1808 ± 6 Ma (Nelson, 1998a), which thereby provides a maximum age for the deformation. Dykes of medium-grained monzogranite (P_-MO-gmeb) are widely emplaced into D_{2n} faults and display a range of textures from massive to foliated, implying that they were intruded coeval with D_{2n}. One of these dykes on MARQUIS (Nelson, 1998b) has been dated at 1797 ± 4 Ma (Sheppard and Swager, 1999).

Farther north in the Limejuice Zone, folded and crenulated metasedimentary rocks of the Leake Spring Metamorphics on EUDAMULLAH are intruded by granites as old as c. 1810 Ma and as young as c. 1785 Ma. The older granites contain an upright foliation, but it is not clear whether this fabric is related to D_{2n}, or to a younger event. Nevertheless, the younger granites provide a younger age limit for D_{2n}. The Middle Spring Granite contains a gneissic fabric parallel to that in the Leake Spring Metamorphics. The granite has an igneous crystallization age of 1788 ± 7 Ma (Wingate et al., in prep.b), which provides an older age limit for D_{2n}/M_{2n} in this zone. The Rubberoid Granite on PINK HILLS, which intrudes the gneissic fabric in the Middle Spring Granite, was sampled at two localities for SHRIMP U–Pb zircon dating. The samples yielded igneous crystallization ages of 1791 ± 4 Ma and 1786 ± 6 Ma (Wingate et al., in prep.a,c), and provide a younger age limit for D_{2n}/M_{2n}. Therefore, the S_{2n} gneissic fabric, and the associated high-T/low-P M_{2n} metamorphism, was coeval with construction of the Minnie Creek batholith.

A preliminary U–Pb monazite age of c. 1785 Ma for schist along the northern margin of the Minnie Creek batholith (GSWA, unpublished data) confirms the presence of Capricorn Orogeny-aged deformation and metamorphism. A psammitic schist from the northern part of the Mooloo Zone yielded a single metamorphic zircon rim grown around older detrital cores. This rim was dated at 1788 ± 12 Ma (1σ; Wingate et al., 2010) and is within error of the other ages for D_{2n}/M_{2n} obtained here.

Tectonic setting

See **Capricorn Orogeny**

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Capricorn Orogeny D_{3n}/M_{3n}

Event type	deformation: undivided, metamorphic: regional
Parent event	Capricorn Orogeny
Tectonic units affected	Gascoyne Province
Tectonic setting	orogen: intracratonic orogen
Metamorphic texture/ tectonic feature	crenulated, faulted, retrogressed
Metamorphic facies from	greenschist facies: chlorite zone
Metamorphic facies to	greenschist facies: chlorite zone

Summary

The third tectonic fabric that can be attributed to the Capricorn Orogeny is referred to as D_{3n}, and the corresponding mineral assemblage, M_{3n}. This fabric is recognized only in the Limejuice Zone where D_{2n} gneissic fabrics and foliations are folded abount upright local- to regional-scale close to tight folds. A well developed crenulation cleavage is developed parallel to the macroscopic F_{3n} fold axial traces.

Distribution

D_{3n} deformation is only present in the Limejuice Zone although the presence of metamorphic zircon rims within quartzites of the Moogie Metamorphics in the Mutherbukin Zone dated at c. 1770 Ma, suggest that this zone may have also been affected by D_{3n} deformation and metamorphism.

Description

In the Limejuice Zone, pelitic and psammitic schists of the Leake Spring Metamorphics are folded about upright, close to tight folds (F_{3n}). A crenulation schistosity is commonly formed parallel to the axial surfaces of the folds; this upright schistosity (S_{3n}) crenulates a millimetre- to centimetre-scale compositional layering (S_{2n}). Associated metamorphic assemblages (M_{3n}), which comprise muscovite–chlorite–quartz(–magnetite) in pelitic rocks and quartz–muscovite(–chlorite) in psammitic rocks, have almost completely replaced M_{2n} assemblages.

Geochronology

Capricorn Orogeny

D_{3n}/ M_{3n}	*Maximum*	*Minimum*
Age (Ma)	1786	1772 ± 6
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Isotopic
References	Wingate et al., in prep.a	Wingate et al., 2010

There are no direct age constraints on the timing of D_{3n} deformation and metamorphism. In the Limejuice Zone, D_{2n} gneissic fabrics and foliations within both the Middle Spring Granite and schists of the Leake Spring Metamorphics are folded around F_{3n} folds indicating that F_3 folding occurred after c. 1785 Ma (the younger age constraint for D_{2n}).

Metamorphic zircon rims on detrital grains from a quartzite (GSWA 187403) sampled from northwestern YINNETHARRA in the Mutherbukin Zone, have been dated at 1772 ± 6 Ma (Wingate et al., 2010). This age is considerably younger than that obtained for the D_{2n} episode and so it is possible that it records deformation associated with D_{3n}; however, no structures can be confidently linked to this period metamorphic zircon growth.

Tectonic setting

See **Capricorn Orogeny**

References

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Pooranoo Metamorphics
(P_-PO-md)

Legend narrative

Pelitic and psammitic schist, quartz metasandstone, feldspathic metasandstone and metaconglomerate, and phyllite

Rank	Group
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-g, P_-TT-g, P_-mw-od (intrusive); P_-ME (unconformable)
Underlying units	AP_-_ha-mgn, P_-LS-xmd-mk, P_-MO-g (unconformable/faulted)

Summary

The Pooranoo Metamorphics comprises mainly pelitic and psammitic schist, feldspathic metasandstone, phyllite, and metaconglomerate. In the Mangaroon Zone, the rocks are commonly gneissic, with migmatitic textures widely developed in the pelites. These metasedimentary and meta-igneous rocks were previously included within the 'Leake Spring Metamorphic Suite' (Williams et al., 1983; Williams, 1986). However, protoliths to the Pooranoo Metamorphics in the Mangaroon Zone have a maximum depositional age of c. 1680 Ma, whereas the protoliths to the Leake Spring Metamorphics were deposited, then deformed and metamorphosed before c. 1810 Ma. The thickness of the sedimentary packages in the Mangaroon Zone are unknown. To the south of the Mangaroon Zone, the base of the Pooranoo Metamorphics is assigned to the Mount James Subgroup, formerly the Mount James Formation. This subgroup contains a well-defined laterally continuous stratigraphy comprised of a lower fluvial succession (Biddenew Formation) overlain by shallow marine quartzites of the Spring Camp Formation. The combined stratigraphy for the Mount James Subgroup is at least 700 m in thickness. The maximum depositional age of for the subgroup is defined by the age of detital zircons dated at c. 1760 Ma. It is not clear if the Pooranoo Metamorphics consists of two temporally discrete metasedimentary packages or whether it is a single progressively deepening basin reflecting a transition from fluvial and shallow marine conditions in the south to deeper water in the north.

Distribution

The Pooranoo Metamorphics outcrop extensively in the Mangaroon Zone in the northern Gascoyne Province, and in the Mutherbukin Zone in the central part of the province. Outliers of Pooranoo Metamorphics are also found on the Minnie Creek batholith in the Limejuice Zone. The Mangaroon Zone is about 70 km wide and is overlain to the west and east by Phanerozoic and Mesoproterozoic sedimentary rocks, respectively. The Pooranoo Metamorphics in the Mangaroon Zone have not been subdivided into named units as no stratigraphy is apparent. Within the Mutherbukin and Limejuice Zones, the Pooranoo Metamorphics contain a recognizable stratigraphy, and are assigned to the Mount James Subgroup. In these zones, the Mount James Subgroup outcrops over much of southwestern Pink Hills, and along the southern edge of Mount Phillips. Smaller outcrops are present in the southeastern corner of Yinnetharra and as a series of small outliers in the Mooloo and Paradise Zones on Glenburgh and in the Errabiddy Shear zone on Yalbra in the southern Gascoyne Province.

Derivation of name

The Pooranoo Metamorphics is named after Pooranoo Well (Zone 50, MGA 382249E 7363317N) in the southeastern part of Mangaroon.

Lithology

Across the southern part of the province, in the Paradise, Mooloo, Mutherbukin, and Limejuice Zones, a recognizable stratigraphy allows division of the Pooranoo Metamorphics into the Mount James Subgroup. This consists of a lower fluvial succession of metaconglomerate, feldspathic metasandstone phyllite or slate and psammitic schist of the Biddenew Formation, which is overlain by shallow marine quartzites and quartz–muscovite schists of the Spring Camp Formation. Further north in the Mangaroon Zone the Pooranoo Metamorphics comprises two main units in roughly equal proportions: psammitic schist and feldspathic metasandstone, and pelitic schist and gneiss. The psammitic schist and feldspathic metasandstone is interlayered with minor pelitic rock and granule metaconglomerate. Graded bedding is preserved in places in the feldspathic metasandstone, and the rocks may be part of a turbiditic sequence. Although no contact relationships have been observed, the apparent transition from the shallow marine quartzites of the Spring Camp Formation northward into turbidite-type deposits in the Mangaroon Zone may suggest a deepening of the basin toward the north.

In the Mangaroon Zone, pelitic schist and gneiss are mainly non-migmatitic, but in the area around the Star of Mangaroon Mine, migmatitic pelitic gneiss is abundant. The migmatites include both diatexites and metatexites. Interlayered cobble and pebble metaconglomerate, granule metasandstone, calc-silicate gneiss and schist, and amphibolite and actinolite schist are minor rock types

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics	PO-
Rock type	metasedimentary siliciclastic	
Lithname	metasiliciclastic rock; undivided	md
Rock code		**P_-PO-md**
Additional lithologies	pelitic gneiss, psammitic gneiss, psephitic schist, psammitic schist	

Contact relationships

In the Mangaroon Zone the Pooranoo Metamorphics are juxtaposed with inliers of the c. 1775 Ma Gooche Gneiss (Moorarie Supersuite) by layer-parallel faults, and are intruded extensively by granites of the 1680–1620 Ma Durlacher Supersuite. The Pooranoo Metamorphics, including the Mount James Subgroup, are unconformably overlain by sedimentary rocks of the Edmund Group (Bangemall Supergroup). In the Limejuice Zone the metamorphic rocks form isolated small outliers unconformably overlying the Minnie Creek batholith (Moorarie Supersuite). In the Mutherbukin Zone the Mount James Subgroup of the Pooranoo Metamorphics unconformably overlies, or is faulted against, the Halfway Gneiss and granites of the Moorarie Supersuite. Along the northern margin of the Mutherbukin Zone, south of the Ti Tree Syncline, psammitic and pelitic schist of the Mount James Subgroup is intruded by granite and pegmatite of the Thirty Three Supersuite.

Geochronology

P_-PO-md	*Maximum*	*Minimum*
Age (Ma)	1758 ± 18	1677
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Inferred
References	Wingate et al., 2009	Nelson, 2005

The best constrained ages of the Pooranoo Metamorphics come from samples in the Mangaroon Zone; however, the stratigraphic position of these samples within the package is unknown. It is entirely possible that these samples form the uppermost part of the basin and were deposited immediately before, or during the early stages of, the Mangaroon Orogeny. A sample of pelitic gneiss with sparse leucosomes from southeast of Maroonah Homestead contains detrital zircons as young as 1680 ± 13 Ma, and also contains several older age components (Nelson, 2004). Two samples of feldspathic metasandstone (GSWA 169056 and 169091) contain youngest age components at 1808 ± 11 Ma and 1800 ± 4 Ma, thus providing a older limit for deposition of the protolith (Sheppard et al., 2005). However, given that feldspathic metasandstone is interbedded with pelitic gneiss, which has a maximum depositional age of c. 1680 Ma, then the precursor to the feldspathic metasandstone must also have been deposited after 1680 ± 13 Ma.

The oldest granite, on the basis of field relationships, to intrude the Pooranoo Metamorphics, is a schlieric granodiorite. The granodiorite was sampled for SHRIMP U– Pb geochronology (Nelson, 2005); and has an igneous crystallization age of 1677 ± 5 Ma (Sheppard et al., 2005); this is the best estimate of the minimum age for the Pooranoo Metamorphics.

Six samples (one from the basal unit of the Biddenew Formation, and five from the Spring Camp Formation) of the Mount James Subgroup yield similar depositional constraints. The samples were collected from a wide geographical area (Yalbra to Mount Phillips) and the youngest detrital zircon present in all samples is dated at c. 1760 Ma. Considering the ambiguity surrounding the stratigraphic position of the samples dated in the Mangaroon Zone, a more conservative estimate for the maximum age of deposition of the group is c. 1760 Ma.

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Mount James Subgroup
(P_-POJ-md)

Legend narrative

Pelitic and psammitic schist, metamorphosed quartz sandstone, and feldspathic metasandstone and metaconglomerate

Rank	Subgroup
Parent	Pooranoo Metamorphics (P_-PO-md)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-g, P_-TT-g, P_-MW-od (intrusive); P_-_au-sp, P_-ME (unconformable); AP_-mgnl-YNAY, P_-MO-g, P_-DU-g, P_-ME, P_-_nr-od
Underlying units	AP_-_ha-mgn, P_-MG-xmh-mk, P_-DA-mg, P_-LS-xmd-mk, P_-MO-g (unconformable/faulted)
Maximum thickness	700 m

Summary

The Mount James Subgroup contains a well-defined stratigraphy and on this basis has been divided into a lower fluvial unit called the Biddenew Formation (P_-POb-mtef) and an upper marine quartzite unit called the Spring Camp Formation (P_-POs-mtqs). The Biddenew Formation crops out mainly in the Mutherbukin and Mooloo Zones but thins rapidly south in the Paradise Zone and does not outcrop in the Errabiddy Shear Zone. The Spring Camp Formation is laterally extensive and a highly recognizable stratigraphic marker that outcrops across the southern Gascoyne Province from the Limejuice Zone through to the Errabiddy Shear Zone. The Biddenew Formation is a package of immature medium- to coarse-grained feldspathic low grade metasedimentary rocks that show abundant cm- to m-scale trough cross-bedding, scour horizons and discontinuous channel horizons that are characteristic of high energy fluvial environments and contains abundant metaconglomerate, pebble metasandstone and feldspathic metasandstone. The Spring Camp Formation consists of a single horizon of a pure, mostly recrystallized sugary textured white quartzite which contains abundant asymmetric and longitudinal ripples, trough cross-stratification and occasional current lineations indicative of deposition in a shallow marine to inter-tidal environment. The top of the sequence is nowhere exposed but most units of the Mount James Subgroup are unconformably overlain by sedimentary rocks of the Mount Augustus sandstone or the Edmund Group. The subgroup was deposited sometime between c. 1760 Ma and c. 1680 Ma.

Distribution

The Mount James Subgroup crops out mainly in the Mutherbukin and Mooloo Zones of the Gascoyne Province (EUDAMULLAH, MOUNT PHILLIPS, MOUNT AUGUSTUS, LOCKIER, YINNETHARRA, PINK HILLS, GLENBURGH, and DAURIE CREEK) although isolated outcrops of Spring Camp Formation quartzites (P_-POs-mtqs) also lie in the Errabiddy Shear Zone on YALBRA, ERRABIDDY, and MARQUIS. As most of the subgroup has been extensively folded and faulted during the Edmundian Orogeny and subsequent events, most outcrops are small (less than 5 km^2), although on MOUNT PHILLIPS on the southern side of the Ti Tree Syncline there is a single extensive outcrop of semi-pelitic staurolite-bearing schist of ~100 km^2. The fluvial Biddenew Formation is extensively present in the Limejuice and Mutherbukin Zones but appears to thin to the south so that only some members are intermittently present in the Mooloo and Paradise Zones and totally absent in the Errabiddy Shear Zone. The Spring Camp Formation is comprised of a single, laterally extensive marine quartzite that can be traced from the Limejuice Zone through to the Errabiddy Shear Zone.

Derivation of name

The type area for the Mount James Formation is defined in the explanatory notes to the MOUNT PHILLIPS 1:250 000 sheet (Williams et al., 1979) as the area between Mount Gascoyne and Spring Camp outcamp on southern YINNETHARRA and PINK HILLS. The derivation of the name 'Mount James' for the formation is not known, but presumably it is after Mount James, a significant hill some 15 km to the west-northwest of the type area. The subdivision and reclassification of the Mount James Formation to the Mount James Subgroup and its constituent Biddenew and Spring Camp formations was conducted during the second edition mapping in the type area on YINNETHARRA and PINK HILLS in 2007–2008 (Sheppard et al., 2008; Sheppard and Johnson, in prep.). The Biddenew Formation was named after Biddenew Creek that flows from the southern side of Mount Gascoyne and the Spring Camp Formation after Spring Camp Creek (rather than the now abandoned Spring Camp outcamp) that flows northeastward from the western margin of Mount Gascoyne.

Lithology

The Mount James Subgroup contains a well-defined stratigraphy and on this basis has been divided into a lower fluvial unit called the Biddenew Formation (P_-POb-mtef) and an upper marine quartzite unit called the Spring Camp Formation (P_-POs-mtqs).

The Biddenew Formation is a package of immature medium- to coarse-grained feldspathic low-grade metasandstones (P_-POb-mtef, P_-POb-mqef, P_-POb-mxq), including low- to medium-grade pelitic (P_-POb-mlsm), semipelitic (P_-POb-mhs), and sericitic schists and phyllites (P_-POb-mlpc). The more abundant feldspathic metasandstones and metaconglomerates show abundant cm- to m-scale trough cross-bedding, scour horizons and discontinuous channel horizons that are characteristic of high energy fluvial environments. The base of the formation is locally marked by a matrix supported, cobble to boulder metaconglomerate (P_-POb-mxq) that contains up to and over 60% rounded quartz vein clasts. Elsewhere the unconformable base is marked either by fine grained sericite or biotite schists

(P_-POb-mlpc, P_-POb-mlsm) that appear to be lateral equivalents of the metaconglomerate or pebble (P_-POb-mqef) and feldspathic metasandstone (P_-POb-mtef) of the overlying members, indicating that this is a very transgressive sequence or that it was deposited over an angular unconformity with significant topography. Where the entire stratigraphy is present, it is observed that the lowermost metaconglomerate grades upward into a granule to pebbly feldspathic metasandstone (P_-POb-mqef). This in turn grades up into a medium-grained feldspathic metasandstone (P_-POb-mtef) with the progressive loss of pebbles and gritty horizons. This unit contains local, discontinuous gritty or pebbly horizons and is the thickest member of the Biddenew Formation. Directly to the east and west of Mount Gascoyne the base of the feldspathic metasandstone is locally underlain by a sequence of 2–3 m-thick interbedded siltstones, fine grained metasandstones, and medium-grained feldspathic metasandstones (P_-POb-mhs).

The top of the feldspathic metasandstone member (P_-POb-mtef) of the Biddenew Formation grades rapidly up into a pure, mostly recrystallized sugary textured white quartzite of the Spring Camp Formation (P_-POs-mtqs). This quartzite contains abundant asymmetric and longitudinal ripples, trough cross-stratification and occasional current lineations indicative of deposition in a shallow marine to inter-tidal environment. The stratigraphic top of the Spring Camp Formation is nowhere present and so the original thickness of this upper marine unit is not known. However, the Spring Camp Formation is very laterally extensive, being present as a distinct mappable unit from the Limejuice Zone in the north through to the Errabiddy Shear Zone in the south — a distance of 120 km. This is in contrast to the Biddenew Formation which is laterally extensive in the Limejuice and Mutherbukin Zones but appears to thin rapidly to the south where it is only a thin, intermittent unit in the Paradise Zone and is absent from the Errabiddy Shear Zone. Both the Biddenew and Spring Camp Formations are unconformably overlain (angular unconformity) by low-grade sedimentary rocks of the Mount Augustus Sandstone (P_-_au-sp) and Edmund Group (P_-ME) suggesting that the Mount James Subgroup must have been tilted prior to deposition of these Mesoproterozoic sedimentary rocks.

Age code	Proterozoic	P_-
Stratigraphic code	Poorano Metamorphics, Mount James Subgroup	POJ-
Rock type	metasedimentary siliciclastic	
Lithname	metasiliciclastic rock; undivided	md
Rock code		**P_-POJ-md**

Contact relationships

In the Limejuice Zone scattered and isolated outcrops of quartzite (P_-POs-mtqs), metasandstone (P_-POb-mtef), and phyllite (P_-POb-mlpc) sit unconformably on granites of the Moorarie Supersuite (P_-MO-g) that form the Minnie Creek batholith. At and around Mount Augustus these rocks are unconformably overlain by the Mount Augustus Sandstone (P_-_au-sp). In the Mutherbukin Zone most members of the Biddenew Formation and Spring Camp Formation are present. The Spring Camp Formation quartzites are mostly in conformable contact with the underlying members of the Biddenew Formation except where they are in faulted contact with the Halfway Gneiss (AP_-_ha-mgn) and granites of the Moorarie Supersuite (P_-MO-g). The Biddenew Formation unconformably overlies most basement rocks including the Halfway Gneiss (AP_-_ha-mgn) and various granites of the Moorarie Supersuite, and schists of both the Moogie Metamorphics (P_-MG-xmh-mk) and Leake Spring Metamorphics (P_-LS-xmd-mk). Along the southern margin of the Ti Tree Syncline rocks of the Biddenew Formation are in faulted contact with low grade sedimentary rocks of the Edmund Group (P_-ME). In this area the Mount James Subgroup is intruded by sheets, stocks, dykes, and veins of younger granites that belong to the Durlacher Supersuite (P_-DU-g) and the Thirty Three Supersuite (P_-TT-g). Abundant metre-wide unmetamorphosed mafic dykes of the Mundine Well Dolerite Suite (P_-MW-od) also intrude the Mount James Subgroup. On the southern parts of YINNETHARRA and PINK HILLS the Mount James Subgroup is unconformably overlain (on an angular unconformity) by Edmund Group sedimentary rocks (P_-ME). In the Mooloo and Paradise Zones the Biddenew Formation is much attenuated, but the Spring Camp Formation quartzites are well represented. These units unconformably overlay higher grade metasedimentary rocks of the Moogie Metamorphics (P_-MG-xmh-md), gneisses of the Dalgaringa Supersuite (P_-DA-mg), and granites of the Moorarie Supersuite (P_-MO-g). In the Errabiddy Shear Zone, Spring Camp Formation quartzites are everywhere in tectonic contact with older and younger units including gneisses of the Yarlarweelor Gneiss Complex (AP_-mgnl-YNAY), granites of the Moorarie Supersuite (P_-MO-g), granites of the Durlacher Supersuite (P_-DU-g), Edmund Group sedimentary rocks (P_-ME), and the Narimbunna Dolerite (P_-_nr-od).

Geochronology

P_-POJ-md	*Maximum*	*Minimum*
Age (Ma)	1758 ± 18	1677
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Inferred
References	Wingate et al., 2009a	Nelson, 2005

A single sample of grey–green phyllite from the Biddenew Formation immediately south of Mount Samuel on southwestern MOUNT AUGUSTUS was sampled for SHRIMP U–Pb zircon geochronology. This unit lies at the base of the Mount James Subgroup and yielded numerous zircons of various ages but the youngest detrital zircon in the sample has a ^{207}Pb*/^{206}Pb* date of 1758 ± 18 Ma, providing a maximum age of deposition (Wingate et al., 2009a). Five samples of the Spring Camp Formation quartzite (P_-POs-mtqs), from various parts of the southern Gascoyne Province, were also selected for SHRIMP U–Pb zircon geochronology to determine their maximum ages of deposition and provenance. The sample from furthest south on YALBRA in the Errabiddy Shear Zone (Nelson, 2001a) indicated a very local provenance; mainly from the Archean Yilgarn Craton. The youngest detrital zircon age component (26 grains) yielded a weighted mean $^{207}Pb^*/^{206}Pb^*$ date of 2616 ± 6 Ma (Nelson, 2001a) providing a maximum age for its deposition. The other four samples from the Limejuice Zone through to the Mooloo Zone, including two samples from the type locality at Mount James on YINNETHARRA, yielded very similar results (Nelson 2001b; Wingate et al., 2010a,b; Wingate et al., 2009b). The youngest zircons in all samples range in age between c. 1800 and c. 1780 Ma, only slightly older than that obtained from the Biddenew Formation sample. The metasediments unconformably overlie granites of the Moorarie Supersuite, the youngest of which is dated at 1782 ± 5 Ma.

A younger age limit for sediment deposition is constrained only indirectly. A phyllite from the basal part of the Biddenew Formation is unconformably overlain by the Mount Augustus Sandstone, and detrital zircons from the sandstone indicate a maximum depositional age of 1679 ± 3 Ma (Wingate et al., 2007), but much firmer constraints are provided by granites of the Durlacher Supersuite that intrude the Pooranoo Metamorphics, the oldest of which is dated at 1677 ± 5 Ma (Nelson, 2005).

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BIDDENEW FORMATION
(P_-POb-mtef)

Legend narrative

Feldspathic metasandstone and minor feldspathic pebbly metasandstone; medium- to coarse-grained; locally ripple marked and cross-bedded

Rank	Formation
Parent	MOUNT JAMES SUBGROUP (P_-POJ-md)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-POs-mtqs (conformable); P_-MEy-st (unconformable); AP_-_ha-mgnw, P_-MOsc-gm (fault)
Underlying units	P_-POb-mqef, P_-POb-mhs (conformable); AP_-_ha-mgnw, AP_-_ha-mgnl, P_-MOsc-gm, P_-MO-gmeb, P_-MO-gmvl, P_-MO-gmml (unconformity)
Minimum thickness	100 m
Maximum thickness	600 m

Summary

The Biddenew Formation is a package of immature, medium- to coarse-grained, feldspathic low-grade metasandstones and metapsephites (P_-POb-mtef, P_-POb-mqef, P_-POb-mxq), including minor low- to medium-grade pelitic (P_-POb-mlsm), semipelitic (P_-POb-mhs), and sericitic schists and phyllites (P_-POb-mlpc) that form the lower part of the Mount James Subgroup. These rocks form a series of discontinuous outcrops in the Limejuice, Mutherbukin, Mooloo, and Paradise Zones of the southern Gascoyne Province. The more abundant feldspathic metasandstones and metaconglomerates show abundant centimetre- to metre-scale trough cross-bedding, scour horizons, and discontinuous channel horizons that are characteristic of high energy fluvial environments. The feldspathic metasandstone itself (P_-POb-mtef) is a medium-grained, poorly-sorted, immature, feldspar-rich metasandstone that frequently contains discontinuous 'gritty' layers and pebble horizons as well as containing randomly distributed, isolated pebble-sized clasts. Trough cross-bedding, 50–100 cm in size, is common and graded bedding is locally abundant. A phyllite from the base of the unit yielded detrital zircon with ages of c. 1760 Ma providing a maximum age constraint on the timing of deposition. The Biddenew Formation and Mount James Subgroup are intruded by granites of the Durlacher Supersuite, the oldest of which is dated at c. 1680 Ma providing the best estimate of a minimum age.

Distribution

The Biddenew Formation is a package of immature, medium- to coarse-grained, feldspathic low-grade metasandstones and metapsephites (P_-POb-mtef, P_-POb-mqef, P_-POb-mxq), including minor low- to medium-grade pelitic (P_-POb-mlsm), semipelitic (P_-POb-mhs), and sericitic schists and phyllites (P_-POb-mlpc) that form the lower part of the Mount James Subgroup. These rocks form a series of discontinuous outcrops in the Limejuice, Mutherbukin, Mooloo, and Paradise Zones of the southern Gascoyne Province (EUDAMULLAH, MOUNT PHILLIPS, MOUNT AUGUSTUS, LOCKIER, YINNETHARRA, PINK HILLS, GLENBURGH, and DAURIE CREEK). The Biddenew Formation is dominated by pelitic schists and phyllites (P_-POb-mlsm and P_-POb-mlpc) in the north in the Limejuice and Mutherbukin Zones and also in the south in the Paradise Zone, although minor amounts of metaconglomerate (P_-POb-mxq) are present in both areas. In the Limejuice and Mutherbukin Zones the Biddenew Formation forms small (<2 km^2) isolated outcrops that sit as inliers within younger granites or as isolated outliers partially overlain by younger sedimentary rocks such as the Mount Augustus Sandstone (P_-_au-st). However, on MOUNT PHILLIPS, pelitic schists (P_-POb-mlsm) form a 3 km long × 500 m wide strip adjacent to gneissic granites of the Durlacher Supersuite and intruded by granites of the Thirty Three Supersuite. A single 900 m long outcrop of pebble-rich feldspathic metasandstone (P_-POb-mqef) lies on LOCKIER close to Paddy Well. In the southernmost part of the Mooloo Zone at Mount Dalgety on DAURIE CREEK, cobble and boulder metaconglomerate (P_-POb-mxq) lies in the core of a regional syncline that unconformably overlies pelitic schists of the Mumba Psammite (Moogie Metamorphics). In the Paradise Zone on GLENBURGH, interbedded slate and metasandstone (P_-POb-mhs) outcrops as a series of 1–5 km long, <1 km wide outliers that form the core of a regional, shallow plunging northeast-southwest trending anticline. In the type area for the Mount James Subgroup, between Mount James and Mount Gascoyne on southern YINNETHARRA and PINK HILLS (the Mooloo Zone), the Biddenew Formation is the thickest and without any observable stratigraphic or structural break. Here the formation is dominated by medium- to coarse-grained feldspathic metasandstone (P_-POb-mtef), although metaconglomerate (P_-POb-mxq), pebble metasandstone (P_-POb-mqef), and semipelitic schist (P_-POb-mhs) are present at the base of the formation.

Specifically, feldspathic metasandstone (P_-POb-mtef) outcrops on southern YINNETHARRA and PINK HILLS in an area between Mount Gascoyne and Mount James and to an area immediately northwest of Mount Steere. In the area between Mount James and Mount Gascoyne the feldspathic metasandstone forms an extensive outcrop (90 km^2), thickening from Mount James toward the east and southeast, and thinning out again on the eastern side of Mount Gascoyne. The unit is faulted-out on the southern side of Mount Gascoyne. A single outcrop 1.5 km^2 is present to the northwest of Mount Steere.

Derivation of name

Subdivision of the Mount James Subgroup into the Biddenew and Spring Camp formations was conducted during the second edition mapping of the type area on southern PINK HILLS and YINNETHARRA in 2007–08 (Sheppard et al., 2008, Johnson et al., 2010). The Biddenew Formation was named after Biddenew Creek that flows from the southern side of Mount Gascoyne.

Lithology

The Biddenew Formation is a package of immature, medium- to coarse-grained, feldspathic low-grade metasandstones and metapsephites (P_-POb-mtef, P_-POb-mqef, P_-POb-mxq), including low- to medium-grade pelitic (P_-POb-mlsm), semipelitic (P_-POb-mhs), and sericitic schists and phyllites (P_-POb-mlpc). The more abundant feldspathic metasandstones and metaconglomerates show abundant cm- to m-scale trough cross-bedding, scour horizons, and discontinuous channel horizons that are characteristic of high energy fluvial environments. Apart from the feldspathic metasandstone (P_-POb-mtef), the other members of the Biddenew Formation will be described in the relevant rock units (P_-POb-mxq, P_-POb-mqef, P_-POb-mlsm, P_-POb-mhs, P_-POb-mlpc).

Feldspathic metasandstone and minor feldspathic pebbly metasandstone (P_-POb-mtef) is a medium-grained, poorly-sorted, immature metasandstone that frequently contains discontinuous ‘gritty’ layers and pebble horizons as well as containing randomly distributed, isolated pebble-sized clasts. Trough cross-bedding, 50–100 cm in size, is common and graded bedding is locally abundant. The matrix is generally medium grained, although locally can increase to be coarse to very coarse, and comprises subangular to sub-rounded quartz (60%), feldspar (30%), and minor sericite and heavy minerals including tourmaline. The pebbles, both the isolated occurrences and those within pebble-rich horizons, are generally rounded with a moderate sphericity and are up to 3 cm in diameter. They are comprised predominantly of quartz vein material although some fine-grained, black chert pebbles are present. Everywhere the pebble-rich areas are matrix supported and are usually found in association with an increase in coarser-grained ‘gritty’ layers. At one locality on the western flank of Mount Gascoyne (SPJPKH000964; Zone 50, MGA 463630E 4270306N) near the upper contact with the Spring Camp Formation, the feldspathic metasandstone contains 1–2 cm spaced symmetrical bifurcating ripples suggesting either east or west paleoflow. These ripples are also indicative of an intertidal to shallow marine environment suggesting that the upper parts of this formation may not be entirely of fluvial origin.

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics, BIDDENEW FORMATION	POb-
Rock type	metasedimentary siliciclastic: psammite	mt
Lithname	psammitic granofels/hornfels	e
1st qualifier	–	
2nd qualifier	felsic/feldspathic; K-metasomatized	f
Rock code		**P_-POb-mtef**

Contact relationships

The contact relationships of the individual members of the Biddenew Formation have been described in detail in the relevant rock units (P_-POb-mxq, P_-POb-mqef, P_-POb-mlsm, P_-POb-mhs, P_-POb-mlpc) and as a formation within the parent rock unit (P_-POJ-md), so only those relating to the feldspathic metasandstone (P_-POb-mtef) will be described here. Feldspathic metasandstone (P_-POb-mtef) outcrops on southern YINNETHARRA and PINK HILLS in an area between Mount Gascoyne and Mount James and to an area immediately northwest of Mount Steere. Between Mount James and Mount Gascoyne, the feldspathic metasandstone is in conformable contact with the underlying pebble metasandstone member (P_-POb-mqef), and locally the interbedded siltstones and metasandstones (P_-POb-mhs). The unit locally oversteps onto basement rocks including the mesocratic and leucocratic Halfway Gneiss (AP_-_ha-mgnw and AP_-ha-mgnl) and granites of the Moorarie Supersuite (P_-MOsc-gm and P_-MO-mgml). On the southern side of Mount Gascoyne the feldspathic metasandstone is in faulted contact with the mesocratic Halfway Gneiss (AP_-_ha-mgnw), pebble metasandstone (P_-POb-mqef), and granite of the Moorarie Supersuite (P_-MOsc-gm). The unit is conformably overlain by quartzite of the Spring Camp Formation (P_-POs-mtqs) and unconformably overlain by low-grade metasedimentary rocks of the Edmund Group (P_-MEy-st). At Mount Steere, the feldspathic metasandstone conformably overlies cobble metaconglomerate (P_-POb-mxq) wherever present, and unconformably overlies granite of the Moorarie Supersuite (P_-MO-gmvl, P_-MO-gmeb).

Geochronology

P_-POb-mtef	*Maximum*	*Minimum*
Age (Ma)	1758 ± 18	1677
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Inferred
References	Wingate et al., 2009	Nelson, 2005

Feldspathic metasandstone (P_-POb-mtef) has not been dated directly. However, a single sample of grey–green phyllite from the base of the Biddenew Formation was sampled for SHRIMP U–Pb zircon geochronology (Wingate et al., 2009). This unit yielded numerous zircons of various ages but the youngest detrital zircon in the sample has a ^{207}Pb*/^{206}Pb* date of 1758 ± 18 Ma, providing a maximum age of deposition for the Biddenew Formation. Additional information is provided by SHRIMP U–Pb analyses of detrital zircons from six samples of the overlying Spring Camp Formation (P_-POs-mtqs). These samples yielded similar results to the Biddenew Formation with the youngest detrital zircons being in the 1800–1785 Ma range.

The younger age constraints are provided only by indirect results. The phyllite that was dated from the basal part of the Biddenew Formation (GSWA 183255) is unconformably overlain by the Mount Augustus Sandstone, and detrital zircons from the sandstone indicate a maximum depositional age of 1679 ± 3 Ma (Wingate et al., 2007), but much firmer constraints are provided by granites of the Durlacher Supersuite that intrude the Pooranoo Metamorphics, the oldest of which is dated at 1677 ± 5 Ma (Nelson, 2005).

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BIDDENEW FORMATION; subunit (P_-POb-mhs)

Legend narrative

Interbedded slate and metasandstone; locally graphitic

Rank	Member
Parent	BIDDENEW FORMATION (P_-POb-mtef)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MEi and P_-MEi-s (faulted), P_-POb-mtef, P_-POs-mtqs (conformable); P_-MEy-st (unconformable)
Underlying units	P_-DA-xmgt-mgm and P_-DA-xmgt-mgg (angular unconformity); P_-POb-mxq (conformable)

Summary

Interbedded slate and metasandstone of the Biddenew Formation form a series of small intermittent folded outcrops stretching from Mount Gascoyne on southern PINK HILLS through the central portion of GLENBURGH onto the eastern edge of DAURIE CREEK. The unit consists of interbedded black slates (or siltstones), and fine-grained, metamorphosed silty sandstone through to fine- and medium-grained metasandstone. Individual members are 1–3 m thick and metasandstone predominates over siltstone or slate. This formation is generally in conformable contact with the underlying and overlying members of the Biddenew Formation, but on GLENBURGH it rests unconformably on Dalgaringa Supersuite gneisses.

Distribution

Interbedded slate and metasandstone of the Biddenew Formation outcrops as a series of 1–5 km long, <1 km wide outliers that form the core of a regional, shallow plunging northeast-trending anticline that transects GLENBURGH and DAURIE CREEK, and as two regional-scale gently folded outcrops around Mount Gascoyne on PINK HILLS. The largest of these, forming the base of Mount Gascoyne, is gently to moderately folded and forms a roughly 12 km^2 outcrop.

Lithology

Interbedded slate and metasandstone of the Biddenew Formation comprises a sequence of finely interbedded black slates (or siltstones) and fine-grained, metamorphosed silty sandstone. On GLENBURGH and DAURIE CREEK the slates are very fine grained, black in colour and locally graphitic. They contain a single, prominent slaty cleavage that is typically at high angle to bedding, which parallels the regional anticlinal fold hinge. The metasandstones are fine grained with a large proportion of silty material that commonly gives them a finely laminated appearance. Locally (e.g. SAOGLE3414; Zone 50, MGA 401800E 7198000N) the metamorphosed silty sandstone is dolomitic and ferruginous or contains porphyroblasts of euhedral magnetite (SAOGLE3213 - Zone 50, MGA 442048E 7214649N). These metasandstone horizons also carry a single penetrative foliation. On PINK HILLS, the unit comprises interbedded, strongly cleaved siltstone, silty sandstone and fine- to medium-grained sandstone. The sandstone units are around 2–3 m thick, and are interbedded with 1–5 m-thick units of siltstone. The siltstone grades rapidly into the overlying sandstone which has a sharp base with the next overlying siltstone. However, no way-up structures have been identified in these interbedded units around Mount Gascoyne.

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics, BIDDENEW FORMATION	POb-
Rock type	metasedimentary siliciclastic: psammite and pelite; interlayered	
Lithname	psammitic and pelitic schist; interlayered	mhs
Rock code		**P_-POb-mhs**

Contact relationships

On GLENBURGH, the Biddenew Formation interbedded slate and metasandstone is in conformable contact with the stratigraphically overlying Spring Camp Formation quartzites (P_-POs-mtqs), but sit unconformably on gneissic granites of the Dalgaringa Supersuite. On the western edge of GLENBURGH and eastern edge of DAURIE CREEK, dolostones and sandstones of the Irregully Formation of the Bangemall Supergroup are in fault contact with the slates. On PINK HILLS around Mount Gascoyne the interbedded slate and metasandstone sit conformably upon coarse-grained, granule- and pebble-rich feldspathic metasandstone (P_-POb-mxq), and are conformably overlain by fine- to medium-grained feldspathic metasandstones (P_-POb-mtef). To the southeast of Mount Gascoyne the Mount James Subgroup is unconformably overlain by sandstones of the Yilgatherra Formation (P_-MEi-st).

Geochronology

P_-POb-mhs	*Maximum*	*Minimum*
Age (Ma)	1758	1677
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., 2009	Nelson, 2005

Interbedded slate and metasandstone of the Biddenew Formation have not been dated directly. However, because they are part of a conformable package of metasedimentary rocks, their depositional ages would be similar to those of other rock units in the same package in the immediate surrounding area. A detrital zircon study of quartzites from the Spring Camp Formation around Mount James yielded detrital zircons as young as 1795–1785 Ma. However, detrital zircons as young as c. 1760 Ma occur in the basal unit of the Biddenew Formation (Wingate et al., 2009). A minimum depositional age is provided only by indirect constraints. The laterally equivalent phyllite unit (P_-POb-mlpc) is unconformably overlain by the Mount Augustus Sandstone, from which detrital zircons indicate a maximum depositional age of 1679 ± 3 Ma (Wingate et al., 2007). However, other units of the Pooranoo Metamorphics to the north and south of the Minnie Creek batholith are intruded by granites of the Durlacher Supersuite, the oldest of which is dated at 1677 ± 5 Ma (Nelson, 2005). This result is the best constraint on the younger limit for deposition of the interbedded slate and metasandstone unit.

References

Nelson, DR 2005, 178027: biotite-muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183255: metasandstone, Mount Samuel; Geochronology Record 772: Geological Survey of Western Australia, 5p.

Wingate, MTD, Bodorkos, S and Sircombe, KN 2007, 148972: feldspathic sandstone, Ulna Well; Geochronology Record 689: Western Australia Geological Survey, 7p.

BIDDENEW FORMATION; subunit (P_-POb-mlpc)

Legend narrative

Phyllite and slate; locally chlorite rich with magnetite porphyroblasts

Rank	Member
Parent	BIDDENEW FORMATION (P_-POb-mtef)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-POs-mtqs (conformable); P_-_au-sc (unconformable)
Underlying units	P_-MO-gmp, P_-MO-gmeb, AP_-_ha-mgnw

Summary

Phyllite is observed predominantly as a series of outliers on granitic rocks of the Minnie Creek batholith. Phyllite comprises a greyish-green phyllite or, where the metamorphic grade is slightly higher such as locally around Mount Augustus and Mount James, a fine-grained chlorite–muscovite–quartz schist. Magnetite porphyroblasts 1–7 mm in diameter are present in places, where they are commonly concentrated in thin layers. Phyllite of the Biddenew Formation unconformably overlies two of the main granites of the Minnie Creek batholith and tonalitic schists of the Halfway Gneiss. The unit is unconformably overlain by basal conglomerate of the Mount Augustus Sandstone (P_-_au-sc).

Distribution

Phyllite forms a series of outliers on granitic rocks of the Minnie Creek batholith on the eastern edge of Mount Phillips and Mount Augustus and as a single outlier on tonalitic Halfway Gneiss on Yinnetharra. On Mount Phillips four outliers are exposed in an area about 4 km long and less than 0.5 km wide. On Mount Augustus, the largest exposure of the outliers is about 8 km^2 in area, but here they are unconformably overlain by sedimentary rocks of the Mount Augustus Sandstone so their subsurface extent may be much greater. On Yinnetharra a single, 1 km-long, poorly exposed outlier lies 4 km northwest of Mount James.

Lithology

Phyllite of the Biddenew Formation mainly comprises a greyish-green phyllite or, where the metamorphic grade is slightly higher such as locally around Mount Augustus and Mount James, a fine-grained chlorite–muscovite–quartz(–garnet) schist. Magnetite porphyroblasts 1–7 mm in diameter are present in places, where they are commonly concentrated in thin layers. At the northwestern end of Mount Augustus, phyllite is interbedded with metamorphosed quartz sandstone and local granule to pebble conglomerate. The base of the phyllite unit is typically marked by 10–15 m of metamorphosed quartz sandstone that is transitional upwards into 5–30 cm-thick medium-grained beds of metamorphosed lithic-sandstone and siltstone (phyllite) and then into homogeneous phyllite. Toward the top of the phyllite unit, increasing amounts of interbedded metamorphosed sandstone marks a gradational contact with overlying metamorphosed quartz sandstone and quartz–mica schist (P_-POs-mtqs). On Yinnetharra the single outcrop of sericite schist is extremely weathered, fine grained, and contains mm- to cm-scale compositional and grain-size layering.

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics, BIDDENEW FORMATION	POb-
Rock type	metasedimentary siliciclastic: pelite	ml
Lithname	phyllite	p
1st qualifier	–	
2nd qualifier	chlorite	c
Rock code		**P_-POb-mlpc**
Additional lithologies	metasandstone	

Contact relationships

Phyllite of the Biddenew Formation unconformably overlies two of the main granites of the Minnie Creek batholith, namely porphyritic biotite monzogranite (P_-MO-gmp) and equigranular biotite monzogranite (P_-MO-gmeb), and tonalitic schists of the Halfway Gneiss. Phyllite conformably overlies metamorphosed quartz sandstone and muscovite–quartz schist (P_-POs-mtqs) about 2 km northwest of Cattlecamp Well on southeastern Mount Phillips.

At site AMT902 (Zone 50, MGA 459970E 7300260N) the contact is gradational over several tens of metres, with pelite interbedded with fine- to medium-grained sandstone in increasing amounts. Phyllite of the Biddenew Formation is unconformably overlain by basal conglomerate of the Mount Augustus Sandstone (P_-_au-sc). On Yinnetharra the sericite schists are unconformable upon the mesocratic Halfway Gneiss.

Geochronology

P_-POb-mlpc	*Maximum*	*Minimum*
Age (Ma)	1758 ± 18	1677
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Inferred
References	Wingate et al., 2009	Nelson, 2005

A specimen of greyish–green phyllite from the Biddenew Formation immediately south of Mount Samuel on southwestern Mount Augustus was sampled for SHRIMP U–Pb zircon geochronology (Wingate et al., 2009). A zircon rim, with very high U (> 4000 ppm) and a low Th/U ratio, indicated a concordant ^{207}Pb*/^{206}Pb* date of c. 1620 Ma, interpreted as the age of low- to medium-grade metamorphism. This also provides a younger age limit for sediment deposition. The youngest detrital zircon in the sample has a ^{207}Pb*/^{206}Pb* date of 1758 ± 18 Ma, providing a maximum age for deposition.

Phyllite unconformably overlies equigranular biotite monzogranite (P_-MO-gmeb) dated at 1783 ± 5 Ma (Kirkland et al., 2009), which provides a slightly older constraint on the maximum age of deposition for the precursor to the phyllite. Phyllite is unconformably overlain by the Mount Augustus Sandstone, from which detrital zircons indicate a maximum depositional age of 1679 ± 3 Ma (Wingate et al., 2007). However, other units of the Pooranoo Metamorphics to the north and south of the Minnie Creek batholith are intruded by granites of the Durlacher Supersuite, the oldest of which is dated at 1677 ± 5 Ma (Nelson, 2005). This result provides the best younger limit for deposition of the precursor to the phyllite unit.

References

Nelson, DR 2005, 178027: biotite–muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Kirkland, CL, Wingate, MTD, Bodorkos, S, and Sheppard, S, 2009, 180938: monzogranite, Leake Spring; Geochronology Record 751: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183255: metasandstone, Mount Samuel; Geochronology Record 772: Geological Survey of Western Australia, 5p.

Wingate, MTD, Bodorkos, S and Sircombe, KN 2007, 148972: feldspathic sandstone, Ulna Well; Geochronology Record 689: Western Australia Geological Survey, 7p.

BIDDENEW FORMATION; subunit (P_-POb-mlsm)

Legend narrative

Biotite–quartz–muscovite schist and quartz–muscovite–biotite schist

Rank	Member
Parent	BIDDENEW FORMATION (P_-POb-mtef)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-POb-mqef (conformable), P_-PO-mwa (intrusive), P_-DUda-mgmu (intrusive), P_-DU-mgm (intrusive), P_-DU-mgms (intrusive), P_-TT-jmgmt-m (intrusive), P_-TT-gmlt (intrusive)
Underlying units	AP_-_ha-mgnw (unconformity and fault), P_-DU-mgn (fault), P_-MEi-kd (fault), P_-MEi-st (fault), P_-MEk-s (fault), P_-MO-mgsl (fault), P_-MO-gte (fault)

Summary

Biotite–quartz–muscovite schist of the Biddenew Formation forms a series of outliers on EUDAMULLAH, MOUNT PHILLIPS, and YINNETHARRA. The schists are pelitic to semi-pelitic in composition, and on EUDAMULLAH and MOUNT PHILLIPS commonly contain randomly oriented and distributed staurolite porphyroblasts. The schists also locally contain garnet that forms an integral part of the S_1 tectonic fabric. On YINNETHARRA, lower grade sericite–biotite–quartz schists are conformably overlain by quartzites of the Spring Camp Formation (P_-POs-mtqs).

Distribution

Biotite–quartz–muscovite schist of the Biddenew Formation forms as a series of outliers on EUDAMULLAH, MOUNT PHILLIPS, and YINNETHARRA. On the southern edge of EUDAMULLAH, biotite–quartz–muscovite schist forms two strips, each about 2 km long, within gneissic to schistose biotite monzogranite and syenogranite (P_-DU-mgn). On MOUNT PHILLIPS, the unit forms a 3 km long × 500 m wide strip adjacent to gneissic granites of the Durlacher Supersuite and intruded by granites of the Thirty Three Supersuite. On YINNETHARRA, a single 500 m long × 200 m wide unit lies at the western end of Mount James, at the stratigraphic base of the Mount James Subgroup (Biddenew Formation), and is in unconformable or tectonic contact with the underlying metatonalitic gneisses of the Halfway Gneiss (AP_-_ha-mgnw), and isconformably overlain by quartzites of the Spring Camp Formation (P_-POs-mtqs).

Lithology

Biotite–quartz–muscovite schist on southern EUDAMULLAH comprises rubble and subcrop of deeply weathered, fine- to medium-grained, biotite–quartz–muscovite schist and coarse-grained quartz–mica schist and granofels (metamorphosed, coarse to very coarse grained, quartz sandstones). On MOUNT PHILLIPS the pelitic to semi-pelitic schists form low rubbly outcrops, are fine to medium grained and invariably contain abundant, randomly oriented and distributed, mm-sized staurolite porphyroblasts. Garnet porphyroblasts are rare, but where present (e.g. Zone 50, MGA 398508E 398508N), form an integral part of the dominant S_1 tectonic fabric. In thin section, most schist units contain abundant <1 mm-sized tourmaline crystals with accessory titanite, ilmenite, and zircon. On YINNETHARRA, the single biotite–quartz–muscovite schist forms the stratigraphic base to the Biddenew Formation and grades upward into medium- to coarse-grained psammitic schists and quartz-pebble conglomerates (P_-POb-mqef). The schist units here are strongly sheared and contain an intense penetrative foliation that is overgrown by abundant, <1 mm-sized euhedral magnetite and tourmaline porphyroblasts.

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics, BIDDENEW FORMATION	POb-
Rock type	metasedimentary siliciclastic: pelite	ml
Lithname	pelitic schist	s
1st qualifier	–	
2nd qualifier	muscovite	m
Rock code		**P_-POb-mlsm**
Additional lithologies	psammitic schist	

Contact relationships

On the southern edge of EUDAMULLAH, biotite–quartz–muscovite schist is in faulted contact with surrounding gneissic to schistose, biotite monzogranite and syenogranite (P_-DU-mgn). On MOUNT PHILLIPS the biotite–quartz–muscovite schists are in contact with a number of differing lithologies. Along the southern edge of the Ti Tree Syncline the schists are in faulted contact with siltstones (P_-MEk-s), sandstones (P_-MEi-st), and dolostones (P_-MEi-kd) of the Bangemall Supergroup. They are intruded by Pooranoo amphibolite (P_-PO-mwa), variably deformed Durlacher Supersuite granites and gneisses (P_-DUda-mgmu, P_-DU-mgn, P_-DU-mgms, P_-TT-jmgmt-m), and granite of the Thirty Three Supersuite (P_-TT-gmlt). They are also in faulted contact with equigranular tonalite (P_-MO-gte) and leucocratic schistose granite (P_-MO-mgsl) of the Moorarie Supersuite. On YINNETHARRA, the schists are in unconformable contact with underlying tonalitic gneisses of the Halfway gneiss (AP_-_ha-mgnw), although this contact has been partially modified during subsequent shearing and folding. The schists are in conformable contact with the stratigraphically overlying quartzites and quartz pebble conglomerates that comprise the bulk of the Biddenew Formation. The transition is gradual over a few tens of metres, marked by the loss of micaceous material and subsequent increase in grain size, with quartz-vein pebbles and/or discontinuous quartz gravel layers developed locally.

Geochronology

P_-POb-mlsm	*Maximum*	*Minimum*
Age (Ma)	1758	1677
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., 2009	Nelson, 2005

The pelitic schist has not been sampled for geochronology. However, on YINNETHARRA, sericite schists are conformably overlain by quartzites of the Spring Camp formation, from which two samples were selected for detrital zircon dating. The youngest detrital zircons in these two samples were dated at c. 1785 and c. 1795 Ma, providing a maximum age of deposition for the underlying Biddenew Formation schists (Wingate et al., 2010a,b). However, detrital zircons as young as c. 1760 Ma have been dated from the basal unit of the Biddenew Formation (Wingate et al., 2009). A minimum age of deposition is provided by numerous intrusions of granitic rocks of the Durlacher Supersuite, the oldest of which is dated at 1677 ± 5 Ma (Nelson, 2005).

References

Nelson, DR 2005, 178027: biotite-muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183255: metasandstone, Mount Samuel; Geochronology Record 772: Geological Survey of Western Australia, 5p.

Wingate, MTD, Kirkland, CL, Johnson, SP and Sheppard S 2010a, 185953: quartzite, Mount James; Geochronology Record 906: Geological Survey of Western Australia, 5p.

Wingate, MTD, Kirkland, CL, Johnson, SP and Sheppard S 2010b, 185954: quartzite, Mount James; Geochronology Record 907: Geological Survey of Western Australia, 5p.

BIDDENEW FORMATION; subunit (P_-POb-mqef)

Legend narrative

Coarse-grained, granule- and pebble-rich feldspathic metasandstone; minor quartz–muscovite schist

Rank	Member
Parent	BIDDENEW FORMATION (P_-POb-mtef)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-POb-mtef, P_-POb-mhs, P_-POs-mtqs (conformable); P_-POs-mtqs, P_-MEy-st (unconformable and fault); P_-MEk-sl, P_-MEi-kd (fault)
Underlying units	P_-POb-mxq (conformable); AP_-_ha-mgnw; P_-MGm-mtsf, P_-MOdu-ggp, P_-MO-gmp, P_-MO-gmeb, P_-MOsc-gm, P_-MO-mgml, P_-LS-mlsm (unconformable and fault); P_-PO-mkq (fault)

Summary

Coarse-grained, granule and pebbly feldspathic metasandstone is part of the Biddenew Formation of the Mount James Subgroup. The unit lies either at the base or just above the base of the subgroup and is confined to elongate semi-continuous, gently to steeply dipping, horizons that crop out in the Mutherbukin and Mooloo Zones in the southern Gascoyne Province. The underlying metaconglomerate, where present, grades into the pebbly metasandstone, as marked by the loss of cobble- to boulder-sized clasts. The pebbly metasandstone contains up to 20–30% sub-rounded to rounded pebble-sized clasts that sit within a poorly sorted, immature feldspar- and quartz-rich matrix. The unit is everywhere matrix supported irrespective of clast content. Over 90% of the clasts are comprised of quartz vein material with minor amounts of recrystallized quartzite, very fine grained black chert, and tourmaline nodules. The matrix is poorly sorted, commonly containing locally 50 cm – 2 m-thick coarser-grained horizons that contain abundant (30-40%) angular quartz clasts up to 2–3 mm in diameter. These ‘gritty’ horizons have scoured bases and typically appear to define paleochannels. Although not dated directly this unit has similar age constraints to the other members of the Biddenew Formation and Mount James Subgroup.

Distribution

Coarse-grained, granule- and pebble-rich feldspathic metasandstone is part of the Biddenew Formation of the Mount James Subgroup. The unit lies either at the base or just above the base of the subgroup and is confined to elongate semi-continuous gently to steeply dipping horizons that crop out in the Mutherbukin and Mooloo Zones in the southern Gascoyne Province. In detail pebbly feldspathic metasandstone forms a single outcrop some 10 km long on the northern side of the Ti Tree Syncline on YINNETHARRA and a series of 2–13 km long outcrops that run from Mount James on southern YINNETHARRA eastward and southward toward and around Mount Gascoyne on southern PINK HILLS. Two small elongate fault bounded outcrops are found at Mount Steere on southern YINNETHARRA. A single 900 m long outlier occurs on eastern LOCKIER close to Paddy Well.

Lithology

Coarse-grained, granule- and pebble-rich feldspathic metasandstone lies stratigraphically above the cobble and boulder metaconglomerate (P_-POb-mxq). The metaconglomerate grades into the pebbly metasandstone with the progressive loss of cobble- to boulder-sized clasts. The pebbly metasandstone commonly contains up to 20–30% sub-rounded to rounded pebble-sized clasts that sit within a poorly sorted, immature feldspar- and quartz-rich matrix. The unit is everywhere matrix supported irrespective of clast content. Although the pebbles are typically randomly distributed, they frequently form discontinuous, 1–2 m-thick matrix supported pebble-rich bands containing up to 50% clasts. Similar to the underlying metaconglomerate, 90% of the clasts comprise quartz-vein material with minor amounts of recrystallized quartzite, very fine grained black chert, and tourmaline nodules. At some localities (e.g. SPJPHK000842; Zone 50, MGA 458848E 7248921N) there is evidence to suggest that some of the more angular quartz-vein pebbles represent folded and dismembered, originally planar, quartz veins that intruded the feldspathic metasandstone. However, these make up a relatively minor proportion of the ‘clasts’ and true quartz-vein clasts can be found at the same locality. The matrix is poorly sorted, commonly containing locally 50 cm – 2 m-thick coarser-grained horizons that contain abundant (30–40%) angular quartz clasts up to 2–3 mm diameter. These ‘gritty’ horizons have scoured bases and typically appear to define paleochannels. Apart from these gritty bands, bedding is typically poorly defined, although 40–50 cm scale (and less commonly 1–2 m scale) trough cross-bedding is locally abundant; however, due to the intense folding and localized shearing paleoflow is difficult to define. The matrix contains over 60% quartz, with feldspar comprising up to 35%, and sericite 5–10%.

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics, BIDDENEW FORMATION	POb-
Rock type	metasedimentary siliciclastic: semipsephite	mq
Lithname	semipsephitic granofels/hornfels	e
1st qualifier	—	
2nd qualifier	felsic/feldspathic; K-metasomatized	f
Rock code		**P_-POb-mqef**

Contact relationships

On the northern side of the Ti Tree Syncline on northern YINNETHARRA, pebbly feldspathic metasandstone sits unconformably on basal metaconglomerates of the Biddenew Formation (P_-POb-mxq) and metasedimentary rocks of the Leake Spring Metamorphics (P_-LS-mlsm). The upper contact at the extreme northwestern part of the outcrop is conformably overlain by quartzite of the Spring

Camp Formation (P_-POs-mtqs), and is everywhere else in full contact with Edmund Group sedimentary rocks (P_-MEk-sl, P_-MEi-kd). Farther south, around Mount James and Mount Steere on southern Yinnetharra and Mount Gascoyne on Pink Hills, the pebbly feldspathic metasandstone is conformable with the cobble to boulder conglomerate wherever it is present, otherwise it sits unconformably on basement rocks including mesocratic gneisses of the Halfway Gneiss (AP_-_ha-mgnw), metasedimentary rocks of the Moogie Metamorphics (P_-MGm-mtsf), and various granites of the Moorarie Supersuite (P_-MOdu-ggp, P_-MO-gmp, P_-MO-gmeb, P_-MOsc-gm, P_-MO-mgml). However, no material from these underlying units is ever found as clasts within the metasandstone. The unit is conformably overlain by feldspathic metasandstone (P_-POb-mtef) that forms the thickest part of the Biddenew Formation, although around Mount James where this unit is not present the pebbly metasandstone is conformably overlain by quartzites of the Spring Camp Formation (P_-POs-mtqs). On the east and western flanks of Mount Gascoyne the pebbly metasandstone is conformably overlain by interbedded siltstones and metasandstones (P_-POb-mhs) rather than passing directly up into the feldspathic metasandstone (P_-POb-mtef) as is evident elsewhere. On the southern part of Pink Hills the Biddenew Formation is dissected and unconformably overlain by sedimentary rocks of the Edmund Group (P_-MEy-st). On Lockier the single outlier sits unconformably upon granitic gneisses of the Halfway Gneiss (AP_-_ha-mgn).

Geochronology

P_-POb-mqef	*Maximum*	*Minimum*
Age (Ma)	1758	1677
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al.,2009	Nelson, 2005

Coarse-grained, granule- and pebble-rich feldspathic metasandstones of the Biddenew Formation have not been dated directly. Because this unit is interbedded with other dated units in the Mount James Subgroup it is interpreted to have the same age relationship as the other Mount James Subgroup members. Detrital zircons as young as c. 1760 Ma have been dated from the basal unit of the Biddenew Formation (Wingate et al., 2009). A minimum age of deposition is provided by the numerous intrusions of granitic rocks from the Durlacher Supersuite the oldest of which is dated at 1677 ± 5 Ma (Nelson, 2005).

References

Nelson, DR 2005, 178027: biotite–muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183255: metasandstone, Mount Samuel; Geochronology Record 772: Geological Survey of Western Australia, 5p.

BIDDENEW FORMATION; subunit (P_-POb-mxq)

Legend narrative

Cobble and boulder metaconglomerate; strongly foliated; locally includes quartzite and muscovite–quartz(–biotite) schist

Rank	Member
Parent	BIDDENEW FORMATION (P_-POb-mtef)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-POb-mqef, P_-POb-mtef (conformable); P_-POs-mtqs, P_-MEi-kd (unconformity); P_-PO-mkq, P_-MEk-sl, P_-MEk-st (fault)
Underlying units	P_-MO-gmeb, P_-MO-mgsl, P_-LS-mlst, P_-LS-mlsm (unconformity); AP_-_ha-mgnw, AP_-_ha-mgnl, P_-MOsc-gm (unconformity and fault)

Summary

Cobble and boulder metaconglomerate is present as many small, disparate outcrops in the Mutherbukin and Mooloo Zones extending from the southern margin of Mount Phillips into northern Yinnetharra, across southern Yinnetharra and Pink Hills, and as an isolated outcrop at Mount Dalgety on Daurie Creek. Cobble and boulder metaconglomerate is the lowermost unit of the Biddenew Formation of the Mount James Subgroup. The base of the metaconglomerate unit is marked by a 5 m-thick, medium-grained, well-sorted quartz metasandstone that grades rapidly into a matrix-supported, pebbly quartz-sandstone and into the massively bedded metaconglomerate. The unit is a matrix supported metaconglomerate with 50–60% rounded to subrounded clasts predominantly of cobble-size but frequently contains isolated or small areas rich in boulder-sized material. Over 90% of the clasts are comprised from medium- to coarse-grained quartz-vein material with minor proportions of foliated quartzite, quartz–tourmaline, and black chert clasts. The matrix to the metaconglomerate is a medium- to coarse-grained, medium to poorly sorted, immature feldspathic sandstone that is generally massive in character but contains locally discrete, 20–30 cm-thick discontinuous layers of metasandstone that show cm-scale cross-bedding. At many localities the metaconglomerate shows evidence of being strongly deformed under large constrictional-type stress components. Commonly the quartz-vein clasts are stretched into cigar-shaped clasts with a preferred, steeply plunging alignment of the long axes and can have aspect ratios up to 100:1:1. There are currently no direct age constraints on the depositional age of this unit but age data from the overlying members of the Biddenew Formation and the Spring Camp Formation quartzites suggest deposition sometime between c. 1760 Ma and c. 1680 Ma.

Distribution

Cobble and boulder metaconglomerate is present as many small, disparate outcrops in the Mutherbukin and Mooloo Zones extending from the southern margin of Mount Phillips to the southeast along the Ti Tree Syncline into northern Yinnetharra. Further outcrops are found around Mount James, Mount Gascoyne, and Mount Steere on southern Yinnetharra and Pink Hills, and also in the core of a regional syncline at Mount Dalgety that straddles the Daurie Creek – Glenburgh boundary. The unit forms the stratigraphic base of the Biddenew Formation of the Mount James Subgroup, but also as sub map-scale lenses and layers within other members of the Biddenew Formation. Apart from the two larger outcrops on southern Mount Phillips and eastern Daurie Creek which have extents of 11 km^2 and 5 km^2 respectively, most outcrops of metaconglomerate are less than 0.5 km^2 reflecting their lenticular nature.

Lithology

Cobble and boulder metaconglomerate is the lowermost unit of the Biddenew Formation of the Mount James Subgroup. However, the metaconglomerate is only locally present forming lenticular outcrops that probably reflect their deposition in isolated channels. At many outcrops such as SPJPKH000846 (Zone 50, MGA 458262E 7249110N) the base of the metaconglomerate unit is marked by a 5 m-thick, medium-grained, well-sorted quartz metasandstone. This unit grades rapidly (within 1m) up into a matrix-supported pebbly quartz sandstone with 30–40% rounded quartz-pebbles and then into the massively bedded, matrix supported, cobble to boulder metaconglomerate. The metaconglomerate is remarkably uniform in composition and structure across the region, a distance of 150 km. The unit is a matrix supported, cobble to boulder conglomerate that locally contains pebble-rich zones and thin (10–30 cm) discontinuous metasandstone layers that commonly show cross-bedding. The pebbles, cobbles, and boulders are rounded to well rounded and range in sphericity from flattened to almost perfect spheres. Quite remarkably the cobbles and boulders throughout the entire formation are comprised predominantly (over 95%) of medium- to coarse-grained vein-quartz. There are only a few localities where clasts of other compositions are present. For example at SPJYIN000843 on the western margin of Mount Gascoyne on Pink Hills (Zone 50, MGA 458926E 7248617N) a 10–15 m metaconglomerate exposure contains 85–90% well-rounded cobbles and boulders of quartz-vein material. The remaining 10–15% comprises pebble- to cobble-sized subrounded foliated quartzite and foliated quartz–tourmaline clasts. On the northern side of the Ti Tree Syncline on Yinnetharra at site PGBYIN000211 (Zone 50, MGA 436752E 7287133N), similar subrounded pebble- to cobble-sized foliated quartzite and quartz–tourmaline clasts form a minor component alongside the predominant quartz-vein clasts. At PGBYIN000180 (Zone 50, MGA 430764E 7287954N) on the southern side of the Ti Tree Syncline, the conglomerate also contains small, rounded pebbles of black chert. These are more common in the overlying pebble metasandstone (P_-POb-mqef). The matrix to the metaconglomerate is a medium- to coarse-grained, medium to poorly sorted, immature feldspathic sandstone that is typically massive in character. However, in areas where there are fewer clasts, or locally as discrete, 20–30 cm-thick discontinuous layers, the metasandstone locally preserves cm-scale cross-bedding defined by sub-mm layers of heavy-mineral rich material.

At many localities, possibly in decimetre- to kilometre-scale fold closures, the metaconglomerate show evidence of being strongly deformed with a large stretching component. Commonly the quartz-vein clasts are stretched into cigar-shaped clasts with a preferred, steeply plunging alignment of the long axes (presumably parallel to the fold hinges). These clasts generally have aspect ratios of 10:1:1 but in some cases can have ratios up to 100:1:1.

In many places it appears as if phyllite (P_-POb-mlpc) and biotite–quartz–muscovite schist (P_-POb-mlsm) are lateral facies equivalents of the metaconglomerate as they commonly occur in a similar straitgraphic position.

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics, BIDDENEW FORMATION	POb-
Rock type	metasedimentary siliciclastic: psephite	mx
Lithname	silicified metaconglomerate	q
Rock code		**P_-POb-mxq**
Additional lithologies	Quartzite, psammitic schist, metasandstone	

Contact relationships

The metaconglomerate is in both unconformable and faulted contact with numerous lithologies of the underlying Glenburgh Terrane and Moorarie Supersuite granites and conformably overlain by other members of the Biddenew Formation. In detail, on southern MOUNT PHILLIPS and northern YINNETHARRA, outcrops of metaconglomerate on both sides of the Ti Tree Shear Zone sit unconformably upon pelitic and semi-pelitic schists of the Leake Spring Formation (P_-LS-mlst and P_-LS-mlsm) and schistose leucocratic metamonzogranite of the Moorarie Supersuite (P_-MO-mgsl). The unit is unconformably overlain by feldspathic and pebble metasandstones (P_-POb-mqef and P_-POb-mtef) of the Biddenew Formation and carbonate rocks of the Irregully Formation of the Edmund Group (P_-MEi-kd), and in faulted contact with various siltstones and sandstones of the Kiangi Creek Formation of the Edmund Group (P_-MEk-sl and P_-MEk-st). Farther south around Mount James and Mount Gascoyne, on southern YINNETHARRA and PINK HILLS, the metaconglomerate sits unconformably and in places in tectonic contact with basement gneisses of the Halfway Gneiss (AP_-_ha-mgnw and AP_-_ha-mgnl) as well as intrusions of the Scrubber Granite (P_-MOsc-gm) that intrude this basement. The metaconglomerates are conformably overlain by pebble metasandstone (P_-POb-mqef) of the Biddenew Formation, unconformably by quartzites of the Spring Camp Formation (P_-POs-mtqs) and in faulted contact with metacarbonates of unassigned Pooranoo Metamorphics (P_-PO-mkq). At Mount Steere on southern YINNETHARRA the metaconglomerates are complexly folded but appear to rest unconformably on metamonzogranites of the Moorarie Supersuite (P_-MO-gmeb) and are conformably overlain by pebble metasandstone (P_-POb-mqef) and (possibly a paraconformity) feldspathic metasandstone (P_-POb-mtef) of the Biddenew Formation and recrystallized quartzites of the Spring Camp Formation (P_-POs-mtqs). At Mount Dalgety, on the eastern edge of DAURIE CREEK, the metaconglomerates rest unconformably on pelitic and semipelitic schists of the Moogie Metamorphics (P_-MGm-mls) and are overlain conformably (although this may also be a paraconformity) by quartzites of the Spring Camp Formation (P_-POs-mtqs).

Geochronology

P_-POb-mxq	*Maximum*	*Minimum*
Age (Ma)	1758	1677
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al.,2009	Nelson, 2005

No samples of metaconglomerate have been dated directly. Because this unit is interbedded with other dated units in the Mount James Subgroup it is interpreted to have the same age relationships as the other Mount James Subgroup members. Detrital zircons as young as c. 1760 Ma have been dated from the basal unit of the Biddenew Formation (Wingate et al., 2009). A minimum age of deposition is provided by the numerous intrusions of granitic rocks from the Durlacher Supersuite, the oldest of which is dated at 1677 ± 5 Ma (Nelson, 2005).

References

Nelson, DR 2005, 178027: biotite-muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183255: metasandstone, Mount Samuel; Geochronology Record 772: Geological Survey of Western Australia, 5p.

SPRING CAMP FORMATION
(P_-POs-mtqs)

Legend narrative

Quartzite and quartz–muscovite schist; foliated; quartz metasandstone, feldspathic metasandstone, and quartz-lithic metasandstone; locally ripple marked and cross-bedded

Rank	Formation
Parent	Mount James Subgroup (P_-POJ-md)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MEi-kd (fault); P_-MEk-sl (fault); P_-DUda-mgmu (intrusive); P_-_au-sc (unconformable); P_-_au-sp (unconformable); P_-MEy-st (unconformable); P_-PO-mkq (fault); P_-MEln-ss (fault); P_-MEv-kd (fault); P_-DUdn-gmp (fault)
Underlying units	P_-MO-gmeb (unconformable); P_-POb-mtef (conformable); P_-POb-mhs (conformable); P_-POb-mqef (conformable and fault); AP_-_ha-mgnw (unconformable and faulted); AP_-_ha-mgnl (unconformable and fault); P_-MO-gge (unconformable); P_-MO-mgsl (unconformable); P_-MO-gmeb (unconformable); P_-LS-mlsm (unconformable); P_-LS-mlst (unconformable); P_-MO-gmp (unconformable); AP_-mgnl-YNAY (fault); P_-_nr-od (fault); P_-MEk-s (fault); P_-MEd-c (fault); P_-DA-xmgt-mgm (unconformable); P_-DA-xmgt-mgg (unconformable); P_-MOsc-gm (unconformable); P_-MOdu-ggp (unconformable); P_-MGm-mls (unconformable)
Maximum thickness	100+ m

Summary

Quartzite, quartz–muscovite schist, and metasandstone are widely distributed throughout the Southern Gascoyne Province cropping out intermittently between YALBRA, ERRABIDDY, and MARQUIS in the south and MOUNT PHILLIPS – EUDAMULLAH in the north. The rocks range from quartz–mica schists in higher-strain zones, to thin- to very thick-bedded, planar laminated or cross-stratified quartz sandstone or recrystallized quartzite. This unit is predominantly composed of well-sorted quartz–feldspar metasandstones and quartzites that are well bedded (10–80 cm) and locally show abundant ripples, trough cross-stratification, and less typical current lineations (especially around Mount James and the outlier some 4 km to the west). These sedimentary structures indicate that they were deposited in a shallow marine to inter-tidal environment, although their subsequent modification during younger deformation events precludes any determination of paleoflow. Because these quartzites form the main ridges in the region, the upper surface of the Spring Camp Formation is always erosional and so the true thickness is not known. A minimum estimate from the least deformed and folded quartzites around Mount Gascoyne is about 100 m. U–Pb SHRIMP dating of detrital zircon from a number of samples indicate ages for the youngest detrital components of 1800–1785 Ma and similar major age peaks at 2450 Ma and 1810–1800 Ma. This would suggest that the samples had a similar source region and that they were deposited sometime between c. 1780 and c. 1680 Ma.

Distribution

Quartzite, quartz–muscovite schist, and metasandstone are widely distributed throughout the southern Gascoyne Province. The units form the tops of the hills on the southern part of MOUNT PHILLIPS, the southwestern corner of MOUNT AUGUSTUS, the northeast and central parts of YINNETHARRA, the southern parts of PINK HILLS, the central and northern parts of GLENBURGH, DAURIE CREEK, LANDOR, ERRABIDDY, MARQUIS, and YALBRA and as small outliers straddling the boundary between EUDAMULLAH and MOUNT PHILLIPS (around 5 km north-northwest of Onslow Well). Three outcrops of P_-POs-mtqs lie on both sides of the Ti-Tree Syncline. On the southern side, a ~150 m wide by 11 km long outcrop can be traced along the southwestern edge of MOUNT PHILLIPS and as a 9 km-long by 1 km-wide horizon on the northeastern part of YINNETHARRA. On the northern side of the Ti-Tree syncline a single outcrop 7 km long by 100–500 m thick straddles the boundary between MOUNT PHILLIPS and YINNETHARRA. On southeastern MOUNT PHILLIPS and adjacent southwestern MOUNT AUGUSTUS it forms two small outliers, each less than 1 km^2, on granites of the Minnie Creek batholith, in addition to a wedge up to 500 m thick between granite of the Minnie Creek batholith and the overlying Mount Augustus Sandstone south of Mount Samuel. On central-eastern YINNETHARRA and central to southwestern PINK HILLS, the quartzites and metasandstones form a semi-continuous train that has been openly folded on a 1–10 km scale and dissected by numerous steep faults. Importantly, this unit forms the majority of outcrop on and around Mount James and Mount Gascoyne. Three, much smaller outliers, ranging in size from 3 km by 3 km to 2 km by 500 m, outcrop on the southern edge of YINNETHARRA around Mount Steere where they are intensely isoclinally folded and contain a penetrative foliation. On GLENBURGH, LANDOR, and DAURIE CREEK, quartzite, quartz–muscovite schist and metasandstone are preserved in the limbs of an upright, tight to isoclinal fold that transects most of the GLENBURGH sheet, with best exposure around Mount Puckford, Fitzpatrick Well, and Sonny Well. The outcrop at Sonny Well straddles the boundary with DAURIE CREEK and units observed at Mount Puckford continue along strike onto LANDOR. Two significant outcrops of metasandstone and metaconglomerate (P_-POb-mxq) form much of the outcrop exposed on Mount Dalgety on DAURIE CREEK. On MARQUIS and ERRABIDDY, the quartzite and metasandstone lie within the Chalba Shear Zone as a series of 5–10 km long, 1–5 km wide, lenticular, fault bounded slices that make up a total strike length of 60 km.

Derivation of name

Subdivision of the Mount James Subgroup into the Biddenew and Spring Camp formations was conducted during the second edition mapping of the type area on southern Pink Hills and Yinnetharra in 2007–08 (Sheppard et al., 2008; Johnson et al., 2010). The Spring Camp Formation was named after Spring Camp Creek that flows northeastward from the western margin of Mount Gascoyne.

Lithology

Quartzite and quartz–muscovite schist, where it rests on the Minnie Creek batholith, is less deformed and metamorphosed at lower grade than in the Nardoo Hills area on southwestern Mount Phillips. The rocks range from quartz–mica schists in higher strain zones, to thin- to very thick-bedded, planar laminated or cross-stratified quartz metasandstone in lower-strain zones. South-southeast of Mount Samuel, the rocks are massive and locally graded from very coarse sandstone bases. Where the metasandstones are interbedded with metasiltstone or phyllite, they are thin- to thick-bedded (5–80 cm), fine- to coarse-grained, with a parallel planar to faintly undulatory lamination. The outlier north-northwest of Onslow Well comprises metamorphosed, well sorted, quartz–feldspar metasandstone and granule metasandstone with interbedded phyllite, as well as some beds (up to 80 cm thick) of metamorphosed quartz-pebble conglomerate and metamorphosed pebbly sandstone. Clasts consist of quartz, as well as round to oval K-feldspar 2–10 mm in diameter; similar to K-feldspar in underlying granites.

On Yinnetharra, Glenburgh, Landor, Daurie Creek, and Pink Hills the units feature variable strain; from weakly cleaved through to strongly foliated. They comprise predominantly well-sorted quartz–feldspar metasandstones and quartzites that are well bedded (10–80 cm) and locally show abundant ripples, trough cross-stratification, and less typical current lineations (especially around Mount James and the outlier some 4 km to the west). However, in these areas, these structures are commonly oversteepened and have invariably been rotated into parallelism with the regional Mesoproterozoic-aged stretching lineation precluding any determination of the paleoflow direction. These sedimentary structures indicate that the sediments were deposited in a shallow marine to inter-tidal environment. Commonly the units contains discontinuous layers and lenses (up to 20–30 cmthick and 50 cm – 30 m length) of pebble and gravel metasandstone or quartz-pebble metaconglomerate, all of which are poorly sorted, matrix supported, and feldspar-rich. The quartzite also commonly contains isolated sub-rounded to rounded clasts, 5–30 mm in diameter, of quartz-vein material and also rare foliated quartzite and recrystallized tourmaline. Around the base of Mount James and the outlier some 4 km to the west, the quartzites and metamorphosed quartz-sandstones contain abundant 0.5 – 10 mm thick, discontinuous, tourmaline-rich, heavy mineral bands that define the bedding or cross-bed foresets.

On Errabiddy and Marquis the unit is comprised predominantly of quartzite that locally contains fuchsite lenses and quartz- metasandstone that is commonly interbedded with metasiltstone. The metamorphosed quartz- metasandstone locally contains abundant ripple marks and cross-beds.

Because these quartzites form the main ridges in the region, the upper surface of the Spring Camp Formation is always erosional and so the true thickness is not known. A minimum estimate from the least deformed and folded quartzites around Mount Gascoyne is about100 m.

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics, SPRING CAMP FORMATION	POs-
Rock type	metasedimentary siliciclastic: psammite	mt
Lithname	quartzite	q
1st qualifier	–	
2nd qualifier	schistose	s
Rock code		**P_-POs-mtqs**
Additional lithologies	metasandstone, phyllite, psammitic schist	

Contact relationships

On Mount Phillips, Yinnetharra, Mount Augustus, and Pink Hills, Quartzite, quartz–muscovite schist, and metasandstone of the Spring Camp Formation (P_-POs-mtqs) is observed to lie conformably on units of the Biddenew Formation (P_-POb-mtef, P_-POb-mqef, P_-POb-mhs). Additionally the metasandstones lie unconformably on a variety of metamorphosed Archean to Paleoproterozoic gneisses (AP_-_ha-mgnl, AP_-_ha-mgnw and P_-MO-mgsl) and granites of the Moorarie Supersuite (P_-MO-gmeb, P_-MO-gge or P_-MO-gmp), or deformed and metamorphosed Leake Spring Metamorphics (P_-LS-mlst and P_-LS-mlsm). In some instances the unconformable contact with the underlying gneisses has been sheared and deformed, for example between Halfway Gneiss (AP_-_ha-mgnw) along the southern margin of Mount James on Yinnetharra. On Pink Hills these units are in unconformable contact with the overlying Edmund Group of the Bangemall Supergroup (P_-MEy-st) but elsewhere are in fault contact with Edmund Group sedimentary rocks (P_-MEv-kd, P_-MEk-sl, P_-MEi-kd), or are intruded by younger Durlacher Supersuite granites (P_-DUda-mgmu). On Mount Augustus, the single outlier lies unconformably on older Moorarie Supersuite granite (P_-MO-gmeb) and the wedge is unconformable on Morrissey Metamorphic schists (P_-LS-mlpc) and unconformably overlain by the Mount Augustus Sandstone (P_-_au-sc and P_-_au-sp). On Errabiddy and Marquis, quartzite, quartz–muscovite schist, and metasandstone (P_-POs-mtqs) are everywhere in faulted contact with older and younger granites, gneisses, and metasedimentary units (AP_-mgnl-YNAY, P_-MO-gmeb, P_-DUdn-gmp, P_-MEk-sl, P_-MEv-kd, P_-MEln-ss, P_-_nr-od, P_-MEk-s, P_-MEd-c).

Geochronology

P_-POs-mtqs	*Maximum*	*Minimum*
Age (Ma)	1782 ± 5	1677
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Inferred
References	Kirkland et al., 2009	Nelson, 2005

Five samples of metamorphosed quartz-metasandstone – quartzite (P_-POs-mtqs), considered to be representative of the Spring Camp Formation, were selected from various parts of the southern Gascoyne Province for SHRIMP U–Pb zircon geochronology. The most southerly sample, a coarse-grained, cross-bedded metasandstone (Nelson, 2001a), was collected about 3.5 km west-southwest of Bungarra Bore, within the Errabiddy Shear Zone on Yalbra. Most zircons yielded an age of 2616 ± 6 Ma (Nelson, 2001a) providing a maximum age of deposition. The remaining detrital zircons provided a spectrum of dates between c. 2750 and c. 3325 Ma. The Archean detrital zircons in this sample are consistent with its local provenance from the nearby Yilgarn Craton.

A second sample is a white, flaggy quartzite collected about 3.5 km southeast of Fitzpatrick Well on Glenburgh (Nelson, 2001b), about 50–70 km north of Bungarra Bore. The sample contains detrital zircons as young as 1801 ± 13 Ma, providing a maximum age of deposition for this quartzite.

Two samples were collected from the summit of a small hill 4.5 km west of Mount James on Yinnetharra, the type section for the Mount James Subgroup. These sample sites are 45 km north of Fitzpatrick Well. Both samples yielded numerous detrital zircons, and the youngest zircon in both samples is dated at 1785 ± 7 Ma (Wingate et al., 2010a,b). The last sample was collected 0.6 km southwest of Nardoo Well on Mount Phillips (Wingate et al., 2009a), about 60 km northwest of Mount James. The sample is a medium-grained, recrystallized foliated quartzite which yielded numerous detrital zircons with ages between 2692 and 1787 Ma. The youngest concordant detrital zircon has an age of 1787 ± 12 Ma, interpreted as a maximum age of deposition.

Additional constraints on the maximum and minimum ages of deposition of the Spring Camp Formation are provided by the granites and gneisses on which the unit unconformably lies, and that intrude it. On Mount Augustus, Mount Phillips, and Yinnetharra, P_-POs-mtqs rests unconformably on Moorarie Supersuite granites, the youngest (P_-MO-gmeb) of which has been dated at 1782 ± 5 Ma (Kirkland et al., 2009). This result is younger than detrital zircons in the formation and provides an older limit for its deposition. On Mount Phillips, P_-POs-mtqs is intruded by the Davey Well Granite (P_-DUda-mgmu) of the Durlacher Supersuite, a sample of which on Eudamullah has a SHRIMP U–Pb zircon age of 1667 ± 4 Ma (Wingate et al., 2009b), providing a minimum age of deposition for the sedimentary package. However, the oldest granite to intrude the Pooranoo Metamorphics is dated at c. 1680 Ma (Nelson, 2005).

Although the five samples were collected over a large area (and are separated by up to 200 km), all suggest a very local source of sediment, yield similar ages of 1800–1785 Ma for the youngest detrital components, and indicate similar major age components, at c. 2450 and 1810–1805 Ma. These observations suggest that they belong to the same depositional package.

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Pooranoo Metamorphics; subunit (P_-PO-mli)

Legend narrative

Migmatitic pelitic gneiss (diatexite and metatexite migmatite)

Rank	Formation
Parent	Pooranoo Metamorphics (P_-PO-md)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-ggvs (gradational); P_-DU-gmlt, P_-DU-gmv, P_-DU-gmvt, P_-DUdi-grpv, P_-DUpi-gmp (intrusive); P_-MEy-s (unconformable)
Underlying units	P_-MOgo-mgm

Summary

Migmatitic pelitic gneiss is the higher grade equivalent of pelitic gneiss and granofels (P_-PO-mln); the two are distinguished by the paucity of partial melting in the latter unit.

Distribution

Migmatitic pelitic gneiss of the Pooranoo Metamorphics outcrops over a wide area on MANGAROON, mainly south of the Mangaroon Syncline, but extends to the southeast onto southwestern EDMUND, northeastern EUDAMULLAH, and northwestern MOUNT PHILLIPS. The lower grade equivalent of the migmatitic pelitic gneiss, pelitic gneiss, and granofels (P_-PO-mln), which is widespread north of the Mangaroon Syncline. The distribution of the migmatitic pelitic gneiss and pelitic gneiss and granofels may reflect differential uplift across the Mangaroon Syncline during the 1030–955 Ma Edmundian Orogeny.

Lithology

Migmatitic pelitic gneiss of the Pooranoo Metamorphics comprises diatexite and metatexite migmatite, with variable amounts of schlieric biotite–muscovite granodiorite (P_-DU-ggvs). Most of the migmatites on northeastern EUDAMULLAH and adjacent northwestern MOUNT PHILLIPS consist of diatexites (Mehnert, 1968; Brown 1973), in which pre-migmatitic structures (e.g. bedding) are not preserved and the solid matrix loses cohesion and moves as a magma. The rock commonly contains abundant coarse-grained feldspar phenocrysts and inclusions of pelitic and psammitic schist, as well as larger blocks of psammitic schist, and granitic and amphibolite gneiss with coherent fabrics, such as a folded foliation. The diatexites locally have a nebulous layering. The diatexites commonly grade into schlieric biotite–muscovite granodiorite at a scale from a metre or less up to hundreds of metres. Metatexites, which preserve pre-migmatitic structures, are much less abundant. They are commonly banded owing to the presence of parallel, thin quartz–feldspar rich leucosomes.

The migmatites around the Star of Mangaroon mine are associated with pelitic gneisses consisting of cordierite, biotite, quartz, microcline, sillimanite, and minor muscovite, or quartz, cordierite, biotite, microcline, sillimanite, and minor plagioclase. The major difference with non-migmatitic pelitic gneisses north of the Mangaroon Syncline is the paucity or absence of plagioclase or muscovite, and the appearance of microcline in gneisses associated with the migmatites.

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics	PO-
Rock type	metasedimentary siliciclastic: pelite	ml
Lithname	pelitic migmatite	i
Rock code		**P_-PO-mli**

Contact relationships

Migmatitic pelitic gneiss is in faulted contact with the 1776 ± 8 Ma Gooche Gneiss; protoliths to the gneiss may originally have been deposited unconformably on the granitic precursor to the Gooche Gneiss. Migmatitic pelitic gneiss contains layers, and in the diatexites, inclusions, of metamorphosed feldspathic sandstone and psammitic schist (P_-PO-mtsf). Migmatitic pelitic gneiss is intruded by veins, dykes, and plutons of a range of granites of the 1680–1620 Ma Durlacher Supersuite. Contacts with most of these granites are sharp, but contacts with schlieric, inclusion-rich granodiorite (P_-DU-ggvs) are typically gradational. The granodiorite is distinguished from the diatexite migmatite by a lower proportion of inclusions and rafts of unmelted metasedimentary rock and Gooche Gneiss. Migmatitic pelitic gneiss is unconformably overlain by sandstone of the Yilgatherra Formation (P_-MEy-s).

Geochronology

P_-PO-mli	*Maximum*	*Minimum*
Age (Ma)	1680 ± 14	1677
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Inferred
References	Nelson, 2004	Nelson, 2005

A sample of pelitic gneiss (P_-PO-mln) sampled for SHRIMP U–Pb zircon geochronology (Nelson, 2004) also provides constraints on the depositional ages of precursors to the migmatitic pelitic gneiss, because the two units are distinguished only by degrees of partial melting. The geochronology sample contains zircon age components at 1680 ± 13 Ma (5 grains), 1741 ± 23 Ma (3 grains), and 1785 ± 7 Ma (18 grains), in addition to older ungrouped zircons. The sample has been contact metamorphosed at high grade by a large pluton of monzogranite, and contains sparse leucosomes. The youngest zircons are small euhedral grains or fragments with no pitting or rounding, in contrast to older zircons. In cathodoluminescence (CL) images the youngest zircons contain complex growth zoning typical of granitic rocks (Corfu et al., 2003), and resemble those of the older zircons (Nelson, 2004). In addition, the youngest zircons do not have the low Th/U ratios typical of many metamorphic zircons (Rubatto and Gebauer, 2000), suggesting that the age component at

1680 ± 13 Ma is detrital, and that these zircons define the maximum depositional age of the sedimentary precursor to the gneiss (Sheppard et al., 2005). The minimum age for deposition of the precursor of the pelitic gneiss is provided by a SHRIMP U–Pb zircon date of 1677 ± 5 Ma for schlieric, inclusion-rich granodiorite (P_-DU-ggvs; Nelson, 2005), which is the oldest granite in the Durlacher Supersuite. The existing geochronology indicates rapid erosion of the source terrain, deposition, and high-grade metamorphism and deformation prior to granite intrusion at c. 1680 Ma.

References

Corfu, F, Hanchar, JM, Hoskin, PWO and Kinny, PD 2003, Atlas of zircon textures, *in* Zircon *edited by* JM Hanchar and PWO Hoskin: Mineralogical Society of America, Reviews in Mineralogy and Geochemistry, v. 53, p. 469–500.

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Nelson, DR 2005, 178027: biotite-muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

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Pooranoo Metamorphics; subunit (P_-PO-mln)

Legend narrative

Pelitic gneiss and granofels composed of biotite–muscovite–quartz–plagioclase–sillimanite; also includes migmatitic pelitic gneiss

Rank	Formation
Parent	Pooranoo Metamorphics (P_-PO-md)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-ggvs, P_-DU-gmp, P_-DU-gmv, P_-DU-gmvt, P_-DUdi-grpv, P_-DUpi-gmp (intrusive); P_-MEy-s (unconformable)
Underlying units	P_-MOgo-mgn

Summary

Pelitic gneiss and granofels outcrops over a wide area in the Mangaroon Zone, in particular, north of the Mangaroon Syncline. The rocks are typically coarse grained, with a strong compositional banding. Pelitic gneiss and granofels is characterized by assemblages including muscovite and sillimanite or muscovite, sillimanite, and cordierite. These pelitic rocks are interlayered with psammitic schist and gneiss, and feldspathic metasandstone (P_-PO-mtsf). A sample of pelitic gneiss taken for SHRIMP U–Pb detrital zircon geochronology yielded a maximum depositional age of 1680 ± 13 Ma.

Distribution

Pelitic gneiss and granofels outcrops over a wide area north of the Mangaroon Syncline, but has a more restricted distribution to the south of the syncline. The majority of the gneiss and granofels is unmelted, but locally metatexite migmatite is present. Layers of feldspathic metasandstone and psammitic schist are locally present. Pelitic granofels over a wide area north of James Bore on southern MANGAROON, has a hornfelsed 'knobbly' appearance, and is intensively veined by the Dingo Creek Granite. The granofels is resistant to weathering and caps many of the hills and ridges.

Lithology

The pelitic gneiss and granofels are typically coarse-grained rocks with a strong compositional banding in areas of low D_{2m}-strain. Where the gneisses are overprinted by D_{2m}, the rocks are commonly schistose. The pelitic gneiss and granofels preserve few or no original sedimentary textures and structures. Some slightly coarser grained semi-pelitic beds still contain a small proportion of coarse sand and granule-sized quartz grains.

Pelitic gneiss and granofels contain assemblages including biotite, muscovite, quartz, plagioclase, and sillimanite; quartz, biotite, cordierite, plagioclase, muscovite, and minor sillimanite; and, plagioclase, biotite, quartz, sillimanite, muscovite, and cordierite. All assemblages include accessory tourmaline and iron-oxide minerals. Sillimanite forms seams and patches of fibrolite that typically nucleate on biotite crystals or large muscovite plates. In some rocks sillimanite also forms small prismatic crystals intergrown with plagioclase and quartz. Garnet is restricted to two small areas on MANGAROON: in the area around Mount Thompson near the southern edge of the sheet area, and about 4 km northwest of Bookatharra Well in the northwestern part of the sheet area.

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics	PO-
Rock type	metasedimentary siliciclastic: pelite	ml
Lithname	pelitic gneiss	n
Rock code		**P_-PO-mln**
Additional lithologies	metasandstone, pelitic migmatite	

Contact relationships

Pelitic gneiss and granofels is in faulted contact with the 1776 ± 8 Ma Gooche Gneiss; protoliths to the gneiss and granofels may originally have been deposited unconformably on the granitic precursor to the Gooche Gneiss. Pelitic gneiss and granofels is interbedded with psammitic schist and gneiss, and feldspathic metasandstone (P_-PO-mtsf) at outcrop scale, and interlayered with the same rocks on a small scale. Pelitic gneiss and granofels is intruded by veins, dykes, and plutons of a range of granites of the 1680–1620 Ma Durlacher Supersuite, and is unconformably overlain by sandstone of the Yilgatherra Formation (P_-MEy-s).

Geochronology

P_-PO-mln	*Maximum*	*Minimum*
Age (Ma)	1680 ± 13	1677 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2004	Nelson, 2005

A sample of pelitic gneiss, from southeast of Maroonah Homestead on MAROONAH yielded detrital zircon age components at 1680 ± 13 Ma (5 grains), 1741 ± 23 Ma (3 grains), and 1785 ± 7 Ma (18 grains), in addition to older ungrouped dates (Nelson, 2004). The sample has been contact metamorphosed at high grade by a large pluton of monzogranite, and contains sparse leucosomes. The youngest zircons are small euhedral grains or fragments with no pitting or rounding, in contrast to older zircons. In cathodoluminescence (CL) images the youngest zircons contain complex growth zoning typical of granitic rocks (Corfu et al., 2003), and resemble the older zircons (Nelson, 2004). In addition, the youngest zircons do not have the low Th/U ratios common in many metamorphic zircons (Rubatto and Gebauer, 2000), suggesting that the zircons at 1680 ± 13 Ma are detrital, and that this component defines the maximum depositional age of the sedimentary precursor to the gneiss. The minimum age for deposition of the precursor of the pelitic gneiss is provided by a SHRIMP U–Pb zircon date of 1677 ± 5 Ma for schlieric, inclusion-rich granodiorite (P_-DU-ggvs; Nelson, 2005), which is the oldest granite in the Durlacher Supersuite. The existing geochronology indicates rapid erosion of the source terrain, deposition, and high-grade metamorphism and deformation prior to granite intrusion at c. 1680 Ma.

References

Corfu, F, Hanchar, JM, Hoskin, PWO and Kinny, PD 2003, Atlas of zircon textures, *in* Zircon *edited by* JM Hanchar and PWO Hoskin: Mineralogical Society of America, Reviews in Mineralogy and Geochemistry, v. 53, p. 469–500.

Nelson, DR 2004, 169094: quartz–plagioclase–biotite–sillimanite gneiss, Woorkailjia Pool; Geochronology Record 88: Geological Survey of Western Australia, 5p.

Nelson, DR 2005, 178027: biotite–muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

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Pooranoo Metamorphics; subunit (P_-PO-mtsf)

Legend narrative

Psammitic schist and gneiss, and feldspathic metasandstone; includes interbedded pelite, quartzite, and granule metaconglomerate

Rank	Formation
Parent	Pooranoo Metamorphics (P_-PO-md)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DUyn-gmi, P_-DUyn-gmv, P_-DUdi-grpv, P_-DUpi-gmg, P_-DU-ggvs, P_-DU-gmv, P_-DU-ggp, P_-DU-gmp (intrusive); P_-MEy-s, P_-MEi-k (unconformable)
Underlying units	P_-MOgo-mgm (faulted)

Summary

Psammitic schist and gneiss, and feldspathic metasandstone is one of the main components of the Pooranoo Metamorphics in the Mangaroon Zone. The unit may be, in part, equivalent to some of the medium- to low-grade feldspathic metasandstone of the Biddenew Formation (P_-POb-mqef, P_-POb-mtef) in the Mutherbukin Zone.

Distribution

Psammitic schist and gneiss outcrops over much of the Mangaroon Zone in the northern Gascoyne Province: namely in the northwestern corner of MANGAROON (and in the adjacent southwestern corner of MAROONAH) and on MANGAROON between the Mangaroon Syncline and the Minga Bar Fault. To the southeast on EDMUND, psammitic schist and gneiss forms numerous rafts and screens in granites of the Durlacher Supersuite. Psammitic schist and gneiss outcrops in the northeastern corner of MOUNT PHILLIPS, east-northeast of Gifford Creek Homestead. This is a continuation of the extensive belt to the northwest on EDMUND and MANGAROON. The unit probably extends farther to the southeast on MOUNT PHILLIPS underneath various regolith units.

Lithology

The rocks range from massive metasandstones with well-preserved sedimentary structures to pegmatite-banded gneissic rocks. Feldspathic metasandstone forms a gently undulating land surface with low rises covered in small boulders.

In low-strain zones on MANGAROON and MAROONAH, grey, feldspathic metasandstone beds are typically 20–30 cm thick, with graded bedding preserved in places. The rocks are fine-grained, but contain up to about 10% coarse sand and granule-sized clasts of quartz. Some beds contain scattered granules and pebbles of milky quartz.

Feldspathic metasandstone is composed of coarse sand and granules of strained quartz in a matrix of fine-grained, granoblastic quartz, plagioclase (oligoclase), biotite, sericite, and epidote. Porphyroblasts of muscovite 0.5 – 1.5 mm in diameter are common, but not abundant. Quartz is the most abundant mineral, typically forming 50–60% of the rock. Microcline is a minor component of some samples. Accessory minerals include zircon, apatite, and, in some samples, tourmaline.

Most of the rock types on northern MOUNT PHILLIPS consist of psammitic gneiss, with minor pelitic gneiss, intruded by various granite veins, dykes, and sheets. The psammitic gneiss is composed of quartz–plagioclase–biotite–muscovite–cordierite, with sparse thin leucosomes.

Lenses of pebble metaconglomerate are locally present; for example, in the area about 4 km northwest of Chubba Well (Zone 50, MGA 356600E 7399110N). The metaconglomerate lenses have sharp bases, and are typically less than 2 m thick.

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics	PO-
Rock type	metasedimentary siliciclastic: psammite	mt
Lithname	psammitic schist	s
1st qualifier	–	
2nd qualifier	felsic/feldspathic; K-metasomatized	f
Rock code		**P_-PO-mtsf**
Additional lithologies	Quartzite, metaconglomerate, pelitic schist	

Contact relationships

Feldspathic metasandstone is in faulted contact in the Mangaroon Zone with the Gooche Gneiss, which is part of the Moorarie Supersuite. Feldspathic metasandstone is intruded by numerous granite units of the 1680–1620 Ma Durlacher Supersuite, and is unconformably overlain by the Mesoproterozoic Edmund Group.

Geochronology

P_-PO-mtsf	*Maximum*	*Minimum*
Age (Ma)	1756 ± 17	1677 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Bodorkos et al., 2006; Nelson, 2002; Nelson, 2004	Nelson, 2005

Three samples of psammitic schist and gneiss have been sampled for SHRIMP U–Pb zircon geochronology to determine the maximum depositional age of the unit and its provenance. An inclusion (about 10 m^2) of feldspathic metasandstone, in the Pimbyana Granite on EDMUND, yielded mainly Paleoproterozoic zircons, including a youngest age component at 1808 ± 11 Ma, interpreted as a maximum age of deposition for the protolith (Nelson, 2002). A sample of strongly hornfelsed, felspathic metasandstone on the southern part of MAROONAH yielded only Paleoproterozoic zircons, including a youngest age component at 1800 ± 4 Ma, interpreted as a maximum depositional age for the precursor sediment (Nelson, 2004), which is within uncertainty of that provided by the sample on EDMUND. In addition, feldspathic metasandstone with well-developed graded bedding on southwestern MAROONAH yielded a maximum depositional age for the precursor sandstone of 1803 ± 7 Ma (Bodorkos et al., 2006). Ten other zircons in this sample yielded $^{207}Pb^{*}/^{206}Pb^{*}$ dates between 2328 and 1906 Ma, and one analysis indicating a $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1756 ± 17 Ma.

Feldspathic metasandstone is interbedded with pelitic gneiss (P_-PO-mln, P_-PO-mli), which has a maximum depositional age of c. 1680 Ma. Therefore, the precursor sediment to the metamorphosed feldspathic sandstone must also have a depositional age of less than c. 1680 Ma. Psammitic schist and gneiss is intruded by several granite units of the Durlacher Supersuite, the oldest of which is dated at 1677 ± 5 Ma (Nelson, 2005). Therefore, the depositional age of the precursor to the psammitic schist and gneiss is constrained to between 1680 ± 13 Ma and 1677 ± 5 Ma.

References

Bodorkos, S, Love, GJ, Nelson, DR and Wingate, MTD 2006, 178747: metamorphosed feldspathic sandstone, North East Bore; Geochronology Record 643: Geological Survey of Western Australia, 4p.

Nelson, DR 2002, 169056: quartz–muscovite–biotite–plagioclase–epidote schist, Fraser Prospect; Geochronology Record 129: Geological Survey of Western Australia, 4p.

Nelson, DR 2004, 169091: metasandstone, Hogan Well; Geochronology Record 120: Geological Survey of Western Australia, 5p.

Nelson, DR 2005, 178027: biotite–muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Pooranoo Metamorphics; subunit (P_-PO-mwa)

Legend narrative

Amphibolite and actinolite–plagioclase schist; garnet-bearing amphibolite locally

Rank	Formation
Parent	Pooranoo Metamorphics (P_-PO-md)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-ggvs, P_-DU-gmvt, P_-DU-mgm, P_-MW-od (intrusive)
Underlying units	P_-PO-mlsm, P_-PO-mli, P_-PO-mln (faulted)

Summary

Amphibolite and actinolite–plagioclase schist is a very minor, but widespread, component of the Pooranoo Metamorphics.

Distribution

Amphibolite and actinolite–plagioclase schist outcrops in the northeastern corner of EUDAMULLAH, and in the southeastern corner of EUDAMULLAH and the adjacent southwestern corner of MOUNT PHILLIPS. In addition, there are two exposures in the area around James Bore on southern MANGAROON. Amphibolite typically forms lenses or pods from a few tens of metres up to 700 m long and less than 100 m wide within metamorphosed siliciclastic rocks. The largest individual exposures are about 2.5 km long in the Nardoo Hills area on southwestern MOUNT PHILLIPS.

Lithology

Amphibolite and actinolite–plagioclase schist are typically foliated, fine- to medium-grained, and equigranular. Most of the unit is quite homogeneous. West of Tommie Well on eastern EUDAMULLAH amphibolite is locally coarser grained and contains idioblastic garnet porphyroblasts up to 1 cm in diameter. In the large exposure east-southeast of Louden Well in the Nardoo Hills area, medium-grained amphibolite locally has a well developed layering (alternating plagioclase-rich and hornblende-rich layers). Some lower strain zones consist of metagabbro.

Immediately west-northwest of James Bore, a folded layer of amphibolite up to 30 m thick outcrops. The amphibolite ranges from coarse grained with relict porphyritic texture, to medium grained and equigranular. About 3 km southeast of James Bore (centred at Zone 50, MGA 374255E 7374540N) metamorphosed, layered mafic and minor ultramafic rocks outcrop over an area of about 0.15 km^2. Thin layers of felsic (?anorthositic) rock are present in places.

Around James Bore the mafic rocks consist primarily of medium-grained actinolite enclosed by fine-grained, granoblastic plagioclase, actinolite, epidote, and titanite. Actinolite crystals may contain cores of clinopyroxene. The ultramafic rocks consist of cummingtonite, some crystals with cores of orthopyroxene, in a matrix of fine-grained serpentinite and green spinel. The rock was probably originally an olivine orthopyroxenite. In the southwestern corner of MOUNT PHILLIPS amphibolites are composed of assemblages of plagioclase (An_{45}) and blue–green amphibole (edenitic ?hornblende), minor quartz, biotite, relict clinopyroxene, and chlorite, with accessory magnetite, rutile, apatite, and zircon, or actinolite, quartz, plagioclase, and magnetite.

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics	PO-
Rock type	meta-igneous mafic	mw
Lithname	amphibolite	a
Rock code		**P_-PO-mwa**
Additional lithologies	mafic schist	

Contact relationships

For the most part it is unclear if the amphibolites represent volcanic or intrusive rocks into the metasedimentary rocks of the Pooranoo Metamorphics. Around James Bore on MANGAROON, the metamorphosed mafic rocks contain evidence for only the second metamorphic event during the Mangaroon Orogeny, unlike the surrounding pelitic gneisses; this observation is consistent with an intrusive origin for the mafic and ultramafic rocks. About 1.5 km east-southeast of Louden Well on MOUNT PHILLIPS, a crenulation lineation in the pelitic schist is roughly parallel to a mineral lineation in the amphibolites; however, it is unclear if the amphibolites post-date S_1 or are just a more competent unit than the surrounding pelitic rocks. The amphibolites are intruded by several granite phases of the Durlacher Supersuite, and by dykes of the c. 755 Ma Mundine Well Dolerite Swarm.

Geochronology

P_-PO-mwa	*Maximum*	*Minimum*
Age (Ma)	1680	1677
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2004	Nelson, 2005

Amphibolite and actinolite–plagioclase schist has not been dated directly. The unit is intruded by schlieric, medium-grained biotite–muscovite granodiorite dated at 1677 ± 5 Ma (Nelson, 2005), which is the oldest phase of the Durlacher Supersuite. This date is the best younger limit for the age of the igneous precursor to the amphibolite and actinolite–plagioclase schist. The older limit for the age of this unit is provided by the maximum depositional age of 1680 ± 13 Ma for metasedimentary rocks of the Pooranoo Metamorphics (Nelson, 2004).

References

Nelson, DR 2004, 169094: quartz–plagioclase–biotite–sillimanite gneiss, Woorkailjia Pool; Geochronology Record 88: Geological Survey of Western Australia, 5p.

Nelson, DR 2005, 178027: biotite–muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Pooranoo Metamorphics; subunit (P_-PO-mxq)

Legend narrative

Cobble- and pebble-metaconglomerate, and coarse-grained, granule and pebbly quartz metasandstone; minor quartz–muscovite schist

Rank	Formation
Parent	Pooranoo Metamorphics (P_-PO-md)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-gmvt, P_-DU-gpt, P_-DU-gmp, P_-DUpi-gmg (intrusive)

Summary

Metaconglomerate and metasandstone outcrop in the Mangaroon Zone north of the Minnie Creek batholith. These metamorphosed siliciclastic rocks may be the equivalent of metaconglomerate and metasandstone (P_-POb-mxq) which commonly mark the Biddenew Formation at thebase of the Mount James Subgroup south of the Minnie Creek batholith, but as the stratigraphic position of the unit in the Mangaroon Zone is unknown, they are retained as separate units.

Distribution

Metaconglomerate and metasandstone outcrops in the Mangaroon Zone on northwestern MANGAROON and adjacent southwestern MAROONAH, where it forms lenses up to about 3 km long within metamorphosed feldspathic sandstone and pelitic gneiss (P_-PO-mtsf, P_-PO-mln). Metaconglomerate and metasandstone outcrops more extensively on the WINNING POOL 1:250 000 sheet area to the northwest (Hocking et al., 1985). Metamorphosed quartz sandstone also forms several thin (<10 m) laterally persistent units north of James Bore on MANGAROON. In the Mutherbukin Zone on southeastern EUDAMULLAH, metaconglomerate and metasandstone forms several discontinuous layers less than 100 m thick, the largest of which may be traced along strike for nearly 12 km. Metaconglomerate and metasandstone typically forms strike ridges with a relief of nearly 50 m above the surrounding units.

Lithology

The most common rock types are metamorphosed cobble- and pebble-conglomerate, coarse quartz sandstone, and pebbly quartz sandstone. Graded bedding is well preserved. Rock types on southeastern EUDAMULLAH are mainly composed of foliated and metamorphosed, coarse- to very coarse-grained quartzite or sandstone, to granule conglomerate. In places there are thin beds (less than 30 cm thick) of metamorphosed fine- to medium-grained quartz sandstone. Higher strain zones consist of coarse- to very coarse-grained quartz–biotite–muscovite schist.

Metaconglomerate contains clasts of milky vein quartz and subordinate dark-grey to black, very fine to fine-grained quartz–magnetite(–muscovite) rock. The matrix of the conglomerate is composed of granules of quartz and minor muscovite. Metamorphosed conglomerate beds are 2–5 m thick, and are interbedded with metamorphosed sandstone beds 0.15 – 0.4 m thick. The conglomerate typically has a prominent lineation defined by strongly stretched clasts, a feature also noted by Hocking et al. (1985).The metamorphosed conglomerates and very coarse-grained sandstones contain granules of quartz with minor feldspar (5%), and traces of heavy minerals.

Metasandstone is typically pale grey, blocky, and medium to coarse grained, although in places it is fine grained and micaceous. Most of the rocks are composed almost entirely of quartz. Where the metasandstone is more strongly recrystallized, it is a quartzite. Metasandstone beds range from 0.05 to 3 m thick. North of Chubba Well, white, thickly bedded, metasandstone with thin heavy mineral bands is exposed.

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics	PO-
Rock type	metasedimentary siliciclastic: psephite	mx
Lithname	silicified metaconglomerate	q
Rock code		**P_-PO-mxq**
Additional lithologies	psammitic schist, metasandstone	

Contact relationships

Metamorphosed conglomerate and quartz sandstone is intruded by medium-grained, even-textured muscovite–tourmaline monzogranite (P_-DU-gmvt) and pegmatite (P_-DU-gpt) north of Chubba Well. On MAROONAH, metamorphosed conglomerate and quartz sandstone is intruded by porphyritic biotite(–muscovite) monzogranite (P_-DU-gmp) north-northeast of Hogan's Well, and by the Pimbyana Granite (P_-DUpi-gmg) north of Chubba Well. In the area between Maroonah Homestead and Red Rock Well, metamorphosed quartz sandstone is interbedded with calc-silicate gneiss (P_-PO-mkq). All of the contacts on southeastern EUDAMULLAH are faulted.

Geochronology

P_-PO-mxq	*Maximum*	*Minimum*
Age (Ma)	1698 ± 9	1675
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Inferred
References	Bodorkos et al.,2006	Nelson, 2005

A medium- to coarse-grained metasandstone on the northern edge of MANGAROON was sampled for SHRIMP U–Pb zircon geochronology. The sampled unit contains thin laminae of heavy minerals parallel to bedding, and scattered angular inclusions of black silicified siltstone up to 1 cm in diameter. Thirty-six analyses were obtained from 35 zircons (Bodorkos et al., 2006). Of these, 32 analyses of 32 zircons with $^{207}Pb^{*}/^{206}Pb^{*}$ ratios that define a single age component indicate a weighted mean date of 1789 ± 4 Ma. Three analyses of two zircons have

$^{207}Pb^*/^{206}Pb^*$ dates of 2658–1817 Ma. The remaining analysis has a $^{207}Pb^*/^{206}Pb^*$ date of 1698 ± 9 Ma, which is interpreted as a maximum age for deposition of the precursor quartz sandstone (Bodorkos et al., 2006).

Metamorphosed conglomerate and quartz sandstone is intruded by granites of the Durlacher Supersuite, the oldest of which is the Pimbyana Granite. A megacrystic biotite(–muscovite) monzogranite from the Pimbyana Granite 4 km southeast of Coorabie Tank on MANGAROON (GSWA 178029) yielded an igneous crystallization age of 1675 ± 11 Ma (Nelson, 2005), and provides a minimum age for deposition of the conglomerate and quartz sandstone.

References

Bodorkos, S, Love, GJ, Nelson, DR, and Wingate, MTD 2006, 178746: metamorphosed quartz sandstone, Chubba Well; Geochronology Record 642: Geological Survey of Western Australia, 4p.

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Pooranoo Metamorphics; subunit (P_-PO-mkq)

Legend narrative

Calc-silicate gneiss composed of actinolite–quartz–plagioclase–clinopyroxene–epidote–titanite; minor dolomitic quartz-granule metasandstone; medium- to coarse-grained; locally with graded bedding

Rank	Formation
Parent	Pooranoo Metamorphics (P_-PO-md)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-mgnl
Underlying units	AP_-_ha-mgnw (unconformable); P_-POs-mtqs, P_-POb-mqef (faulted)

Summary

Calc-silicate gneiss is a very minor component of the Pooranoo Metamorphics, being largely confined to an area west of Mount James on YINNETHARRA and two areas on EUDAMULLAH. Calc-silicate gneiss is typically a massive to gneissic, coarse-grained rock, locally marked by large radiating crystals of dark green diopside.

Distribution

Calc-silicate gneiss is mainly confined to two main areas on southeastern EUDAMULLAH, as well as immediately west of Mount James on southeastern YINNETHARRA. On EUDAMULLAH, the two main areas are a 10 km^2 area around 7 km south-southwest of Four Corners Well, and a 1 km^2 area about 4.5 km east-southeast of Davey Well. Calc-silicate gneiss mostly forms layers up to a few tens of metres wide that may be traced along strike for several hundred metres. In the area south-southwest of Four Corners Well there are also two lenses of calc-silicate gneiss about 100m wide. There are also several small discontinuous lenses approximately 3 km south-southeast of Kanes Gossan (Zone 50, MGA 424198E 7359754N) on EDMUND. On YINNETHARRA, calc-silicate rocks outcrop over about 2.5 km^2 immediately west of Mount James. Calc-silicate gneiss typically outcrops as narrow, low rises or knolls with a dark brown colour on aerial photographs.

Lithology

Calc-silicate gneiss is typically a massive to gneissic, coarse-grained rock, locally marked by large radiating crystals of dark green diopside. Some outcrops contain minor interlayered quartzite, and in places the calc-silicate gneiss is layered owing to the presence of 2–5 cm-thick bands of quartzite. Assemblages include garnet–?diopside–quartz and garnet–epidote–quartz–diopside and, more rarely, diopside–plagioclase–microcline–quartz. Actinolite and chlorite are commonly present, partly replacing diopside.

On EDMUND, Pearson (1996) described the calc-silicate rocks as wollastonite–diopside–grossular-garnet–carbonate rocks, which are variably brecciated and veined by carbonate, and actinolite–epidote–carbonate–titanite rocks. A pegmatitic diopside-rich calc-silicate rock outcrops at the core of a wollastonite–diopside–grossular-garnet–carbonate gneiss just south of Kanes Gossan (Pearson, 1996).

On YINNETHARRA, the dolomitic quartz granule sandstone is a medium grained clastic unit comprised of 40–60%, 1–5mm wide, 5–15mm long, sub-rounded recrystallized quartz clasts set within a fine grained, sugary textured calc-silicate matrix. The quartz clasts are invariably aligned to form a coarse fabric and at some localities a gradation in clast grain-size defines crudely graded bedding. The matrix is comprised of an interlocking assemblage of irregular shaped quartz and K-feldspar, acicular clots of actinolite with abundant anhedral clinozoisite inclusions, anhedral to subhedral diopside and accessory euhedral titanite. Outcrops closer to the northerly contact with the Halfway Gneiss are generally much finer grained and lack quartz clasts. These units occasionally contain randomly distributed 2–8 mm in diameter, slightly flattened elliptical spots comprised of radially arranged muscovite blades with fine grained interstitial quartz. The matrix of these units is comprised of very fine grained, interlocking even-textured quartz and irregular shaped carbonate with randomly oriented green biotite, tourmaline and muscovite. The mineralogy of P_-PO-mkq indicates that it is of sedimentary origin having been metamorphosed and deformed in the lower amphibolite facies after deposition of the Pooranoo Metamorphics at c. 1680 Ma.

Age code	Proterozoic	P_-
Stratigraphic code	Pooranoo Metamorphics	PO-
Rock type	metasedimentary carbonate	mk
Lithname	calc-silicate rock	q
Rock code		**P_-PO-mkq**
Additional lithologies	metasandstone	

Contact relationships

At site SXSEUD6668 (Zone 50, MGA 394445E 7302743N) inclusions of calc-silicate gneiss are found in foliated leucocratic muscovite(–biotite) metamonzogranite (P_-DU-mgml). West of Mount James, the dolomitic quartz-granule sandstone is in faulted contact with the siliciclastic units of the Biddenew and Spring Camp Formations to the south, specifically P_-POb-mxq and P_-POs-mtqs. Although there is a gap in exposure at the contact, the deeply dissected and sharp topography indicate the presence of a steeply dipping fault. The northern contact with the Halfway Gneiss (AP_-_ha-mgnw) is unexposed, being covered by extensive colluvium; however, the contact parallels the topography suggesting that it is of low angle and probably an angular unconformity rather than a fault.

Geochronology

P_-PO-mkq	*Maximum*	*Minimum*
Age (Ma)	1758	1677
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., 2009	Nelson, 2005

Calc-silicate gneiss has not been dated directly. If the unit is conformable with the pelitic and psammitic schist and gneiss of the Pooranoo Metamorphics, then the maximum deposition age for the unit is 1758 ± 18 Ma as for the other siliciclastic metasedimentary rocks of the Pooranoo Metamorphics (Wingate et al., 2009). The best estimate of the minimum age for the unit is provided by schlieric, medium-grained biotite–muscovite granodiorite dated at 1677 ± 5 Ma (Nelson, 2005), which is the oldest phase of the Durlacher Supersuite to intrude the Pooranoo Metamorphics.

References

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Durlacher Supersuite (P_-DU-g)

Legend narrative

Granite and minor gabbro and metamorphosed equivalents

Rank	Supersuite
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-ME (unconformable); P_-TT-g, P_-mod-GA, P_-mw-od (intrusive)
Underlying units	P_-PO-md, P_-MO-g, P_-LS-xmd-mk, AP_-ha-mgn (intrusive)

Summary

The 1680–1620 Ma Durlacher Supersuite is one of three main granite supersuites that intrude the Gascoyne Province. The supersuite was intruded during the Mangaroon Orogeny. In the Mangaroon Zone the supersuite comprises biotite–muscovite bearing monzogranite, granodiorite, and syenogranite, and some muscovite–tourmaline(–biotite) monzogranite dated at between c. 1675 Ma and c. 1660 Ma. These rocks are, in the main, undeformed or weakly deformed large plutons and plugs, with associated dykes and veins. Many of the plutons are elongate parallel to the structural grain in the Mangaroon Zone.

In the Mutherbukin Zone, the Durlacher Supersuite comprises biotite metamonzogranite, and biotite–muscovite(–tourmaline) metamonzogranite and metasyenogranite. In this zone, the rocks are typically moderately to strongly foliated, owing to the overprinting effects of the Mutherbukin and Edmundian Orogenies. The granites have igneous crystallization ages of c. 1665 Ma to c. 1650 Ma. In the Yarlarweelor Gneiss Complex, the main phase of the Discretion Granite has been dated at c. 1620 Ma, although there are also screens of granite with ages of c. 1640 Ma.

The majority of units within the Durlacher Supersuite are strongly peraluminous, with S-type characters suggesting they were derived largely by remelting of older crust that included a significant proportion of metasedimentary rock. They were generated during the high-temperature intracontinental Mangaroon Orogeny.

Distribution

The Durlacher Supersuite forms plutons, plugs, and dykes mainly in two east-southeast trending zones: the 70 km-wide Mangaroon Zone in the northern Gascoyne Province, and the 50 km-wide Mutherbukin Zone in the central part of the province. Large batholithic masses of porphyritic monzogranite and syenogranite mostly outcrop in the northern part of the Mangaroon Zone; the southern half is dominated by irregular intrusions of variably deformed schlieric biotite–muscovite granodiorite (P_-DU-ggvs). In the Mutherbukin Zone, the Durlacher Supersuite is dominated by the batholithic mass of the Davey Well Granite, centred on YINNETHARRA.

Large plutons belonging to the supersuite are also present on the central part of MAROONAH farther north (Martin et al., 2005), and on DAURIE CREEK farther to the south. On MARQUIS, large plutons of the c. 1620 Ma Discretion Granite intrude reworked Archean gneisses in the Yarlarweelor Gneiss Complex to the southeast of the Gascoyne Province (Sheppard & Swager, 1999).

Derivation of name

The Durlacher Supersuite is named after Durlacher Creek (Zone 50, MGA 407500E 7347400N) on EDMUND.

Lithology

The Durlacher Supersuite in the Mangaroon Zone mainly consists of monzogranite and syenogranite with lesser granodiorite, and minor amounts of tonalite and rare gabbro. The monzogranite, syenogranite, and granodiorite are medium- to coarse-grained and porphyritic (mainly tabular phenocrysts and megacrysts of K-feldspar), and contain: biotite only; biotite and muscovite; or muscovite, biotite, and tourmaline. Mesocratic granodiorite and tonalite phases are mostly equigranular. Gabbro intrusions contain xenocrysts of K-feldspar and quartz and display mingling textures with the granites. Coarse-grained porphyritic to megacrystic biotite(–muscovite) monzogranite to syenogranite of the Pimbyana Granite comprises the largest group of intrusions in the Mangaroon Zone. Other notable units include the Dingo Creek Granite and Yangibana Granite (Martin et al., 2005).

In the Mutherbukin Zone, the largest unit of the supersuite is the Davey Well Granite, which consists of strongly foliated, coarse-grained biotite metamonzogranite with round K-feldspar phenocrysts up to 6 c. in diameter. Other rock types in the zone include foliated and gneissic, biotite(–muscovite) metamonzogranite and metasyenogranite, and foliated, muscovite(–tourmaline) metamonzogranite and metasyenogranite. These rocks are medium grained and equigranular to sparsely porphyritic. A minor, but distinctive unit is aegirine–augite- or hornblende-bearing metamorphosed quartz-diorite and metatonalite of the Tetlow Granite. These units forms lenses within the Davey Well Granite.

In the Boora Boora Zone on MAROONAH, the Durlacher Supersuite comprises several intrusions, one larger than 250 km^2, of medium-grained biotite–muscovite granodiorite and monzogranite. In the Yarlarweelor Gneiss Complex rocks of the supersuite consist of medium-grained, porphyritic biotite monzogranite with tabular K-feldspar phenocrysts of the Discretion Granite (Sheppard and Swager, 1999).

Parent	Top of lithostratigraphic order (TOL)	P_-DU-
Rock type	Igneous granitic	g
Rock code		**P_-DU-g**
Additional lithologies	syenogranite, tonalite, gabbro, pegmatite, granodiorite	

Contact relationships

Granites (and gabbro) of the Durlacher Supersuite extensively intruded rocks of the c. 1680 Ma Pooranoo Metamorphics. However, where these granites intrude older rocks, they cannot, in all instances, reliably be distinguished from granites of the 1820–1775 Ma Moorarie Supersuite unless dated. Nevertheless, granites of the Durlacher Supersuite intrude the Gooche Gneiss, which is part of the Moorarie Supersuite, in the Mangaroon Zone, and rocks of the Leake Spring Metamorphics, Moorarie Supersuite and Halfway Gneiss in the Mutherbukin Zone. Granites of the Durlacher Supersuite are unconformably overlain by sedimentary rocks of the Edmund Group (Bangemall Supergroup) on Maroonah and Mangaroon, and are intruded by metadolerite (P_-mod-GA) in the Mutherbukin Zone, and by dykes of the Mundine Well Dolerite Suite over a wide area.

Geochronology

P_-DU-g	*Maximum*	*Minimum*
Age (Ma)	1677 ± 5	1619 ± 15
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2005	Nelson, 1998

The oldest dated unit in the Durlacher Supersuite is a schlieric, inclusion-rich granodiorite (P_-DU-ggvs) with an igneous crystallization age of 1677 ± 5 Ma (Nelson, 2005) from the Mangaroon Zone. The youngest dated unit is a massive, porphyritic biotite monzogranite (Discretion Granite; P_-DUdn-gmp) with an igneous crystallization age of 1619 ± 15 Ma (Nelson, 1998) from the Yarlarweelor Gneiss Complex. Several phases of the Durlacher Supersuite have been dated, including the Pimbyana, Yangibana, Dingo Creek, and Davey Well Granites. Most of the granites in the Mangaroon Zone have igneous crystallization ages between c. 1675 and c. 1660 Ma. In the Mutherbukin Zone, most granites of the supersuite have been dated between c. 1665 and c. 1650 Ma. However, granites with crystallization ages between c. 1650 and c. 1620 Ma are known from the Mooloo and Boora Boora Zones in the southern and northern parts of the Gascoyne Province, respectively, and in the Yarlarweelor Gneiss Complex to the southeast.

References

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DAVEY WELL GRANITE
(P_-DUda-mgmu)

Legend narrative

Schistose, coarse-grained, strongly porphyritic biotite metamonzogranite; round phenocrysts of K-feldspar up to 6 cm in diameter

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-mod-GA, P_-DU-mgrl, P_-DU-mgmb, P_-DU-mgml, P_-TT-jmgmt-m, P_-TT-gmlt, P_-TT-gpvt (intrusive); CP-LY-sepg (unconformable)
Underlying units	AP_-_ha-mgnw, AP_-_ha-mgnl, P_-DU-mgtx, P_-DU-mgn, P_-DU-mgnl, P_-PO-mlsm, P_-PO-mkq, P_-PO-mxq, P_-MO-mgts, P_-LS-mwa, P_-LS-mlsg (intrusive)

Summary

The Davey Well Granite is one of the largest, and most distinctive granite units in the Gascoyne Province. It outcrops over at least 1,500 km^2 in the Mutherbukin Zone in the centre of the province. The granite forms what was previously referred to as the 'Yinnetharra Gneiss Dome' by Williams (1986). The Davey Well Granite comprises schistose, coarse-grained, strongly porphyritic biotite metamonzogranite; oval to round K-feldspar phenocrysts are mostly 1–4 cm in diameter, but locally form megacrysts (>5 cm in diameter). Three SHRIMP U–Pb zircon dates from the unit yielded igneous crystallization ages of 1667 ± 4 Ma, 1653 ± 10 Ma and 1648 ± 6 Ma. The unit probably consists of multiple intrusive events spanning several million years.

Distribution

The Davey Well Granite forms two very large intrusions, one on EUDAMULLAH and the other on YINNETHARRA, as well as a smaller pluton in the Chalba Shear Zone on southern YINNETHARRA. The Davey Well Granite outcrops over much of southeastern EUDAMULLAH, and probably underlies more than 500 km^2 of the southern part of the sheet, extending onto MOUNT SANDIMAN to the west. On aeromagnetic images, this intrusion resembles a sigma porphyroclast with 'tails' suggesting sinistral shear. The Davey Well Granite also outcrops over about 950 km^2 on YINNETHARRA to the southeast — this intrusion was previously referred to as the 'Yinnetharra Gneiss Dome' by Williams (1986). The Davey Well Granite outcrops as boulders, tors and pavements, and typically forms low, undulating country with very coarse- to coarse-grained sandy aprons of colluvium.

Derivation of name

The Davey Well Granite was named after the abandoned Davey Well (Zone 50, MGA 390726E 7303784N) on EUDAMULLAH.

Lithology

The Davey Well Granite is a reasonably homogeneous unit comprising schistose, coarse-grained, strongly porphyritic biotite metamonzogranite, although there is some variation in the abundance and size of K-feldspar phenocrysts. Oval to round K-feldspar phenocrysts are mostly 1–4 cm in diameter, but locally form megacrysts (>5 cm in diameter). The K-feldspar phenocrysts typically constitute around 30% of the rock, but in places they make up only 10–15%. The phenocrysts have inclusions of fine-grained biotite, quartz, and ?plagioclase, which commonly define growth zones.

Most of the rocks are moderately to strongly foliated, particularly adjacent to the southern margin of the Minnie Creek batholith, where the rocks are locally gneissic. On EUDAMULLAH, the foliation in the Davey Well Granite typically dips steeply to the south. On YINNETHARRA, the foliation dips steeply to the south along the northern edge of the intrusion, but also defines a very broad arc that is convex to the southeast. The dip on the foliation is commonly moderate or even shallow. In parts of the Davey Well Granite the foliation is an L-tectonite fabric: for example south of Yinnetharra Homestead. Zones of massive or weakly foliated metamonzogranite are not common, probably being best developed west and southwest of Davey Well. Weakly deformed rocks consist of massive, coarse-grained, strongly porphyritic biotite monzogranite with 1–2 mm long euhedral crystals of titanite; these are intergrown in places with iron oxide minerals suggesting that the titanite is magmatic. The monzogranite also contains crystals of allanite about 0.2 mm long, as well as accessory zircon and apatite. Microperthite phenocrysts contain abundant blebby to stringer-like inclusions of microperthite and microcline and quartz and biotite and plagioclase. Quartz is recrystallized in part to sub-grain mosaics and plagioclase is weakly sericitized. Biotite is dark brown.

The Davey Well Granite commonly contains small scattered inclusions of grey biotite microgranite, as well as larger blocks (up to a few metres long) of foliated leucocratic biotite metamonzogranite. Inclusions of biotite-rich pelitic schist are also present, particularly near the margins of the intrusions.

Age code	(P_-DU-g)	P_-
Stratigraphic code	Durlacher Supersuite, DAVEY WELL GRANITE	DUda-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	–	
2nd qualifier	augen	u
Rock code		**P_-DUda-mgmu**

Contact relationships

Schistose, coarse-grained, strongly porphyritic biotite metamonzogranite is in contact with several other units of the Durlacher Supersuite, as well as metasedimentary and meta-igneous rocks of the Leake Spring Metamorphics and Pooranoo Metamorphics. Many of the contacts are faulted, but inclusions of several units are widespread, if never abundant. Inclusions in the Davey Well Granite comprise calc-silicate gneiss (P_-PO-mkq) and cobble and boulder metaconglomerate (P_-POb-mxq) of the Pooranoo Metamorphics, and amphibolite (P_-LS-mwa) of the Leake Spring Metamorphics. Much of the Davey Well Granite also contains scattered lenticular inclusions of fine-grained biotite–quartz–muscovite schist and quartz–muscovite–biotite schist (P_-POb-mlsm). In places, medium-grained sparsely porphyritic biotite monzogranite inclusions are present; these may represent earlier crystallized parts of the intrusion, as they contain scattered K-feldspar phenocrysts similar to those in the host granite. In the area between Tommie Well and Granite Well on EUDAMULLAH, the Davey Well Granite contains inclusions and rafts of garnet- or staurolite-bearing pelitic schist (P_-LS-mlsg) and mesocratic, equigranular to sparsely porphyritic biotite metatonalite and metamorphosed quartz-diorite (P_-MO-mgts). Along the northern edge of, and within, the Chalba Shear Zone, the Davey Well Granite is in faulted contact with leucocratic gneissic granite of the Halfway Gneiss (AP_-_ha-mgnl), and over a much wider area is presumably intrusive into both the mesocratic and leucocratic Halfway Gneiss (AP_-_ha-mgmw and AP_-_ha-mgnl). These relationships are also evident along the southern margin of the main pluton of Davey Well Granite on YINNETHARRA.

The Davey Well Granite is intruded by massive metamorphosed dolerite and foliated amphibolite (P_-mod-GA), particularly east and southeast of Four Corners Well, and by dykes of foliated, leucocratic biotite–muscovite syenogranite (P_-DU-mgrl) and a pluton of foliated leucocratic muscovite(–biotite) monzogranite (P_-DU-mgml) in the southeastern corner of EUDAMULLAH. About 6 km northwest of Daly Bore on YINNETHARRA (stop SXSYIN007876; Zone 50, MGA 432600E 7258304N) a raft of Davey Well Granite 10 m long and 1 m wide is present within foliated and banded medium-grained biotite metamonzogranite (P_-DU-mgmb). The Davey Well Granite is intruded by units of the Thirty Three Supersuite across the southern edge of MOUNT PHILLIPS and adjacent northern edge of YINNETHARRA; specifically, veins, dykes, and plutons of foliated, leucocratic metamonzogranite (P_-TT-jmgmt-m), and veins and dykes of leucocratic, medium-grained muscovite–tourmaline(–biotite) monzogranite (P_-TT-gmlt) and muscovite–tourmaline pegmatite (P_-TT-gpvt). The Davey Well Granite in the southwestern corner of EUDAMULLAH is unconformably overlain by diamictite, sandstone, and siltstone (CP-LY-sepg) of the Lyons Group. The unit is also extensively intruded by dolerite dykes of the Mundine Well Dolerite suite (P_-MW-od).

Geochronology

P_-DUda-mgmu	*Maximum*	*Minimum*
Age (Ma)	1667 ± 4	1648 ± 6
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Wingate et al., 2009	Wingate et al., 2010a

Schistose, coarse-grained, strongly porphyritic biotite metamonzogranite was sampled for SHRIMP U–Pb zircon geochronology from a low-strain zone about 2.3 km southwest of Davey Well on eastern EUDAMULLAH (Zone 50, MGA 388798E 7302568N). The sample (Wingate et al., 2009) is a massive, coarse-grained, strongly porphyritic biotite metamonzogranite. The majority of zircons provided a crystallization age of 1667 ± 4 Ma. The Davey Well Granite was also sampled (Wingate et al., 2010a) adjacent to where the Cobra – Dairy Creek Road crosses the Gascoyne River on YINNETHARRA. At this locality, leucocratic melt pockets related to the Edmundian Orogeny are developed within gneissic metamonzogranite. From the leucogranite a concordia age of 1648 ± 6 Ma was obtained and interpreted as the age of magmatic crystallization of the host monzogranite. In addition, metamorphic zircon rims were dated at 1000 ± 8 Ma and interpreted as the age of high-grade metamorphism that formed the leucocratic segregations (Wingate et al., 2010a).

The Davey Well Granite was also dated from a small pluton within the Chalba Shear Zone on YINNETHARRA. This sample yielded a crystallization age of 1653 ± 10 Ma (Wingate et al., 2010b). The two samples on YINNETHARRA are within uncertainty of each other but outside that of the monzogranite from EUDAMULLAH, suggesting that the Davey Well Granite may be a composite intrusion assembled over millions of years.

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DAVEY WELL GRANITE; subunit (P_-DUda-mgmw)

Legend narrative

Coarse-grained, porphyritic, mesocratic biotite metamonzogranite; round and tabular phenocrysts of K-feldspar up to 3 cm in diameter

Rank	Member
Parent	DAVEY WELL GRANITE (P_-DUda-mgmw)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MW-od (intrusive), CP-LY-sepg (unconformable)
Underlying units	P_-DU-mgnw (intrusive), P_-DUda-mgmu (mingled)

Summary

Coarse-grained, porphyritic, mesocratic biotite metamonzogranite is a minor phase of the Davey Well Granite, being exposed only on the central part of LOCKIER.

Distribution

Coarse-grained, porphyritic, mesocratic biotite metamonzogranite outcrops only at the western end of the Gascoyne Province on LOCKIER. It forms a pluton nearly 40 km^2 immediately east of Snake Well, as well as a dismembered intrusion a short distance to the southeast along the northern edge of the Chalba Shear Zone.

Lithology

Coarse-grained, porphyritic, mesocratic biotite metamonzogranite is typically medium to coarse grained. The rocks are rich in biotite, and range from porphyritic to seriate. The metamonzogranite comprises less than 10% round and tabular phenocrysts of K-feldspar, typically about 1 cm in diameter, but some are up to 3 cm in diameter. In places the metamonzogranite grades into metagranodiorite. At site SXSGAS008358 (Zone 50, 371496E 7270157N) the metamonzogranite is heterogeneous, and contains K-feldspar augen with partly resorbed zones mantled by overgrowths. The unit commonly contains scattered inclusions of fine-grained, biotite-rich micrograinite. The majority of the rocks are strongly foliated.

Age code	Proterozioc	P_-
Stratigraphic code	Durlacher Supersuite, DAVEY WELL GRANITE	DUda-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	mesocratic	w
Rock code		**P_-DUda-mgmw**

Contact relationships

Coarse-grained, porphyritic, mesocratic biotite metamonzogranite is typically strongly foliated, and contacts are variably tectonised. The unit appears to intrude seriate to coarsely porphyritic mesocratic gneiss of the Durlacher Supersuite (P_-DU-mgnw), and appears to grade into schistose, coarse-grained, strongly porphyritic biotite metamonzogranite of the Davey Well Granite (P_-DUda-mgmu). At site SXSGAS008358 (MGA Zone, 50, 371496E 7270157N) coarse-grained, porphyritic, mesocratic biotite metamonzogranite contains metre-scale oval-shaped inclusions of foliated, coarse-grained porphyritic metamonzogranite (P_-DUda-mgmu). This site may represent a zone of mingling between the two units.

Coarse-grained, porphyritic, mesocratic biotite metamonzogranite is intruded by veins and thin dykes of foliated pink, fine-grained metamonzogranite or metasyenogranite of the Durlacher Supersuite, and dykes of the Mundine Well Dolerite Suite. The mesocratic metamonzogranite is also unconformably overlain by the Lyons Group.

Geochronology

P_-DUda-mgmw	*Maximum*	*Minimum*
Age (Ma)	1667	1648
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., 2009	Wingate et al., 2010

Coarse-grained, porphyritic, mesocratic biotite metamonzogranite has not been dated directly, but is inferred to be the same age as the main porphyritic phase of the Davey Well Granite, with which it appears to either be mingled or to grade into.

References

Wingate, MTD, Kirkland, CL, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183215: porphyritic metamonzogranite, Davey Well; Geochronology Record 771: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL, S, Sheppard, S and Johnson, SP 2010, 185945: pegmatite lenses in metamonzogranite, Yinnetharra Homestead; Geochronology Record 901: Geological Survey of Western Australia, 5p.

DINGO CREEK GRANITE
(P_-DUdi-grpv)

Legend narrative

Porphyritic biotite–muscovite monzogranite to syenogranite; fine- to medium-grained with thin, tabular K-feldspar phenocrysts defining a trachytic texture

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-gmv, P_-DU-gmvt, P_-DU-gpt, P_-nr-od (intrusive); P_-MEy-s (faulted)
Underlying units	P_-MOru-mgm, P_-PO-mtsf, P_-PO-mln, P_-DUpi-gmw (intrusive)

Summary

The Dingo Creek Granite is one of the more distinctive granites in the Gascoyne Province. It characteristically contains thin, tabular K-feldspar phenocrysts defining a trachytic texture. The Dingo Creek Granite is widely distributed in the Mangaroon Zone in the northern part of the province as a series of intrusions parallel to the structural grain of the surrounding metasedimentary rocks. Three specimens from the unit sampled for SHRIMP U–Pb zircon geochronology by Pearson (1996) and GSWA have yielded igneous crystallization ages of c. 1675 Ma.

Distribution

The unit forms several southeast-trending intrusions over an area about 35 km long and 5 km wide on the central part of MANGAROON. Another intrusion on the eastern edge of the sheet area is probably part of another southeast-striking belt of intrusions of similar dimensions on EDMUND. This unit also forms a pluton around Doorawarrah Spring on the western edge of MANGAROON, and numerous veins and dykes in the area north of James Bore. The intrusions on EDMUND extend onto the northeastern corner of MOUNT PHILLIPS. More than 20 km to the southeast is an isolated exposure of Dingo Creek Granite amongst regolith, suggesting that this unit may also underlie part of northwestern MOUNT AUGUSTUS. In addition, there are two small plugs in the southern Limejuice Zone that are also assigned to the Dingo Creek Granite. The first, a plug about 2 km^2 of medium-grained biotite–muscovite monzogranite with thin tabular K-feldspar phenocrysts, northeast of Kendell Bore in the southeastern part of MOUNT PHILLIPS, and the second, a plug about 0.5 km^2 southwest of No. 1 Bore on PINK HILLS.

The Dingo Creek Granite forms low, rugged hills, and outcrops as boulders, tors, and, locally, whalebacks.

Derivation of name

The Dingo Creek Granite was named after Dingo Creek (Zone 50, MGA 409500E 7363500N) on EDMUND. The Dingo Creek Granite was previously referred to as the Dingo Granite by Pearson (1996) and Pearson et al. (1996), but was renamed because of potential confusion with the Dingo intrusion in the Pilbara.

Lithology

Intrusions of Dingo Creek Granite are composed of numerous southeast-striking sheets from a few metres up to a few hundred metres wide. Thin tabular K-feldspar phenocrysts mostly less than 1 cm long comprise 30% or more of the rock; locally they make up to 60% of the rock (Pearson, 1996). Phenocrysts commonly have a strong preferred orientation defining a magmatic foliation. This foliation typically strikes southeast parallel to a tectonic foliation (S_{2m}: see **Late Paleoproterozoic Mangaroon Orogeny**) in rocks of the surrounding Pooranoo Metamorphics, and dips steeply to the northeast or southwest. The Dingo Creek Granite is composed of porphyritic, fine- to medium-grained biotite–muscovite monzogranite and syenogranite. Phenocrysts of microperthite commonly contain inclusions of plagioclase and blebby quartz. Chocolate-brown biotite and muscovite are partly recrystallized to finer grained aggregates

Age code	(P_-DU-g)	P_-
Stratigraphic code	Durlacher Supersuite, DINGO CREEK GRANITE	DUdi-
Rock type	Igneous granitic	g
Lithname	syenogranite	r
1st qualifier	porphyritic	p
2nd qualifier	muscovite	v
Rock code		**P_-DUdi-grpv**

Contact relationships

The Dingo Creek Granite is mainly surrounded by large areas of the Pimbyana Granite. At the margins of separate intrusions about 4.5 km southeast of Coorabie Tank (Zone 50, MGA 385760E 7367230N) and 2 km east of Chararoo Outcamp (Zone 50, MGA 370940E 7386770N), and on EDMUND, fine- to medium-grained porphyritic granite of the Dingo Creek Granite intrudes megacrystic monzogranite of the Pimbyana Granite. In the area about 2 km northeast of Chararoo Outcamp there are numerous inclusions and rafts of megacrystic Pimbyana Granite in Dingo Creek Granite. Around Doorawarrah Spring on MANGAROON, the Dingo Creek Granite intrudes rocks of the Pooranoo Metamorphics. On EDMUND, rafts of leucocratic tourmaline-bearing granite (P_-DU-gmvt) are locally present within the Dingo Creek Granite.

The Dingo Creek Granite is extensively intruded by veins and dykes of muscovite–biotite(–tourmaline) granite and pegmatite (P_-DU-gmv, P_-DU-gmvt, P_-DU-gpt). On MANGAROON the Dingo Creek Granite is intruded by a dolerite sill of the c. 1465 Ma Narimbunna Dolerite, and is faulted against the Yilgatherra Formation at the base of the Edmund Group.

Geochronology

P_-DUdi-grpv	*Maximum*	*Minimum*
Age (Ma)	1674 ± 8	1674 ± 8
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2002; Nelson, 2005; Pearson, 1996	Nelson, 2002; Nelson, 2005; Pearson, 1996

The Dingo Creek Granite was first dated by Pearson (1996) using SHRIMP U–Pb in zircon. The sample was taken from Mount Phillips, about 3 km south of the Edmund sheet boundary, and has an igneous crystallization age of 1674 ± 6 Ma. Two additional samples were collected for SHRIMP geochronology during the course of remapping on Edmund, and from nearly 50 km to the west-northwest on Mangaroon. The two samples have identical igneous crystallization ages of 1674 ± 8 Ma (Nelson, 2002, 2005).

References

Nelson, DR 2002, 169062: porphyritic syenogranite, Contessis Bore; Geochronology Record 136: Geological Survey of Western Australia, 4p.

Nelson, DR 2005, 178028: biotite–muscovite syenogranite dyke, Coorabie Tank; Geochronology Record 537: Geological Survey of Western Australia, 5p.

Pearson, JM 1996, Alkaline rocks of the Gifford Creek Complex, Gascoyne Province, Western Australia — their petrogenetic and tectonic significance: University of Western Australia, Perth, PhD thesis (unpublished) 286p.

Pearson, JM, Taylor, WR and Barley, ME 1996, Geology of the alkaline Gifford Creek Complex, Gascoyne Complex, Western Australia: Australian Journal of Earth Sciences, v. 43, p. 299–309.

DISCRETION GRANITE
(P_-DUdn-gmp)

Legend narrative

Medium-grained, porphyritic biotite monzogranite; tabular phenocrysts of K-feldspar

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MW-od
Underlying units	AP_-_mgnw-YNAY, AP_-_mgnl-YNAY, A-gge-YNA, P_-MO-gmeb, P_-DUdn-gma (intrusive)

Summary

The Discretion Granite mainly comprises medium-grained, porphyritic biotite monzogranite, with minor amounts of equigranular or weakly porphyritic biotite monzogranite (P_-DUdn-gme) and fine- to medium-grained, porphyritic biotite monzogranite (P_-DUdn-gma). The unit forms a large, composite intrusion at the northern edge of the Yarlarweelor Gneiss Complex, where it mostly intrudes reworked Archean granitic gneisses. The main phase of the granite has been dated at 1619 ± 15 Ma.

Distribution

The Discretion Granite is well exposed around, and northeast of, Mount Marquis on central Marquis, where it forms rounded hills covered with tors and boulders, and whalebacks. Smaller exposures are present north of Anderson Well and around Red Rock on the eastern edge of Marquis. The latter exposure continues for a short distance eastwards onto Milgun. Extensive sand plains separate the three main exposures, but airborne magnetic data indicate that the exposures are all linked below the surface. Therefore, the Discretion Granite probably forms an elongate intrusion over 40 km long and up to 10 km wide trending east-southeasterly.

Derivation of name

The Discretion Granite is named after Discretion Bore on eastern Marquis.

Lithology

The bulk of the Discretion Granite is composed of medium-grained, porphyritic biotite monzogranite with tabular phenocrysts of K-feldspar. Porphyritic, medium-grained monzogranite consists of 15–30% tabular phenocrysts of microcline in an anhedral or subhedral granular groundmass of microcline, oligoclase, biotite (2–7%), and small amounts of muscovite intergrown with biotite. Microcline phenocrysts commonly contain small inclusions of plagioclase, biotite, and quartz. Accessory mineral assemblages are magnetite, ilmenite, apatite, zircon, and allanite or, in more felsic samples, magnetite, apatite, and zircon.

All samples show some degree of recrystallization and development of secondary minerals, such as weak to moderate sericite alteration of plagioclase, epidote rims on magnetite, and titanite rims on ilmenite. Granophyric textures are present in some samples.

The Discretion Granite contains inclusions of porphyritic, fine-grained monzogranite and a fine-grained, equigranular, biotite-rich rock, in addition to inclusions of country rock close to the margins of the pluton. The monzogranite and biotite-rich inclusions are widespread, but only locally abundant. An exception is the area about 3–4 km west-northwest of Round Yard Bore, north of Mount Marquis, where angular to subangular monzogranite inclusions up to a metre in diameter are abundant. Both inclusion types are commonly round or elliptical. The monzogranite inclusions are typically less than 30 cm in diameter, and the biotite-rich inclusions up to 5 cm in diameter.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite, DISCRETION GRANITE	DUdn-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	porphyritic	p
Rock code		**P_-DUdn-gmp**

Contact relationships

Massive, medium-grained, porphyritic monzogranite of the Discretion Granite intruded mesocratic granitic gneiss about 2 km north of Anderson Well. In addition, several dykes of monzogranite with tabular K-feldspar phenocrysts cut mesocratic granitic gneiss (AP_-_mgnw-YNAY) about 300 m northwest of Anderson Well. About 5 km northeast of Cardingie Bore (Zone 50, MGA 564440E 7212250N), weakly porphyritic monzogranite of the Discretion Granite (P_-DUdn-gme) intruded strongly banded, pegmatite-veined, leucocratic granite gneiss (AP_-_mgnl-YNAY). About 3 km west-southwest of Round Yard Bore (Zone 50, MGA 570540E 7208050N), the Discretion Granite intruded grey, pegmatite-veined, gneissic biotite granodiorite (A-gge-YNA). The Discretion Granite also intruded diffusely banded, fine- to medium-grained monzogranite (P_-MO-gmeb) about 5 km east of Cardingie Bore (Zone 50, MGA 565740E 7209950N).

About 6 km east of Cardingie Bore (Zone 50, MGA 566140E 7209050N), dykes of medium-grained porphyritic monzogranite (P_-DUdn-gmp) intruded fine-grained porphyritic monzogranite (P_-DUdn-gma). In addition, north and north-northeast of Mount Marquis, highly elongate rafts of fine-grained porphyritic monzogranite are included within variably foliated, medium-grained, porphyritic monzogranite. The rafts are aligned roughly parallel with a variably tectonized igneous flow fabric defined by an alignment of tabular K-feldspar phenocrysts. The fabric defines a broad arc open to the southeast. The contact between the porphyritic and equigranular, medium-grained monzogranite (P_-DUdn-gme) around Red Rock is sharp and, in part, faulted. In the absence of veins, dykes, or inclusions of one phase in the other, their relative age could not be established.

Geochronology

P_-DUdn-gmp	*Maximum*	*Minimum*
Age (Ma)	1644 ± 6	1619 ± 15
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2001	Nelson, 1998

Medium-grained, porphyritic, monzogranite from about 2 km north of Anderson Well (Zone 50, MGA 592640E 7198050N) yielded a crystallization age of 1619 ± 15 Ma (Nelson, 1998). A fine- to medium-grained, weakly porphyritic monzogranite (P_-DUdn-gma) that comprises a 20 × 50 m pendant within the main phase of the Discretion Granite yielded a crystallization age of 1644 ± 6 Ma (Nelson, 2001).

References

Nelson, DR 1998, 142855: porphyritic monzogranite, Anderson Well; Geochronology Record 371: Geological Survey of Western Australia, 4p.

Nelson, DR 2001, 168751: biotite monzogranite, Round Yard Bore; Geochronology Record 219: Geological Survey of Western Australia, 5p.

DISCRETION GRANITE; subunit (P_-DUdn-gme)

Legend narrative

Equigranular or weakly porphyritic biotite monzogranite; medium grained

Rank	Member
Parent	DISCRETION GRANITE (P_-DUdn-gmp)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MW-od
Underlying units	AP_-_mgnl-YNAY (intrusive)

Summary

Equigranular to weakly porphyritic monzogranite is a volumetrically minor phase of the Discretion Granite.

Distribution

Equigranular to weakly porphyritic monzogranite of the Discretion Granite is common around Red Rock on the eastern edge of MARQUIS and eastwards onto the western edge of MILGUN. It outcrops over an area of about 4–5 km^2 and is surrounded by the main porphyritic phase of the Discretion Granite. The equigranular phase is partly covered by sandplain deposits, but its subsurface extent may not be much greater than presently exposed.

Lithology

Equigranular, medium-grained monzogranite has the same mineralogy as the porphyritic phase; namely, sparse tabular phenocrysts of microcline in an anhedral or subhedral granular groundmass of microcline, oligoclase, biotite (2–7%), and small amounts of muscovite intergrown with biotite. Microcline phenocrysts commonly contain small inclusions of plagioclase, biotite, and quartz. Accessory mineral assemblages are magnetite, ilmenite, apatite, zircon, and allanite or, in more felsic samples, magnetite, apatite, and zircon.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite, DISCRETION GRANITE	DUdn-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	even-grained/even textured/ equigranular	e
Rock code		**P_-DUdn-gme**

Contact relationships

The contact between the equigranular, medium-grained monzogranite and porphyritic monzogranite (P_-DUdn-gmp) is exposed around Red Rock. The contact is sharp and, in part, faulted, but in the absence of veins, dykes, or inclusions of one phase in the other, their relative age could not be established.

Geochronology

P_-DUdn-gme	*Maximum*	*Minimum*
Age (Ma)	1644	1619
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson 2001	Nelson, 1998

Equigranular, medium-grained monzogranite has not been dated directly, but is inferred to be the same age as the main porphyritic phase of the Discretion Granite, which has been dated at 1619 ± 15 Ma (Nelson, 1998).

References

Nelson, DR 1998, 142855: porphyritic monzogranite, Anderson Well; Geochronology Record 371: Geological Survey of Western Australia, 4p.

Nelson, DR 2001, 168751: biotite monzogranite, Round Yard Bore; Geochronology Record 219: Geological Survey of Western Australia, 4p.

DISCRETION GRANITE; subunit (P_-DUdn-gma)

Legend narrative

Fine- to medium-grained, porphyritic biotite monzogranite; tabular phenocrysts of K-feldspar

Rank	Member
Parent	DISCRETION GRANITE (P_-DUdn-gmp)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DUdn-gmp, P_-MW-od (intrusive)

Summary

Fine- to medium-grained, porphyritic biotite monzogranite with tabular phenocrysts of K-feldspar is a minor component of the Discretion Granite. The fine- to medium-grained monzogranite appears to form rafts within the main phase of the granite.

Distribution

Fine- to medium-grained, porphyritic biotite monzogranite of the Discretion Granite is present about 5.5 km east of Cardingie Bore on northwestern Marquis. In the area around Mount Marquis in the central part of Marquis, large, very elongate rafts of massive or weakly foliated, pale-grey, leucocratic biotite monzogranite (previously shown as P_gm on Marquis; Sheppard and Swager, 1999) are included within the Discretion Granite. These were previously thought to be dykes (Sheppard and Swager, 1999), but SHRIMP U–Pb zircon dating of one of these occurrences, shows it to be slightly older than the main mass of the Discretion Granite. These rocks are reassigned to a member of the Discretion Granite.

Lithology

Fine-grained, porphyritic monzogranite of the Discretion Granite is composed of 10–15% phenocrysts of microcline and subordinate plagioclase in an anhedral granular groundmass of quartz, oligoclase, microcline, biotite, and a little muscovite. Accessory mineral assemblages are the same as those in the coarser grained phases of the Discretion Granite. The rafts around Mount Marquis are medium to fine grained and most are weakly porphyritic, containing up to about 5% rounded, grey K-feldspar phenocrysts less than 7 mm in diameter.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite, DISCRETION GRANITE	DUdn-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	fine-grained	a
Rock code		**P_-DUdn-gma**

Contact relationships

About 6 km east of Cardingie Bore (Zone 50, MGA 566140E 7209050N), dykes of medium-grained porphyritic monzogranite (P_-DUdn-gmp) intruded fine-grained porphyritic monzogranite. In addition, north and north-northeast of Mount Marquis, highly elongate rafts of fine-grained porphyritic monzogranite are included within variably foliated medium-grained porphyritic monzogranite. The rafts are aligned roughly parallel with a variably tectonized igneous flow fabric defined by an alignment of tabular K-feldspar phenocrysts. The fabric defines a broad arc open to the southeast.

Geochronology

P_-DUdn-gma	*Maximum*	*Minimum*
Age (Ma)	1644 ± 6	1644 ± 6
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2001	Nelson, 2001

A fine- to medium-grained weakly porphyritic monzogranite that comprises a 20 × 50 m pendant within the main phase of the Discretion Granite yielded a crystallization age of 1644 ± 6 Ma (Nelson, 2001). The main porphyritic phase of the Discretion Granite (P_-DUdn-gmp) has been dated at 1619 ± 15 Ma (Nelson, 1998).

References

Nelson, DR 1998, 142855: porphyritic monzogranite, Anderson Well; Geochronology Record 371: Geological Survey of Western Australia, 4p.

Nelson, DR 2001, 168751: biotite monzogranite, Round Yard Bore; Geochronology Record 219: Geological Survey of Western Australia, 4p.

Sheppard, S and Swager, CP 1999. Geology of the Marquis 1:100 000 sheet: Geological Survey of Western Australia, 1:100 000 Geological Series Explanatory Notes, 21p.

PIMBYANA GRANITE (P_-DUpi-gmw)

Legend narrative

Massive, medium-grained, megacrystic and porphyritic biotite(–muscovite) monzogranite; tabular megacrysts of K-feldspar up to 7 cm long

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DUdi-grpv, P_-DUyn-gmv, P_-DU-gmv, P_-DU-gmvt, P_-DU-gpt, P_-nr-od, P_-mw-od (intrusive); P_-MEy-s (unconformable)
Underlying units	P_-POru-mgm, P_-LS-mlsg, P_-LS-mlsm, P_-PO-mgg, P_-PO-mtsf, P_-PO-mln, P_-PO-mli, P_-PO-mxq (intrusive)

Summary

The Pimbyana Granite is one of the largest granite units in the Gascoyne Province. It outcrops over a strike length of more than 120 km, and up to 30 km wide, in the Mangaroon Zone from northwestern MANGAROON to northwestern MOUNT AUGUSTUS. Much of the unit may comprise a single intrusion. The most abundant rock type is a coarse-grained, porphyritic to megacrystic biotite (–muscovite) monzogranite to syenogranite that contains tabular megacrysts of K-feldspar up to 7 cm long. Three specimens from the unit sampled for SHRIMP U–Pb zircon geochronology have yielded igneous crystallization ages of c. 1675 Ma.

Distribution

The Pimbyana Granite (P_-DUpi-gmw, P_-DUpi-gt, P_-DUpi-gmi) (Pearson et al., 1996; Martin et al., 2002) is the largest granite unit in the Mangaroon Zone. The bulk of the unit outcrops on MANGAROON and EDMUND, where it is mainly restricted to north of the Mangaroon Syncline and its extension to the southeast. Farther along strike to the southeast, the Pimbyana Granite forms a series of inliers and isolated exposures over an area of more than 60 km^2 amongst units of the Edmund Group and regolith on northeastern MOUNT PHILLIPS and adjacent northwestern MOUNT AUGUSTUS. The unit outcrops over a strike length of about 120 km. The Pimbyana Granite also forms an intrusion extending for nearly 30 km^2 on northwestern PINK HILLS. The granite is very well exposed, and forms extensive low rugged hills covered in boulders, tors, and whalebacks; the latter commonly have a reddish appearance on aerial photographs and in the field.

Derivation of name

The Pimbyana Granite is named after Pimbyana Creek (Zone 50, MGA 434000E 7350000N) on EDMUND. The name 'Pimbyana Granite' was first used by Pearson et al. (1996). A brief description was provided, along with two whole-rock chemical analyses. The synonym 'Pimbyana Granitoid' was introduced by Krapež (1999) but no justification was given for the name change.

Lithology

The most abundant rock type is a coarse-grained porphyritic to megacrystic biotite(–muscovite) monzogranite to syenogranite (P_-DUpi-gmw). Where the Pimbyana Granite contains abundant inclusions of metasedimentary and mafic meta-igneous rocks it is mapped as a separate unit (P_-DUpi-gmi).

The phenocrysts and megacrysts (i.e. phenocrysts larger than 5 cm) that characterize the Pimbyana Granite typically comprise 20–40% of the rock, and are tabular. The phenocrysts are commonly aligned to define an igneous foliation, which typically trends subparallel to the regional tectonic foliation in the area. Tabular phenocrysts and megacrysts typically have a microperthitic texture, and commonly contain inclusions of quartz, plagioclase, and biotite. However, in places the granite contains abundant rounded megacrysts up to 8 cm in diameter, some with graphic textures. For example, northeast of Bald Hill North, and between Bald Hill North and Henderson Bore, the Pimbyana Granite locally contains rounded megacrysts of K-feldspar that are up to 7 cm long and 6 cm wide. Some of the megacrysts are concentrated in narrow zones or channels where they may comprise up to 90% of the rock. Groundmass muscovite and biotite are commonly partly recrystallized, with some biotite replaced by chlorite. Sericitization of plagioclase is accompanied by titanite pseudomorphs after ilmenite or titanomagnetite.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite, PIMBYANA GRANITE	DUpi-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	megacrystic	w
Rock code		**P_-DUpi-gmw**

Contact relationships

The Pimbyana Granite intrudes metasedimentary rocks of the Pooranoo Metamorphics, and near the margins of intrusions, inclusions and screens of metasedimentary rock may be abundant. Elsewhere the granite typically contains scattered small (<5 cm diameter), dark-grey inclusions of biotite-rich metapelitic rock. Inclusions of vein quartz are locally abundant. On northwestern PINK HILLS, the Pimbyana Granite intrudes units of the Leake Spring Metamorphics and Moorarie Supersuite.

The megacrystic monzogranite to syenogranite phase is intruded by both the Dingo Creek Granite and the Yangibana Granite, and by extensive veins and dykes of muscovite–biotite granite (P_-DU-gmv) and tourmaline-bearing granite and pegmatite (P_-DU-gmvt, P_-DU-gpt). The Pimbyana Granite is unconformably overlain by the Yilgatherra Formation at the base of the Edmund Group along the flanks of the Mangaroon Syncline on central and western MANGAROON and on EDMUND.

About 200 m northwest of Frasers–Yangibana Prospect on south-central EDMUND, fine- to medium-grained and equigranular to sparsely porphyritic tonalite (P_-DUpi-gt) locally grades into medium-grained granite with scattered 2–6 cm long tabular K-feldspar megacrysts. The megacrystic phase locally forms veins in the tonalite, but the irregular nature of the veins and dykes, and the cuspate and lobate nature of the contacts, suggests that the tonalite was not fully crystallized when intruded by the megacrystic granite.

Geochronology

P_-DUpi-gmw	*Maximum*	*Minimum*
Age (Ma)	1675 ± 11	1673 ± 15
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2005	Nelson, 2002

The main phases of the Pimbyana Granite (P_-DUpi-gmw) have been dated using SHRIMP U–Pb in zircon. A porphyritic biotite–muscovite syenogranite from 5 km southeast of Yangibana Bore on EDMUND has an igneous crystallization age of 1673 ± 15 Ma (Nelson, 2002). A porphyritic to megacrystic biotite(–muscovite) monzogranite from the same phase 4 km southeast of Coorabie Tank on MANGAROON has an igneous crystallization age of 1675 ± 11 Ma (Nelson, 2005). The sample from EDMUND also has a xenocrystic zircon age component at 1788 ± 17 Ma, which is within uncertainty of the crystallization age of the Gooche Gneiss (P_-MOgo-mgn). The geochronology suggests that there is little or no age difference between the porphyritic to megacrystic phase of the Pimbyana Granite (P_-DUpi-gmw) and the fine- to medium-grained tonalite and granodiorite (P_-DUpi-gt), which is dated at 1674 ± 8 Ma. This conclusion is in accordance with observed field relationships.

References

Krapež, B 1999, Stratigraphic record of an Atlantic-type global tectonic cycle in the Palaeoproterozoic Ashburton Province of Western Australia: Australian Journal of Earth Sciences, v. 46, p. 71–87.

Martin, DM, Thorne, AM and Occhipinti, SA 2002, Edmund, W.A. Sheet 2150: Geological Survey of Western Australia, 1:100 000 Geological Series.

Nelson, DR 2002, 169060: porphyritic syenogranite, Yangibana Bore; Geochronology Record 134: Geological Survey of Western Australia, 4p.

Nelson, DR 2005, 178029: biotite monzogranite, Coorabie Tank; Geochronology Record 538: Geological Survey of Western Australia, 4p.

Pearson, JM, Taylor, WR and Barley, ME 1996, Geology of the alkaline Gifford Creek Complex, Gascoyne Complex, Western Australia: Australian Journal of Earth Sciences, v. 43, p. 299–309.

PIMBYANA GRANITE; subunit (P_-DUpi-gmi)

Legend narrative

Porphyritic, medium- to coarse-grained, biotite–muscovite granodiorite to syenogranite, with inclusions of metasedimentary and metamafic rock; tabular megacrysts of K-feldspar; includes minor tonalite and quartz diorite

Rank	Member
Parent	PIMBYANA GRANITE (P_-DUpi-gmw)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DUdi-grpv, P_-DUyn-gmv, P_-DU-gmv, P_-DU-gmvt, P_-DU-gpt, P_-nr-od, P_-mw-od (intrusive); P_-MEy-s (unconformable)
Underlying units	P_-PO-mtsf, P_-PO-mln, P_-PO-mli, P_-PO-mxq (intrusive)

Summary

Pimbyana Granite with abundant xenoliths of metasedimentary and metamafic rocks is transitional to the main mass of the granite (P_-DUpi-gmw). The xenolith-rich unit forms a series of irregular intrusions only on southern and southeastern EDMUND.

Distribution

Where the Pimbyana Granite contains abundant inclusions of metasedimentary and mafic meta-igneous rocks it is mapped as a separate unit (P_-DUpi-gmi). Inclusion-rich Pimbyana Granite forms a series of very irregularly shaped plutons from the Hook REE prospect on southern EDMUND east-southeast down to Pimbyana Creek in southeastern EDMUND, a distance of around 15 km.

Lithology

The most abundant rock type is a coarse-grained, porphyritic to megacrystic, biotite(–muscovite) monzogranite to syenogranite. The phenocrysts and megacrysts (i.e. phenocrysts larger than 5 cm) that characterize the Pimbyana Granite typically comprise 20–40% of the rock, and are tabular. The phenocrysts are commonly aligned to define an igneous foliation, which typically trends subparallel to the regional tectonic foliation in the area. Tabular phenocrysts and megacrysts typically have a microperthitic texture, and commonly contain inclusions of quartz, plagioclase, and biotite. However, in places the granite contains abundant rounded megacrysts up to 8 cm in diameter, some with graphic textures.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite, PIMBYANA GRANITE	DUpi-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	inclusion- or xenolith-rich	i
Rock code		**P_-DUpi-gmi**
Additional lithologies	quartz diorite, tonalite	

Contact relationships

See **P_-DUpi-gmw**

Geochronology

See **P_-DUpi-gmw**

P_-DUpi-gmi	*Maximum*	*Minimum*
Age (Ma)	1675	1673
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2005	Nelson, 2002

Pimbyana Granite with abundant xenoliths of metasedimentary and metamafic rocks is transitional to the main mass of the unit (P_-DUpi-gmw), which is dated at c. 1675 Ma (Nelson, 2002, 2005).

References

Nelson, DR 2002, 169060: porphyritic syenogranite, Yangibana Bore; Geochronology Record 134: Geological Survey of Western Australia, 4p.

Nelson, DR 2005, 178029: biotite monzogranite, Coorabie Tank; Geochronology Record 538: Geological Survey of Western Australia, 4p.

PIMBYANA GRANITE; subunit (P_-DUpi-gt)

Legend narrative

Equigranular, fine- to medium-grained, biotite tonalite and granodiorite

Rank	Member
Parent	PIMBYANA GRANITE (P_-DUpi-gmw)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA

Summary

Equigranular, fine- to medium-grained, biotite tonalite and granodiorite is a minor component of the Pimbyana Granite. A sample from the unit taken for SHRIMP U–Pb zircon geochronology yielded an igneous crystallization age of 1674 ± 8 Ma.

Distribution

Equigranular, fine- to medium-grained, biotite tonalite and granodiorite (P_-DUpi-gt) of the Pimbyana Granite is only abundant in the area east and southeast of the Star of Mangaroon mine on MANGAROON, and around the Frasers–Yangibana Prospect on EDMUND.

Lithology

This unit is an equigranular, fine- to medium-grained, biotite tonalite and granodiorite (P_-DUpi-gt). The unit is in part metamorphosed and foliated.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite, P IMBYANA GRANITE	DUpi-
Rock type	Igneous granitic	g
Lithname	tonalite	t
Rock code		**P_-DUpi-gt**

Contact relationships

About 200 m northwest of Frasers–Yangibana Prospect on south-central EDMUND, equigranular, fine- to medium-grained, biotite tonalite and granodiorite (P_-DUpi-gt) locally grades into a medium-grained granite with scattered 2–6 cm long tabular K-feldspar megacrysts. The megacrystic phase locally forms veins in the tonalite, but the irregular nature of the veins and dykes, and the cuspate and lobate nature of the contacts, suggests that the tonalite was not fully crystallized when intruded by the megacrystic granite.

Geochronology

P_-DUpi-gt	*Maximum*	*Minimum*
Age (Ma)	1674 ± 8	1674 ± 8
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2002	Nelson, 2002

A sample of fine- to medium-grained, equigranular biotite tonalite (P_-DUpi-gt) from about 500 m northwest of the Frasers–Yangibana Prospect has an igneous crystallization age of 1674 ± 8 Ma (Nelson, 2002), which is indistinguishable from the age of the porphyritic monzogranite to syenogranite phase. This sample is incorrectly described in Nelson (2002) as a metasandstone.

References

Nelson, DR 2002, 169054: quartz–plagioclase–biotite–orthoclase–muscovite schist, Fraser Prospect; Geochronology Record 127: Geological Survey of Western Australia, 5p.

TETLOW GRANITE
(P_-DUtl-mgt)

Legend narrative

Aegirine–augite- or hornblende-bearing metamorphosed quartz-diorite and metatonalite; scattered inclusions of amphibolite

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DUda-mgmu

Summary

The Tetlow Granite was previously described as a unit of ‘alkaline anorthositic gneiss’ by Williams et al. (1983), who described them briefly and presented partial whole-rock analyses for three samples. Sheppard and Farrell (2005) described these rocks as aegerine–augite bearing metaleucogabbros, and presented major and trace element analyses for five samples. The rocks are dominated by plagioclase ($An_{10–30}$), but are unusual for mafic rocks because the plagioclase is quite sodic ($An_{10–30}$) and they contain a ‘green clinopyroxene’, in addition to abundant titanite (up to 5%), and allanite, zircon, and xenotime. The rocks are reinterpreted as alkaline metamorphosed quartz-diorite and metatonalite. The Tetlow Granite forms thin layers and lenses that are almost entirely restricted to within the Davey Well Granite.

Distribution

Aegirine-augite- or hornblende-bearing metamorphosed quartz-diorite and minor metatonalite are largely confined to a southeasterly trending belt about 85 km long and about 10 km wide in the central part of the Gascoyne Province. Williams et al. (1983) noted that these alkaline rocks always form elongate bodies that are closely associated with large masses of foliated, coarsely porphyritic biotite monzogranite of the Davey Well Granite (P_-DUda-mgmu). However, there are no minerals in the Davey Well Granite indicative of alkaline affinity. The alkaline rocks form boudinaged lenses and layers about 20–300 m long and 2–25 m wide, commonly in concentrations 2–10 km^2 in areal extent. The main concentrations are north of New Well and west of Tommie Well on Eudamullah, and southwest of Yinnetharra Homestead and southeast of Mango Bore on Yinnetharra. Metamorphosed alkaline quartz diorite, tonalite, and quartz anorthosite outcrop as knolls or low ridges, and are commonly difficult to distinguish from the surrounding monzogranite on aerial photographs. Many of the alkaline rocks have dirty grey weathered surfaces resembling those of calc-silicate rocks.

Derivation of name

The Tetlow Granite is named after Tetlow Well (Zone 50, MGA 407053E 7270056N) on western Yinnetharra.

Lithology

Aegirine-augite- or hornblende-bearing metamorphosed quartz-diorite and metatonalite are medium- to coarse-grained, and range from metamorphosed quartz-diorite through metatonalite (with 10–25% pyroxene and amphibole), to metamorphosed quartz-anorthosite (>90% plagioclase) in minor segregations. Plagioclase phenocrysts are preserved in places. Locally, the rocks contain magnetite crystals 5–10 mm in diameter. The alkaline rocks commonly have a weak centimetre-scale compositional layering, defined by variations in the proportion of plagioclase to the mafic silicates and oxide minerals. A subtle compositional layering on the scale of a few metres is also present in some exposures. Aegirine–augite- or hornblende-bearing metamorphosed quartz-diorite and minor metatonalite locally contain elongate inclusions of amphibolite and fine- to medium-grained, metamorphosed, mesocratic quartz diorite.

At one locality about 20 km east-northeast of Eudamullah Homestead (Zone 50, MGA 377686E 7299747N), leucocratic metamorphosed quartz-diorite, along with minor amphibolite and coarse-grained hornblendite, define a horizon about 3–4 m thick within metasedimentary schist and gneissic medium-grained monzogranite. The leucocratic metamorphosed quartz-diorite contains a centimetre- to decimetre-scale crude banding defined by layers and lenses rich in hornblende. About 200 m to the north, a foliated leucocratic quartz diorite layer about 10 m thick (with locally abundant epidote), is bordered by a thin band of amphibolite.

Low-strain outcrops are uncommon. One example at site SXSYIN007885 (Zone 50, MGA 428087E 7254588N), just over 7 km east-southeast of Mango Bore on Yinnetharra, a layer of medium- to coarse-grained, foliated, leucocratic, metamorphosed quartz-diorite within macrocrystic metamonzogranite is exposed. The leucocratic, metamorphosed quartz-diorite has oval to round plagioclase macrocrysts with a texture very similar to that of the K-feldspar macrocrysts in the metamonzogranite. There are no clearly defined contacts between the two rock types.

Aegirine-augite- or hornblende-bearing metamorphosed quartz-diorite, which is the most common rock type, comprises plagioclase (oligoclase to andesine), subordinate aegerine–augite or amphibole, and lesser amounts of quartz (5–12%), epidote, titanite, and allanite. Other minerals present include grossular, titanomagnetite, zircon, and apatite. Accessory allanite and zircon are present even in samples of amphibolite (metamorphosed gabbro). With an increase in quartz, some of the rocks grade into tonalitic compositions, whereas others contain less than 10% mafic minerals, and are metamorphosed quartz anorthosites. Most of the rocks have an anhedral granular or granoblastic texture, but some samples (e.g. GSWA 183213) contain remnants of a subhedral granular igneous texture. In rocks with a granoblastic texture, aegerine–augite has straight grain boundaries with epidote and fine-grained titanite, and sharp boundaries with plagioclase. In some samples aegerine–augite forms oikocrysts with small inclusions of hornblende, quartz, and plagioclase. Amphibole ranges from hornblende to a sodic hornblende with deep bluish-green pleochroism. Epidote, titanite, and grossular may form fine-grained clots up to 10 mm in diameter with blebby quartz inclusions. Titanite, which constitutes about 1–5% of the rocks, forms idioblastic 1–2 mm long crystals with blebby inclusions of quartz, as well as fine-grained xenoblastic crystals. Allanite is typically partly or wholly altered and is mantled by epidote or, less commonly, titanite. Titanomagnetite has straight grain boundaries adjacent to titanite and allanite.

The metamorphosed quartz-diorite, at the relatively low-strain exposure at site SXSYIN007855, contains about 50% plagioclase (andesine), 15% quartz, and about 30% diopside and tremolite, with a few percent titanite and scattered altered allanite crystals. Microcline forms rare patches or inclusions in plagioclase. Most of the rock has a granoblastic texture, but there are some domains with a finer grain size and subgrain quartz development.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite, TETLOW GRANITE	DUtl-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metatonalite	t
Rock code		**P_-DUtl-mgt**

Contact relationships

Aegirine–augite- or hornblende-bearing metamorphosed quartz-diorite and minor metatonalite, and surrounding metamonzogranite of the Davey Well Granite, were metamorphosed at amphibolite-facies conditions, and all have the same moderate to strong tectonic foliation or L-tectonite fabric. Contacts between the metamorphosed alkaline rocks and metamonzogranite are typically tectonic. However, at one relatively low-strain locality 5.5 km northwest of New Well on EUDAMULLAH (Zone 50, MGA 392922E 7297584N), field relationships suggest that the metamorphosed, alkaline, leucocratic quartz-diorite is older than the monzogranite; monzogranite apophyses in metamorphosed quartz-diorite are finer grained and less porphyritic than the metamonzogranite away from the contact, and the margins of the metamorphosed quartz-diorite is altered to epidote, whereas the adjacent metamonzogranite is fresh.

Geochronology

P_-DUtl-mgt	*Maximum*	*Minimum*
Age (Ma)	1663 ± 5	1663 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Wingate et al., 2009	Wingate et al., 2009

Metamorphosed, leucocratic, alkaline quartz-diorite was sampled for SHRIMP U–Pb zircon geochronology from a 120-metre long layer about 6.7 km south-southeast of Davey Well on eastern EUDAMULLAH (Zone 50, MGA 392922E 7297584N). The sample (Wingate et al., 2009) is a gneissic rock composed of plagioclase–quartz–aegerine-augite–epidote–titanite–grossular–allanite–hornblende–titanomagnetite. The majority of zircons provided a crystallization age of 1663 ± 5 Ma (Wingate et al., 2009). The igneous crystallization age of the metamorphosed, leucocratic, alkaline quartz-diorite is indistinguishable from that of the Davey Well Granite (1667 ± 4 Ma). In addition, prliminary SHRIMP U–Pb dating of titanite that grew during medium-grade metamorphism in samples GSWA 88471 and 183213, suggests an age of c. 1280 Ma for metamorphism.

References

Sheppard, S and Farrell, TR 2005, Aegerine–augite bearing meta-leucogabbros in the Gascoyne Complex: Geological Survey of Western Australia, Annual Review 2004–05, p. 53–58.

Williams, SJ, Williams, IR, Chin, RJ, Muhling, PC and Hocking, RM 1983, Mount Phillips, WA: Geological Survey of Western Australia, 1:250 000 Geological Series Explanatory Notes, 29p.

Wingate, MTD, Kirkland, CL, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183207: metadiorite, Teddy Bore; Geochronology Record 769: Geological Survey of Western Australia, 4p.

YANGIBANA GRANITE (P_-DUyn-gmv)

Legend narrative

Equigranular to locally weakly porphyritic, medium-grained biotite–muscovite monzogranite; locally contains tourmaline; may contain inclusions of metasedimentary rock or porphyritic granodiorite

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-gpt (intrusive)
Underlying units	P_-MOgo-mgn, P_-PO-mtsf, P_-DUpi-gmw (intrusive)

Summary

Massive, leucocratic, medium-grained biotite–muscovite syenogranite to monzogranite of the Yangibana Granite outcrops in the Mangaroon Zone on EDMUND and MOUNT PHILLIPS. The unit forms two irregular shaped intrusions. Two specimens from the unit sampled for SHRIMP U–Pb zircon geochronology have yielded igneous crystallization ages of c. 1660 Ma.

Distribution

The Yangibana Granite mostly outcrops on EDMUND, but extends southeast across the boundary onto the northern edge of MOUNT PHILLIPS. The granite forms two irregular plutons, one on EDMUND, centred south of the Lions Ear rare earth element (REE) prospect, and the other centred southeast of the Frasers–Yangibana REE Prospect. The latter intrusion covers about 100 km^2, and the former, about 90 km^2. Both intrusions are composite bodies, composed of inclusion-poor (P_-DUyn-gmv) and inclusion-rich (P_-DUyn-gmi) phases. Thin (up to 2 cm wide) schlieren of biotite, which trend parallel to the edge of the pluton, form part of the Yangibana Granite adjacent to, and a few hundred metres south into the pluton.

Derivation of name

The Yangibana Granite was named after Yangibana Creek (Zone 50, MGA 411500E 7356300N) on EDMUND. The unit was named and described by Pearson (1996) and mentioned by Pearson et al. (1996). This definition expands on the distribution of the unit as described by Pearson (1996).

Lithology

The Yangibana Granite (P_-DUyn-gmv; Pearson, 1996; Martin et al., 2002) is a massive, leucocratic, medium-grained biotite–muscovite syenogranite to monzogranite, which ranges from being equigranular to slightly porphyritic. Locally the granite contains clots of tourmaline.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite, YANGIBANA GRANITE	DUyn-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	muscovite	v
Rock code		**P_-DUyn-gmv**

Contact relationships

Dykes and veins of the Yangibana Granite intrude metasedimentary rocks in the area, and in some areas the abundance of metasedimentary material within the granite warrants a separate mappable unit (P_-DUyn-gmi). Dykes and veins of the granite consistently intrude the Pimbyana Granite; however, its relationship to the extensive Dingo Creek Granite was not observed during mapping. Some thin tourmaline-bearing pegmatite dykes (P_-DU-gpt) intrude the Yangibana Granite. Most of these are too small to show on the map but some are large enough to show; for example a pegmatite dyke 3.5 km west of Henderson Bore that intrudes the Pimbyana Granite.

Geochronology

P_-DUyn-gmv	*Maximum*	*Minimum*
Age (Ma)	1660 ± 9	1659 ± 10
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2002a	Nelson, 2002b

The granite has been dated at two localities on EDMUND: 4 km southeast of Fraser Bore (Nelson, 2002b) and 4 km southeast of Yangibana Bore (Nelson, 2002a). Nineteen zircons from sample 169055 were selected for SHRIMP U–Pb dating; of these, the youngest group of 15 zircons defines an age of 1659 ± 10 Ma, interpreted as the age of igneous crystallization (Nelson, 2002a). Sixteen concordant to slightly discordant analyses of 16 zircons in sample GSWA 169059 selected for analysis gave an age of 1660 ± 9 Ma, which is interpreted as the crystallization age.

References

Martin, DM, Thorne, AM and Occhipinti, SA 2002, Edmund, W.A. Sheet 2150: Geological Survey of Western Australia, 1:100 000 Geological Series.

Nelson, DR 2002a, 169059: muscovite–biotite monzogranite, Yangibana Bore; Geochronology Record 133: Geological Survey of Western Australia, 4p.

Nelson, DR 2002b, 169055: biotite–muscovite monzogranite, Fraser Well; Geochronology Record 128: Geological Survey of Western Australia, 4p.

Pearson, JM 1996, Alkaline rocks of the Gifford Creek Complex, Gascoyne Province, Western Australia — their petrogenetic and tectonic significance: University of Western Australia, Perth, PhD thesis (unpublished) 286p.

Pearson, JM, Taylor, WR and Barley, ME 1996, Geology of the alkaline Gifford Creek Complex, Gascoyne Complex, Western Australia: Australian Journal of Earth Sciences, v. 43, p. 299–309.

YANGIBANA GRANITE
(P_-DUyn-gmi)

Legend narrative

Equigranular to locally weakly porphyritic, medium-grained biotite–muscovite monzogranite with abundant inclusions of metasedimentary rock or porphyritic granodiorite

Rank	Member
Parent	YANGIBANA GRANITE (P_-DUyn-gmv)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-gpt (intrusive); P_-MEy-s (unconformable)
Underlying units	P_-MOgo-mgn, P_-PO-mtsf, P_-DUpi-gmw (intrusive)

Summary

The Yangibana Granite forms two irregularly shaped intrusions of leucocratic, medium-grained biotite–muscovite monzogranite. Roughly equal amounts of the intrusions are composed of inclusion-rich monzogranite (P_-DUyn-gmi) and inclusion-poor monzogranite (P_-DUyn-gmv).

Distribution

The inclusion-rich phase of the Yangibana Granite (P_-DUyn-gmi) extends from around Yangibana Bore on southwestern EDMUND, east-southeastwards onto the northeastern corner of MOUNT PHILLIPS. The unit forms part of two irregularly shaped plutons.

Lithology

The Yangibana Granite (P_-DUyn-gmi) is a massive, leucocratic, medium-grained biotite–muscovite syenogranite to monzogranite, with abundant inclusions of metasedimentary rock or porphyritic granodiorite.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite, YANGIBANA GRANITE	DUyn-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	inclusion- or xenolith-rich	i
Rock code		**P_-DUyn-gmi**

Geochronology

P_-DUyn-gmi	*Maximum*	*Minimum*
Age (Ma)	1660	1659
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2002a	Nelson, 2002b

This phase of the Yangibana Granite has not been directly dated but is interpreted to be the same age as the main phase (P_-DUyn-gmv), dated at c. 1660 Ma

References

Nelson, DR 2002a, 169059: muscovite–biotite monzogranite, Yangibana Bore; Geochronology Record 133: Geological Survey of Western Australia, 4p.

Nelson, DR 2002b, 169055: biotite–muscovite monzogranite, Fraser Well; Geochronology Record 128: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-ggb)

Legend narrative

Mesocratic, medium-grained, equigranular biotite granodiorite

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-gpt (intrusive); P_-MEy-st (faulted)
Underlying units	P_-DUpi-gmw (mingled)
Primary mineralogy	biotite

Summary

Mesocratic biotite granodiorite is a very minor component of the Durlacher Supersuite. It comprises several plugs in the Mangaroon Zone.

Distribution

Mesocratic biotite granodiorite forms several small plutons (<4 km^2) in the area between White Bore and Old Alma Well in the eastern part of MANGAROON.

Lithology

The mesocratic biotite granodiorite is much darker than most other granites of the Durlacher Supersuite, and it has a pitted texture on weathered surfaces. Rocks of this unit characteristically contain crystals of hydrated allanite about 1 mm long. The granodiorite is moderately recrystallized to an anhedral granular rock composed of sutured quartz, sodic plagioclase, microcline, greenish-brown biotite, and sericite.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	Igneous granitic	g
Lithname	granodiorite	g
1st qualifier	biotite	b
Rock code		**P_-DU-ggb**

Contact relationships

Mesocratic biotite granodiorite intrudes megacrystic biotite monzogranite of the Pimbyana Granite about 2.8 km southeast of White Bore (Zone 50, MGA 385570E 7374080N). Elsewhere, in the pluton centred southwest of North Well, the granodiorite contains abundant xenocrysts of partly rounded tabular K-feldspar crystals, and has diffuse contacts with megacrystic monzogranite of the Pimbyana Granite. These observations are consistent with local mingling of the two granite units. Mesocratic biotite granodiorite is intruded by veins and dykes of muscovite–tourmaline pegmatite (P_-DU-gpt). One of the plutons has a sharp contact with the Dingo Creek Granite, but the relative ages of the two units cannot be determined.

Mesocratic biotite granodiorite is in faulted contact with the Yilgatherra Formation at the base of the Edmund Group.

Geochronology

P_-DU-ggb	*Maximum*	*Minimum*
Age (Ma)	1674	1674
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2002	Nelson, 2002

Mesocratic biotite granodiorite has not been dated directly. However, the granodiorite appears to be coeval with the Pimbyana Granite (P_-DUpi-gmw), dated at c. 1675 Ma.

References

Nelson, DR 2002, 169054: quartz–plagioclase–biotite–orthoclase–muscovite schist, Fraser Prospect; Geochronology Record 127: Geological Survey of Western Australia, 5p.

Durlacher Supersuite; subunit (P_-DU-ggp)

Legend narrative

Grey, massive, medium-grained, porphyritic biotite granodiorite

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-mw-od (intrusive)
Underlying units	P_-MO-mggn, P_-PO-mtsf, P_-PO-mln (intrusive); P_-DU-gmv (mingled)

Summary

Grey, massive, medium-grained, porphyritic biotite granodiorite is a minor component of the Durlacher Supersuite in the Mangaroon Zone. A sample from the unit taken for SHRIMP U–Pb zircon geochronology yielded an igneous crystallization age of 1678 ± 6 Ma.

Distribution

Grey, massive, medium-grained, porphyritic biotite granodiorite (P_-DU-ggp) is exposed in the northwestern corner of MANGAROON, and in the southwestern corner of MAROONAH to the north. In addition, several small exposures, some of which are too small to show on the map, are present in the northwestern corner of MAROONAH. The granodiorite outcrops as whalebacks and tors amongst sheetwash and calcrete. It forms numerous plugs, which may be part of a large pluton or plutons below the current level of exposure.

Lithology

Typically, medium-grained, porphyritic biotite granodiorite contains up to 30% tabular phenocrysts of K-feldspar 1–2 cm long. The phenocrysts locally define a weak flow fabric.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	Igneous granitic	g
Lithname	granodiorite	g
1st qualifier	porphyritic	p
Rock code		**P_-DU-ggp**

Contact relationships

The granodiorite intrudes the various Paleoproterozoic metasedimentary rock units of the Pooranoo Metamorphics east of Maroonah Homestead, and foliated and gneissic granodiorite and tonalite (P_-MO-mggn) in the north. Near the edges of the pluton east of the homestead, the granodiorite contains numerous inclusions of psammitic schist and gneiss, and feldspathic metasandstone (P_-PO-mtsf) and biotite-rich pelitic gneiss (P_-PO-mln). About 2 km northeast of Maroonah Homestead (Zone 50, MGA 352919E 7404146N), the granodiorite contains round to elliptical inclusions, up to 5 m in diameter, of muscovite–biotite granite (P_-DU-gmv). Some of the inclusions contain segregations of tourmaline pegmatite, veins of which intrude the porphyritic granodiorite. Collectively, these features imply that the granodiorite intruded the muscovite–biotite granite before the latter had entirely solidified; that is, the two plutons are the same age.

Geochronology

P_-DU-ggp	*Maximum*	*Minimum*
Age (Ma)	1678 ± 6	1678 ± 6
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2005	Nelson, 2005

A granodiorite sample (GSWA 178030) from about 3 km southeast of Robinson Well on MAROONAH contains a single group of zircons dated by SHRIMP U–Pb at 1678 ± 6 Ma, which defines the igneous crystallization age (Nelson, 2005). Given the field relationships outlined above, this date also is the age of the igneous crystallization of the muscovite–biotite granite (P_-DU-gmv).

References

Nelson, DR 2005, 178030: biotite granodiorite, Robinson Well; Geochronology Record 539: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-ggvs)

Legend narrative

Schlieric, medium-grained biotite–muscovite granodiorite and minor flow-banded biotite–muscovite monzogranite, both with abundant inclusions of metasedimentary rock and augen gneiss

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-gmb, P_-DUpi-gmw, P_-DUdi-grpv, P_-DU-gmv, P_-DU-gmvt, P_-DU-gpt (intrusive); P_-MEy-s (unconformable)
Underlying units	P_-MOgo-mgn, P_-PO-mtsf, P_-PO-mln, P_-PO-mli, P_-PO-mkq (intrusive)

Summary

Schlieric, biotite–muscovite granodiorite is the oldest unit of the Durlacher Supersuite, as indicated by both the field relationships and its SHRIMP U–Pb zircon igneous crystallization age of 1677 ± 5 Ma. The granodiorite is mainly confined to the southern half of the Mangaroon Zone (that is, south of the Mangaroon Syncline), where it is closely associated with migmatitic pelitic gneiss (P_-PO-mli) of the Pooranoo Metamorphics. The paucity of the granodiorite in the northern half of the Mangaroon Zone coincides with the presence of non-melted pelitic gneiss (P_-PO-mln) and reflects a greater amount of uplift south of the Mangaroon Syncline relative to the north side. The granodiorite forms irregularly shaped intrusions that are elongate in a southeasterly direction, parallel to the structural grain in the enclosing metasedimentary rocks. The intrusions are strongly layered, with the layering defined by schlieren, by abundant inclusions of country rock, and by variations in composition, grain size, and phenocryst content of the granodiorite. The granodiorite has an S-type character.

Distribution

Schlieric, inclusion-rich, muscovite–biotite granodiorite extensively intrudes the Pooranoo Metamorphics, and Gooche Gneiss, in the Mangaroon Zone south of the Mangaroon Syncline; outcrops of the unit are sparse north of the syncline. The granodiorite forms a southeast-trending belt on MANGAROON, and onto northeastern EUDAMULLAH and northwestern MOUNT PHILLIPS. There is also a very small (<2 km^2) intrusion of the granodiorite near the northern edge of MOUNT PHILLIPS, centred about 4 km east-southeast of Tabletop Well. The granodiorite forms irregular plutons composed of numerous steeply dipping to vertical sheet-like bodies with numerous screens of country rock. The intrusions are elongate parallel to the regional structural grain. The ends of the intrusions comprise numerous tongues of granodiorite with stoped blocks and inclusions of country rock. The granodiorite also intrudes the Pooranoo Metamorphics north of the Mangaroon Syncline, but forms only veins and thin sheets that are too small to display separately. On EDMUND, a biotite–muscovite–cordierite tonalite with abundant inclusions (up to 30%) of pelitic and calc-silicate schist outcrops as an irregularly shaped plug approximately 0.5 km^2 about 2 km southwest of Fraser Bore on EDMUND.

Areas underlain by the granodiorite consist of undulating countryside similar to that of the Pooranoo Metamorphics, but with outcrops consisting mainly of boulders with some tors and pavements.

Lithology

The most abundant rock type is a layered, medium-grained, sparsely porphyritic, muscovite–biotite granodiorite which hosts abundant inclusions of metasedimentary rock (pelitic schist and gneiss, psammitic schist and gneiss, and feldspathic metasandstone), with lesser amounts of vein quartz (with or without tourmaline), pegmatite, and augen gneiss (Gooche Gneiss; P_-MOgo-mgn). Inclusions can usually be related directly to the local country rocks. In the area between Minga Bar Well and Coolinbah Well near the western edge of Mangaroon, a biotite–muscovite phase is commonly interlayered with the granodiorite. The granodiorite is heterogeneous on both outcrop and regional scales. Layering in the granodiorite is defined by composition (locally monzogranitic or tonalitic), grain size, and phenocryst abundance. Some layers are rich in rounded megacrysts of K-feldspar up to about 5 cm in diameter and in inclusions of pegmatite up to 10 cm in diameter. Along the southern edge of MANGAROON (for example Zone 50, MGA 384470E 7345340N) the megacrysts can be traced along to partly disaggregated dykes of pegmatite, which appear to have intruded the granite before it had solidified.

On EDMUND, the plug of biotite–muscovite–cordierite tonalite is massive, medium grained, and equigranular. Cordierite is very fresh, and is readily identifiable in hand-specimen as a grey anhedral mineral. The tonalite contains accessory tourmaline, titanite and opaques. The presence of abundant muscovite and cordierite, and the large concentration of metasedimentary inclusions, suggests that the granite represents an anatectic melt derived from sedimentary material.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	Igneous granitic	g
Lithname	granodiorite	g
1st qualifier	muscovite	v
2nd qualifier	schlieric	s
Rock code		**P_-DU-ggvs**
Additional lithologies	monzogranite	

Contact relationships

Schlieric, inclusion-rich, muscovite–biotite granodiorite normally contains up to 50% inclusions and screens, chiefly of the main metasedimentary rock units in the Pooranoo Metamorphics, including pelitic gneiss (P_-

PO-mln, P_-PO-mli), and psammitic schist and gneiss and feldspathic metasandstone (P_-PO-mtsf), but also of foliated and gneissic granite of the Gooche Gneiss (P_-MOgo-mgn). Contacts between the granodiorite and Pooranoo Metamorphics, both at outcrop scale and smaller scales, are commonly gradational. The gneissic layering in inclusions is truncated at a high angle by enclosing granodiorite, indicating that the schlieric, inclusion-rich granodiorite post-dated the first deformation and associated high-grade metamorphism of the Mangaroon Orogeny. The granodiorite commonly contains a southeast-striking, steeply dipping tectonic foliation parallel to S_{2m} in rocks of the enclosing Pooranoo Metamorphics, which is absent or less-well developed in the granites that intrude the granodiorite. The granodiorite typically displays a weak to prominent igneous layering parallel to the S_{2m} foliation, and veins and dykes intrude along the S_{2m} fabric in the country rocks. Larger intrusions of granodiorite are composed of steeply dipping, southeast-striking sheets. Collectively, these features indicate that the granodiorite was emplaced broadly coeval with D_{2m}.

Schlieric, inclusion-rich, muscovite–biotite granodiorite is intruded by most of the other major granite units of the Durlacher Supersuite; for example, the Pimbyana Granite (P_-DUpi-gmw, P_-DUpi-gt), Dingo Creek Granite (P_-DUdi-grpv), muscovite–biotite granite (P_-DU-gmv, P_-DU-gmvt), and tourmaline–muscovite pegmatite and leucocratic granite (P_-DU-gpt). Thin (<1 m-wide) dykes of equigranular, medium-grained granite (P_-DU-gmb) cut the plug of cordierite-bearing tonalite on EDMUND, but are too small to show on the map. North of Doorawarra Well on western MANGAROON, schlieric, inclusion-rich, muscovite–biotite granodiorite is unconformably overlain by the Yilgatherra Formation at the base of the Edmund Group.

Geochronology

P_-DU-ggvs	*Maximum*	*Minimum*
Age (Ma)	1677 ± 5	1677 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2005	Nelson, 2005

The schlieric, inclusion-rich granodiorite was sampled about 3 km south of Russell Well (Zone 50, MGA 363140E 7357610N) for SHRIMP U–Pb zircon geochronology. Out of 26 zircons analysed from the sample, the youngest 12 grains define a single group at 1677 ± 5 Ma, interpreted as the igneous crystallization age of the granodiorite (Nelson, 2005). This is nominally the oldest crystallization age in the Durlacher Supersuite, and is consistent with the field relationships.

References

Nelson, DR 2005, 178027: biotite–muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-gmb)

Legend narrative

Equigranular medium-grained biotite granite

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	P_-DUpi-gmw

Summary

Medium-grained biotite granite is a very minor component of the Durlacher Supersuite in the Mangaroon Zone.

Distribution

Medium-grained biotite granite is confined to a small pluton, and a few plugs scattered over MANGAROON and EDMUND. The largest intrusion, which is nearly 4 km long and about 1.5 km wide, outcrops west of Alma Outcamp.

Lithology

Medium-grained biotite granite is typically equigranular and massive, with few inclusions. In places the granite has a well-developed flow banding. Parts of the unit contain up to 10% tabular and round K-feldspar phenocrysts 5–10 mm long and scattered oval quartz phenocrysts 3–4 mm in diameter.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	biotite	b
Rock code		**P_-DU-gmb**

Contact relationships

Veins and dykes of medium-grained biotite granite intrude strongly megacrystic, coarse-grained biotite monzogranite of the Pimbyana Granite.

Geochronology

P_-DU-gmb	*Maximum*	*Minimum*
Age (Ma)	1673	1619
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2002	Nelson, 1998

Medium-grained biotite granite has not been dated. It is younger than the Pimbyana Granite, but its minimum age is unconstrained. Medium-grained biotite granite is inferred to be part of the Durlacher Supersuite and, therefore, to have a minimum age of c. 1620 Ma.

References

Nelson, DR 1998, 142855: porphyritic monzogranite, Anderson Well; Geochronology Record 371: Geological Survey of Western Australia, 4p.

Nelson, DR 2002, 169060: porphyritic syenogranite, Yangibana Bore; Geochronology Record 134: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-gmp)

Legend narrative

Fine- to medium-grained biotite(–muscovite) monzogranite; porphyritic; contains small biotite-rich clots

Rank	Formation
Parent	Durlacher Supersuite P_-DU-g
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	P_-PO-mln, P_-PO-mtsf, P_-DU-mog (intrusive)

Summary

Fine- to medium-grained, porphyritic biotite(–muscovite) monzogranite is a minor component of the Durlacher Supersuite. The unit forms two intrusions in the Mangaroon Zone, as well as a couple of plugs and some accompanying dykes.

Distribution

Fine- to medium-grained porphyritic biotite(–muscovite) monzogranite is largely confined to an intrusion greater than 25 km^2 in area south and southwest of Collins Well on MAROONAH, and to an intrusion covering about 50 km^2 that straddles the boundary between MANGAROON and EUDAMULLAH near Stone Tank Well. The pluton on MAROONAH probably extends farther west onto TOWERA, where it is yet to be mapped. The pluton near Stone Tank Well strikes southeast, and it is about 18 km long, around 4 km long at its northwestern end, but tapering to about 1 km wide at its southeastern end. A pluton of the same rock type also outcrops on the southern edge of MANGAROON around Nelsons Bore.

The porphyritic biotite(–muscovite) monzogranite forms low hills covered with tors and boulders, or pavements amongst sheetwash and colluvium.

Lithology

Fine- to medium-grained, porphyritic biotite(–muscovite) monzogranite is typically massive. It contains phenocrysts of microperthite/microcline in an anhedral granular groundmass with a grain size of 1.5 – 3.0 mm. The phenocrysts have abundant subhedral plagioclase inclusions, as well as some quartz and biotite inclusions. The rocks contain up to 10% biotite and less than 1% muscovite. The porphyritic texture and a greater abundance of biotite distinguish it from the muscovite–biotite granite (P_-DU-gmv). Accessory apatite, allanite, and zircon are predominantly enclosed within, or adjacent to, biotite. Rare magnetite is present, although most has been replaced by epidote in conjunction with the sericitization of plagioclase. Biotite crystals commonly contain lamellae of prehnite or, less commonly, epidote.

The monzogranite is typically homogeneous, but about 5 km north-northeast of Hogan Well the unit consists of alternating sheets of sparsely and strongly porphyritic monzogranite. The sheets are 0.3 – 1.0 m thick and dip steeply to the south-southeast.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	porphyritic	p
Rock code		**P_-DU-gmp**

Contact relationships

The monzogranite, and associated dykes, intrude pelitic gneiss (P_-PO-mln) and psammitic schist and gneiss and feldspathic metasandstone (P_-PO-mtsf) of the Pooranoo Metamorphics. Adjacent to the pluton on MAROONAH, feldspathic metasandstone is hornfelsed. About 5.6 km west-northwest of North Mullara Bore, porphyritic, biotite–muscovite monzogranite intrudes massive metagabbro (P_-DU-mog).

Geochronology

P_-DU-gmp	*Maximum*	*Minimum*
Age (Ma)	1696 ± 20	1696 ± 20
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2004	Nelson, 2004

The monzogranite was sampled for SHRIMP U–Pb zircon geochronology about 4.5 km north-northeast of Hogan Well (Zone 50, MGA 349780E 7412530N). The monzogranite has an igneous crystallization age of 1696 ± 20 Ma, derived from the youngest group of five zircons (Nelson, 2004).

References

Nelson, DR 2004, 169090: porphyritic biotite monzogranite, Hogan Well; Geochronology Record 46: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-gmv)

Legend narrative

Leucocratic, medium-grained, muscovite–biotite granodiorite and monzogranite; equigranular to weakly porphyritic

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-gpt (intrusive); P_-MEy-s (unconformable)
Underlying units	P_-MOgo-mgn, P_-LS-mlsg, P_-LS-mlsm, P_-MO-gmeb, P_-MO-gmp, P_-PO-mtsf, P_-PO-mln, P_-PO-mli, P_-DUpi-gmw, P_-DUdi-grpv (intrusive)

Summary

Leucocratic, medium-grained, biotite–muscovite granodiorite and monzogranite is a widespread and voluminous component of the Durlacher Supersuite. The vast majority of the unit outcrops in the Mangaroon Zone, but deformed and metamorphosed equivalents, namely foliated leucocratic muscovite(–biotite) metamonzogranite (P_-DU-mgml) and foliated leucocratic muscovite(–tourmaline) metamonzogranite (P_-DU-mgmt), are abundant in the Mutherbukin Zone. The biotite–muscovite granodiorite and monzogranite contains the same rock types as the Yangibana Granite on EDMUND, but the latter name has been retained only for intrusions on EDMUND, because geochronological studies indicate that at least some of the intrusions on MANGAROON and MAROONAH are probably significantly younger. Intrusions assigned to biotite–muscovite granodiorite and monzogranite may span the age range of the Durlacher Supersuite.

Distribution

Biotite–muscovite granodiorite and monzogranite (P_-DU-gmv, P_-DU-gmvt) outcrops mainly within the Mangaroon Zone. The unit is voluminous on MAROONAH, and outcrops as plutons, plugs, and dykes over a wide area on MANGAROON, and southeastwards onto the northeastern corner of EUDAMULLAH and the adjacent northwestern corner of MOUNT PHILLIPS. The unit also forms several plugs and sheet-like bodies mainly along the southern flank of the Minnie Creek batholith.

Biotite–muscovite granodiorite and monzogranite forms a large pluton (>240 km^2) centred west of the Joy Helen prospect on MAROONAH. This pluton comprises muscovite–biotite granodiorite and monzogranite, and, at its northwestern and southern ends, muscovite–tourmaline (–biotite) monzogranite. Exposures of weakly porphyritic, muscovite–biotite granodiorite and monzogranite west of Middle Bore, and east and south of Red Rock Bore, represent either continuations of the same pluton or separate intrusive bodies.

Lithology

Biotite–muscovite granodiorite and monzogranite consists of equigranular or weakly porphyritic, medium-grained, biotite–muscovite granodiorite and monzogranite (P_-DU-gmv), and medium-grained, muscovite–tourmaline (–biotite) monzogranite (P_-DU-gmvt). These two rock types may grade into each other; for example, in the pluton about 8.5 km west-northwest of Mundong Well on MAROONAH. In this pluton the monzogranite is locally garnet bearing. The rocks are uniformly massive, except where cut by narrow faults or shear zones. The unit outcrops as whalebacks and pavements, which are readily visible on aerial photographs, and low rugged hills covered with tors and boulders.

Biotite–muscovite granodiorite and monzogranite typically contains less than 10% tabular microcline phenocrysts, 7–15 mm long in a groundmass with a 2–3 mm average grain size. The phenocrysts locally define a weak flow fabric and contain inclusions of quartz and plagioclase; the latter are commonly aligned with the microcline crystal faces. Rare oval-shaped phenocrysts up to 4 cm long are present in places. Muscovite is locally more abundant than biotite, although in the eastern part of the large pluton west of the Joy Helen Prospect, the reverse is typical. Biotite–muscovite granodiorite and monzogranite locally has clots or splays of fine- to medium-grained tourmaline crystals. Plagioclase is extensively sericitized, and biotite is recrystallized and partly replaced by chlorite.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	muscovite	v
Rock code		**P_-DU-gmv**
Additional lithologies	monzogranite	

Contact relationships

Plutons, plugs, and dykes of biotite–muscovite granodiorite and monzogranite intrude all the metamorphosed sedimentary and igneous rocks in the Mangaroon and Boora Boora Zones. There is commonly little evidence of contact metamorphism associated with the biotite–muscovite granodiorite and monzogranite, which may be, in part, related to the quartzofeldspathic nature of many of the country rocks. However, even pelitic schists around and to the southeast of the Laura Prospect on MAROONAH, show no evidence of hornfels texture. The large pluton centred west of the Joy Helen Prospect on MAROONAH contains several screens of pelitic schist. Inclusions are not common in the biotite–muscovite granodiorite and monzogranite, but 1.2 km southeast of Red Rock Bore inclusions of pegmatite-banded, psammitic gneiss and schist and feldspathic metasandstone (P_-PO-mtsf) up to 1 m long are present.

Biotite–muscovite granodiorite and monzogranite, in addition to intruding numerous stratigraphic units within the Mangaroon Zone, also intrudes several units of the Moorarie Supersuite and Morrissey Metamorphics along the flanks of the Minnie Creek batholith. Plugs and sheets intrude garnet- or staurolite-bearing pelitic schist and gneiss (P_-LS-mlsg) and muscovite-rich pelitic schist (P_LS-mlsm) of the Morrissey Metamorphics, as well as equigranular biotite monzogranite (P_-MO-gmeb) and porphyritic biotite monzogranite (P_-MO-gmp) of the Minnie Creek batholith.

The biotite–muscovite granodiorite and monzogranite is intruded by numerous planar veins and dykes of tourmaline–muscovite pegmatite (P_-DU-gpt). The large pluton of biotite–muscovite granodiorite and monzogranite on Maroonah is unconformably overlain to the east and south by sedimentary rocks of the Yilgatherra Formation at the base of the Edmund Group.

Geochronology

P_-DU-gmv	*Maximum*	*Minimum*
Age (Ma)	1677	1619 ± 15
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Isotopic
References	Nelson, 2005	Nelson, 2004

Medium-grained, weakly porphyritic, biotite–muscovite granodiorite and monzogranite (P_-DU-gmv) was sampled for SHRIMP U–Pb zircon geochronology about 1 km east-northeast of Red Rock Bore (Zone 50, MGA 361420E 7409000N). The rock at this locality contains scattered clots <1 cm in diameter of fine-grained tourmaline and feldspar. The sample is a partly recrystallized muscovite–biotite–tourmaline(–garnet) granodiorite and yielded a range of zircon ages, with most of the zircons belonging to two groups at 1681 ± 10 Ma (12 analyses) and 1810 ± 21 Ma (8 analyses; Nelson, 2004). The youngest analysis in the sample — 1619 ± 15 Ma — was derived from a rim which Nelson (2004) described as 'structureless'. The analysis is concordant, and Nelson (2004) interpreted it as approximating the crystallization age of the granodiorite. However the cathodoluminescence image from the grain reveals it to be concentrically zoned (Fig. 1 of Nelson 2004) and of similar appearance to the other analysed grains. Two alternative interpretations are possible. First, the grain at c. 1620 Ma has undergone Pb-loss during a period of metamorphism and the main population at 1681 ± 10 Ma represents the age of crystallization. Second, the grain at c. 1620 Ma has not undergone Pb-loss and is part of the main c.1680 Ma population effectively reducing the weighted mean Pb–Pb age of the group. In support of this second interpretation, about 10 km to the southwest of this sample site, field relationships indicate that a small intrusion of muscovite–biotite granodiorite is coeval with a pluton of porphyritic biotite granodiorite (P_-DU-ggp) dated at 1677 ± 5 Ma (Nelson, 2005). Additionally, the biotite–muscovite granodiorite and monzogranites post-dates the main phase of the Mangaroon Orogeny (D_{1m} and D_{2m}) implying that it is younger than c. 1675 Ma.

References

Nelson, DR 2004, 169092: biotite–muscovite monzogranite, Red Rock Bore; Geochronology Record 103: Geological Survey of Western Australia, 4p.

Nelson, DR 2005, 178027: biotite–muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-gmvt)

Legend narrative

Leucocratic, medium-grained muscovite–tourmaline(–biotite) monzogranite; locally garnet bearing

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-gmv)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-gpt, P_-MEy-st, P_-MEi-kd, P_-MEi-sl (unconformable)
Underlying units	P_-MOmi-mgmn, P_-MOru-mgm, P_-MO-gmeb, P_-MO-mgg, P_-MO-xmg-m, P_-LS-mhs, P_-LS-mlsm, P_-MO-mggn, P_-PO-mln, P_-PO-mtsf (intrusive)

Summary

Leucocratic, medium-grained, muscovite–tourmaline(–biotite) monzogranite is a widespread, if not voluminous, component of the Durlacher Supersuite. The unit forms irregularly shaped plutons, typically closely associated with medium-grained biotite–muscovite granodiorite and monzogranite (P_-DU-gmv). The bulk of the muscovite–tourmaline(–biotite) monzogranite outcrops in the Mangaroon Zone, but plutons assigned to the unit also outcrop in the Limejuice Zone. The deformed and metamorphosed equivalent, foliated, leucocratic, muscovite(–tourmaline) metamonzogranite (P_-DU-mgmt), is abundant in the Mutherbukin Zone. A sample of monzogranite was selected for zircon geochronology but all of the zircons are interpreted to be xenocrysts. Based on field relationships the age of the unit is younger than 1677 Ma.

Distribution

Leucocratic, medium-grained, muscovite–tourmaline(–biotite) monzogranite outcrops widely in the Mangaroon Zone, and at the southeastern end of the Limejuice Zone. In the Mangaroon Zone, leucocratic, muscovite–tourmaline(–biotite) monzogranite is present both north and south of the Mangaroon Syncline. The monzogranite either comprises intrusions associated with medium-grained biotite–muscovite granodiorite and monzogranite (P_-DU-gmv), or the two rock units form composite intrusions. West of the Joy Helen prospect on Maroonah, a large pluton of muscovite–biotite granodiorite and monzogranite contains, at its northwestern and southern ends, muscovite–tourmaline(–biotite) monzogranite. A east-southeast trending intrusion along the southern edge of the Mangaroon Zone south of Pelt Well straddling the boundary between Eudamullah and Mount Phillips is nearly 25 km long and 3–4 km wide. In addition, several plugs and sheet-like bodies that outcrop in the eastern half of Eudamullah and the adjacent western part of Mount Phillips, mainly on the margins of the Minnie Creek batholith, are assigned to this unit. Several plugs or plutons of muscovite–tourmaline(–biotite) monzogranite are also present along the western edge of Maroonah.

At the southeastern end of the Limejuice Zone on Candolle and eastern Pink Hills, leucocratic, muscovite–tourmaline(–biotite) monzogranite forms several irregularly shaped intrusions about 5–40 km^2 in area.

Lithology

Muscovite–tourmaline(–biotite) monzogranite (P_-DU-gmvt) is medium to fine grained, and equigranular or sparsely porphyritic. The rocks are typically leucocratic, and comprise plagioclase, quartz, microcline, muscovite, biotite, and tourmaline. Tourmaline forms prismatic or skeletal crystals up to 4 mm long intergrown with quartz and plagioclase. In the pluton west-northwest of Mundong Well, fine-grained biotite locally forms small (2–3 mm) hexagonal clots after garnet. In a sheet to the north of this pluton fresh garnet is present. Plagioclase is variably replaced by albite (An_{05}) and sericite, and biotite is partly recrystallized and chloritized. Muscovite–tourmaline(–biotite) monzogranite locally contains pegmatitic pods and segregations. Muscovite–tourmaline(–biotite) monzogranite has a localized compositional layering defined by variations in biotite content.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	muscovite	v
2nd qualifier	tourmaline	t
Rock code		**P_-DU-gmvt**

Contact relationships

Muscovite–tourmaline(–biotite) monzogranite may grade into medium-grained biotite–muscovite granodiorite and monzogranite (P_-DU-gmvt); for example, in the pluton about 8.5 km west-northwest of Mundong Well on Maroonah. Muscovite–tourmaline(–biotite) monzogranite, in addition to intruding numerous stratigraphic units within the Mangaroon Zone, also intrudes several units of the Moorarie Supersuite and Leake Spring Metamorphics along the flanks of the Minnie Creek batholith. Plugs and sheets intrude garnet- or staurolite-bearing pelitic schist and gneiss (P_-LS-mlsg) and muscovite-rich pelitic schist (P_-LS-mlsm) of the Leake Spring Metamorphics, as well as mesocratic, equigranular to sparsely porphyritic biotite metatonalite and metamorphosed quartz-diorite (P_-MO-mgts), equigranular to sparsely porphyritic biotite tonalite and granodiorite (P_-MO-gte), and porphyritic biotite monzogranite (P_-MO-gmp) of the Minnie Creek batholith. There is commonly little evidence of contact metamorphism associated with the muscovite–tourmaline(–biotite) monzogranite, which may be, in part, related to the quartzofeldspathic nature of many of the country rocks. However, on Maroonah, even pelitic schists (P_-LS-mhs; around and to the southeast of the Laura Prospect) show no evidence of hornfels texture. Muscovite–tourmaline(–biotite) monzogranite west of the Joy Helen prospect on Maroonah is unconformably overlain by the Yilgatherra Formation at the base of the

Edmund Group. On CANDOLLE muscovite–tourmaline(–biotite) monzogranite forms a series of intrusions into older granitic rocks of the Middle Spring Granite and Moorarie Supersuite (P_-MOmi-mgmn, P_-MOru-mgm, P_-MO-gmeb, P_-MO-mgg, P_-MO-xmg-m) and metasedimentary rocks of the Leake Spring Metamorphics (P_-LS-mhs, P_-LS-mlsm). The monzogranites are unconformably overlain by sedimentary rocks of the Edmund Group (P_-MEy-st, P_-MEi-kd, P_-MEi-sl).

Geochronology

P_-DU-gmvt	*Maximum*	*Minimum*
Age (Ma)	1677	1619
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2005	Nelson, 1998

A sample of muscovite–tourmaline(–biotite) monzogranite was taken 3.7 km south of Pelt Well on northeastern EUDAMULLAH at site TRFEM244 (Zone 50, MGA 392170E 7337210N). The sample (GSWA 88410) is a foliated, fine- to medium-grained, sparsely porphyritic muscovite–biotite(–tourmaline) monzogranite with biotite clots and biotite-rich inclusions up to 30 or 40 mm long. Almost all zircons separated from the sample belong to one of two groups (Bodorkos et al., 2006). Group 1 comprises 10 analyses of nine zircons with ^{207}Pb*/^{206}Pb* ratios that define a single group with a weighted mean date of 1688 ± 7 Ma (MSWD = 0.43). Group 2 comprises 32 analyses of 32 zircons, obtained from cores with ^{207}Pb*/^{206}Pb* ratios that define a single group with a weighted mean date of 1805 ± 6 Ma (MSWD = 0.64). Field relations indicate that the monzogranite intruded schlieric biotite–muscovite granodiorite (P_-DU-ggvs) dated at 1677 ± 5 Ma (Nelson, 2005), and support the interpretation that all of the analysed zircons are entrained xenocrysts. The majority of the analyses in Group 1 are characterized by very low Th/U values (less than 0.1), consistent with a metamorphic origin for the zircon rims. Consequently the date of 1688 ± 7 Ma indicated by the 10 analyses in Group 1 is interpreted as the age of high temperature metamorphism in the source region of the monzogranite and therefore a maximum limit on the age of igneous crystallization (Bodorkos et al., 2006). Muscovite–tourmaline(–biotite) monzogranite west of the Joy Helen prospect on MAROONAH is unconformably overlain by the Yilgatherra Formation, which is inferred to have a depositional age of about 1620 Ma, thus providing an estimate for the minimum age for the muscovite–tourmaline(–biotite) monzogranite.

References

Bodorkos, S, Love, GJ and Wingate, MTD 2006, 88410: muscovite–biotite monzogranite, Dry Corner Bore; Geochronology Record 609: Geological Survey of Western Australia, 4p.

Nelson, DR 1998, 142855: porphyritic monzogranite, Anderson Well; Geochronology Record 371: Geological Survey of Western Australia, 4p.

Nelson, DR 2005, 178027: biotite–muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-gpt)

Legend narrative

Tourmaline–muscovite pegmatite and coarse-grained granite, and fine-grained, leucocratic tourmaline–muscovite monzogranite

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	P_-LS-mhs, P_-LS-mlsm, P_-MO-mggn, P_-MO-mgmn, P_-PO-mtsf, P_-PO-mln, P_-DU-ggvs, P_-DUpi-gmw (intrusive)

Summary

Tourmaline–muscovite pegmatite and coarse-grained granite, and fine-grained, leucocratic tourmaline–muscovite monzogranite forms dykes that intrude all the main rock units in the Mangaroon and Boora Boora Zones. Some dykes also intrude granites of the Minnie Creek batholith in the Limejuice Zone. The dykes are probably closely related to the leucocratic, medium-grained, muscovite–tourmaline(–biotite) monzogranite (P_-DU-gmvt). This unit has not been dated and is given the same age range age as for the supersuite at 1680–1620 Ma.

Distribution

Tourmaline–muscovite pegmatite and fine-grained, leucocratic granite (P_-DU-gpt) form dykes that intrude a large part of the Boora Boora and Mangaroon Zones, and to a minor extent, the Limejuice Zone. The dykes are particularly abundant in the area southeast of Bookathanna Well on central MANGAROON, and in the northwestern corner of MAROONAH, where they are up to 1 km long and 3 m wide. On MAROONAH many of the dykes strike north to north-northeast, but others, where they intrude metamorphosed sedimentary and granitic rocks, are subparallel to the existing foliation or gneissic layering. Several sheet-like composite bodies of tourmaline–muscovite pegmatite and leucocratic granite are present around the Laura Prospect on MAROONAH. Northwest of James Bore on MANGAROON composite dykes of pegmatite and leucocratic granite are well developed. A few small swarms of dykes of tourmaline–muscovite pegmatite in the southeastern part of the Mutherbukin Zone on eastern PINK HILLS and western CANDOLLE are inferred to be part of the Durlacher Supersuite.

Lithology

Dykes and sheets mainly comprise pegmatite or leucocratic granite, but the two rock types locally grade into each other, and some dykes contain pegmatite margins and leucocratic granite cores. The leucocratic tourmaline–muscovite granite has a similar mineralogy to the tourmaline-bearing phase of the muscovite–biotite granite (P_-DU-gmvt). The two rock types have the same field relationships, and pegmatitic segregations are present within the muscovite–biotite granite. For these reasons, the pegmatite and leucocratic granite are considered to be the same age as the muscovite–biotite granite.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	Igneous granitic	g
Lithname	pegmatite	p
1st qualifier	tourmaline	t
Rock code		**P_-DU-gpt**
Additional lithologies	monzogranite	

Contact relationships

Dykes of tourmaline–muscovite pegmatite and fine-grained, leucocratic granite intrude all the main rock units of the Boora Boora and Mangaroon Zones, and, to a minor extent, granites of the Limejuice Zone. Tourmaline–muscovite pegmatite dykes inferred to belong to the Durlacher Supersuite also intruded metasedimentary rocks of the Leake Spring Metamorphics and granites of the Moorarie Supersuite in the southeastern part of the Mutherbukin Zone.

Geochronology

P_-DU-gpt	*Maximum*	*Minimum*
Age (Ma)	1688	1619
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Bodorkos et al., 2006	Nelson, 2004

Tourmaline–muscovite pegmatite and fine-grained, leucocratic granite (P_-DU-gpt) has not been dated directly. However, the unit has the same field relationships as muscovite–tourmaline(–biotite) granite (P_-DU-gmvt), and pegmatitic segregations are present within the muscovite–tourmaline(–biotite) granite. For these reasons, the pegmatite and leucocratic granite are considered to be the same age as the muscovite–tourmaline(–biotite) granite. Two samples of muscovite–tourmaline(–biotite) granite have been dated; one from southwestern MAROONAH has a probable age around 1619 ± 15 Ma (Nelson,2004), whereas the other has a maximum age of 1688 ± 7 Ma (Bodorkos et al., 2006).

References

Bodorkos, S, Love, GJ and Wingate, MTD 2006, 88410: muscovite–biotite monzogranite, Dry Corner Bore; Geochronology Record 609: Geological Survey of Western Australia, 4p.

Nelson, DR 2004, 169092: biotite–muscovite monzogranite, Red Rock Bore; Geochronology Record 103: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-mgm)

Legend narrative

Massive to foliated, medium-grained, porphyritic biotite metamonzogranite to metagranodiorite

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-mgmb (intrusive)
Underlying units	AP_-_ha-mgnl, P_-LS-mhs, P_-MO-mgn (intrusive)

Summary

Massive to foliated, medium-grained, porphyritic biotite metamonzogranite to metagranodiorite is a minor component of the Durlacher Supersuite. It comprises several intrusions within the Mutherbukin Zone on YINNETHARRA. The unit may be closely related to both foliated, equigranular or sparsely porphyritic, biotite(–muscovite) metamonzogranite (P_-DU-mgmb) and the Davey Well Granite. As a consequence, the medium-grained, porphyritic biotite metamonzogranite to metagranodiorite is inferred to have an igneous crystallization age of about 1667 Ma.

Distribution

Medium-grained, porphyritic biotite metamonzogranite to metagranodiorite is restricted to the eastern edge of YINNETHARRA across to the western edge of PINK HILLS. The unit comprises a crescent-shaped intrusion at least 20 km long and up to 2.5 km wide on YINNETHARRA, as well as several small sheets (all less than 2 km^2) within gneissic to foliated granites of the Moorarie Supersuite (P_-MO-mgn and P_-MO-mgnl). Both of the larger intrusions have been truncated by faults. The metamonzogranite to metagranodiorite typically outcrops as boulders and tors, with scattered pavements and whalebacks amongst sandy sheetwash and low-gradient colluvial deposits.

Lithology

Medium-grained, porphyritic biotite metamonzogranite to metagranodiorite contains 10–25% square and round K-feldspar phenocrysts 0.5 – 1.5 cm in diameter. Coarser grained varieties may contain phenocrysts up to 3 cm in diameter. The round phenocrysts commonly have concentric growth zones marked by small inclusions of biotite and quartz. These phenocrysts resemble those in the Davey Well Granite. However, the presence of square or squat tabular phenocrysts in the metamonzogranite to metagranodiorite, along with the lower proportion of phenocrysts and the finer grain size, serve to distinguish it from the Davey Well Granite. The metamonzogranite to metagranodiorite ranges from foliated to nearly massive.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
Rock code		**P_-DU-mgm**
Additional lithologies	metagranodiorite	

Contact relationships

Medium-grained, porphyritic biotite metamonzogranite to metagranodiorite intrudes leucocratic granitic gneiss and foliated leucocratic granite of the 2660–2430 Ma Halfway Gneiss (AP_-_ha-mgnl), pelitic and psammitic schist of the Leake Spring Metamorphics (P_-LS-mhs) deposited between c. 1840 Ma and c. 1810 Ma, and pegmatite-banded gneissic and foliated granites of the 1820–1775 Ma Moorarie Supersuite. Medium-grained, porphyritic biotite metamonzogranite to metagranodiorite is intruded by medium-grained, equigranular metamonzogranite (P_-DU-mgmb) about 3.5 km north of Daly Bore on YINNETHARRA (SXSYIN007847; Zone 50, MGA 436368E 7257567N).

Geochronology

P_-DU-mgm	*Maximum*	*Minimum*
Age (Ma)	1667	1667
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., 2009	Wingate et al., 2009

Medium-grained, porphyritic biotite metamonzogranite to metagranodiorite has not been dated directly, nor has the unit of foliated, medium-grained, equigranular or sparsely porphyritic biotite(–muscovite) metamonzogranite (P_-DU-mgmb) that intrudes it. The medium-grained, porphyritic biotite metamonzogranite to metagranodiorite is inferred to be of similar age to this unit, and, as a corollary, to the Davey Well Granite (P_-DUda-mgmu); that is, about 1667 Ma (Wingate et al., 2009).

References

Wingate, MTD, Kirkland, CL, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183215: porphyritic metamonzogranite, Davey Well; Geochronology Record 771: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-mgmb)

Legend narrative

Foliated, medium-grained and fine- to medium-grained, equigranular or sparsely porphyritic, biotite(–muscovite) metamonzogranite; commonly with igneous banding

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-mod-GA, P_-TT-gpvt (intrusive); P_-MGm-mtq, P_-MOru-mgm, P_-MEk-mh, P_-MEd-ml and P_-MEl-mlsd (faulted)
Underlying units	P_-LS-mhs, P_-DUda-mgmu, P_-POb-mlsm; P_-PO-mwa, P_-DU-mgm (intrusive)

Summary

Foliated, medium-grained and fine- to medium-grained, equigranular or sparsely porphyritic, biotite(–muscovite) metamonzogranite comprises a series of deformed intrusions throughout the Mutherbukin Zone in the centre of the Gascoyne Province. The rocks commonly have a well-developed igneous layering, which is roughly parallel to the margins of the intrusions. The intrusions range between about 10 and 70 km^2 in size, and are probably composite, sheet-like bodies. The metamonzogranite has not been dated, but it is inferred to have intruded at about 1665 Ma.

Distribution

Foliated, medium-grained, and fine- to medium-grained, equigranular or sparsely porphyritic, biotite(–muscovite) metamonzogranite outcrops over a wide area in the Mutherbukin Zone in the central part of the Gascoyne Province. The metamonzogranite mainly outcrops along the margins of the Davey Well Granite (P_-DUda-mgmu) on southeastern EUDAMULLAH, southwestern MOUNT PHILLIPS, and to the southeast on much of central YINNETHARRA and extending onto the central western part of PINK HILLS. Foliated, medium-grained, equigranular biotite(–muscovite) metamonzogranite forms numerous sheet-like intrusions 15 km or more long, and up to 4 km wide. The intrusions, in places, display an igneous banding. One of the larger intrusions, which straddles the boundary between EUDAMULLAH and MOUNT PHILLIPS, also contains a considerable amount of schistose, coarse-grained, strongly porphyritic, biotite metamonzogranite (P_-DUda-mgmu), although it cannot be separated as a mappable unit.

Lithology

Foliated, medium-grained and fine- to medium-grained, biotite(–muscovite) metamonzogranite is equigranular to sparsely porphyritic. Locally, the rocks may be moderately porphyritic, as in the intrusion on northwestern YINNETHARRA. Oval, or rarely, squat tabular, phenocrysts of K-feldspar are mostly 1–3 cm in diameter (although in places they reach 5 cm). These phenocrysts are similar in size and shape to the schistose coarse-grained, strongly porphyritic biotite metamonzogranite that comprises the bulk of the Davey Well Granite (P_-DUda-mgmu). Biotite is the main mafic mineral, but minor muscovite is common, some of which may be primary. In places the rocks are layered. Layering is defined by 1–20 cm-thick alternating medium-grained and fine- to medium-grained, equigranular metamonzogranite, with variable amounts of biotite. The layers may be irregular and, in part, may have cuspate or lobate contacts between individual layers.

The metamonzogranite is variably foliated, although, in places, it is massive. Lower strain zones on the eastern part of YINNETHARRA may show small patches or lenses of leucocratic granite, which probably represent small pockets of melt that has migrated into dilational sites. Locally the metamonzogranite is gneissic and pegmatite banded. The metamonzogranite is typically free of inclusions, although in places it contains small inclusions of pelitic schist.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier		
2nd qualifier	biotite	b
Rock code		**P_-DU-mgmb**

Contact relationships

Foliated, medium-grained, and fine- to medium-grained, equigranular or sparsely porphyritic, biotite(–muscovite) metamonzogranite has rare inclusions of schistose, coarse-grained, strongly porphyritic, biotite metamonzogranite belonging to the Davey Well Granite (P_-DUda-mgmu) southwest of Peak Bore on EUDAMULLAH (SXSEUD6632; Zone 50, MGA 386056E 7305479N). About 6 km northwest of Daly Bore on YINNETHARRA (SXSYIN007876; Zone 50, MGA 432600E 7258304N) a raft of Davey Well Granite 10 m long and 1 m wide is present within foliated and banded, medium-grained, biotite metamonzogranite (P_-DU-mgmb). The small pluton near Louden Well on southwestern MOUNT PHILLIPS intrudes amphibolite (P_-PO-mwa) and biotite–quartz–muscovite schist (P_-POb-mlsm) of the Biddenew Formation. The same pluton, along its western edge, contains inclusions of gabbro and mesocratic granite (Zone 50, MGA 402579E 7300623N). In the same area, about 500 m north-northeast of Louden Well, schistose, medium-grained, biotite metamonzogranite contains inclusions of a mesocratic metagranite with round K-feldspar phenocrysts similar to those in the host metamonzogranite. About 3.5 km north of Daly Bore on YINNETHARRA (SXSYIN007847; Zone 50, MGA 436368E 7257567N) a sharp planar contact between medium-grained, equigranular metamonzogranite and medium-grained, porphyritic metamonzogranite (P_-DU-mgmp) is exposed. The contact strikes 110° parallel to a weak foliation, and the equigranular phase veins the porphyritic phase. On eastern YINNETHARRA and western

Pink Hills medium-grained, equigranular or sparsely porphyritic, biotite(–muscovite) metamonzogranite intrudes gneissic granites of the Moorarie Supersuite (P_-MO-mgnl) and semi pelitic schists (P_-LS-mhs) of the Leake Spring Metamorphics, containing decimetre- to kilometre-scale inclusions of both units. The western margin is truncated by the Ti Tree Shear Zone that places it in faulted contact with Moorarie Supersuite granites (P_-MOru-mgm), quartzite of the Moogie Metamorphics (P_-MGm-mtq), and low- to medium-grade sedimentary rocks of the Edmund Group (P_-MEk-mh, P_-MEd-ml and P_-MEl-mlsd).

Foliated, medium-grained, equigranular or sparsely porphyritic, biotite(–muscovite) metamonzogranite is intruded by dykes of massive metamorphosed dolerite and foliated amphibolite (P_-mod-GA), and muscovite–tourmaline pegmatite assigned to the Thirty Three Supersuite (P_-TT-gpt).

Geochronology

P_-DU-mgmb	*Maximum*	*Minimum*
Age (Ma)	1667	1667
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Wingate et al., 2009	Wingate et al., 2009

Foliated, medium-grained, equigranular or sparsely porphyritic, biotite(–muscovite) metamonzogranite has not been dated. However, the similarity in size and shape of the K-feldspar phenocrysts to those in the schistose, coarse-grained, strongly porphyritic, biotite metamonzogranite phase of the Davey Well Granite, along with mineralogical similarities between the two, suggests that the two units are genetically related. The two units also show a strong spatial association. If this interpretation is correct, then the SHRIMP U–Pb zircon age for the Davey Well Granite of 1667 ± 4 Ma (Wingate et al., 2009), approximates that of the foliated, medium-grained, equigranular or sparsely porphyritic, biotite(–muscovite) metamonzogranite.

References

Wingate, MTD, Kirkland, CL, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183215: porphyritic metamonzogranite, Davey Well; Geochronology Record 771: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-mgml)

Legend narrative

Foliated, leucocratic muscovite(–biotite) metamonzogranite; medium grained; equigranular

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MW-od (intrusive)
Underlying units	P_-PO-mkq, P_DUda-mgmu (intrusive)

Summary

Foliated, leucocratic muscovite(–biotite) metamonzogranite is the deformed equivalent of medium-grained biotite–muscovite granodiorite and monzogranite (P_-DU-gmv). The distribution of the two units reflects the absence or presence of Mesoproterozoic to early Neoproterozoic reworking. The foliated metamonzogranite is largely confined to the Mutherbukin Zone where this younger reworking is concentrated. The unit has not been dated and thus has an age range equivalent to that for the supersuite (1680–1620 Ma).

Distribution

Foliated, leucocratic muscovite(–biotite) metamonzogranite comprises several intrusions on the south side of the Ti Tree Syncline, and one on the northeast side. The largest intrusion, in the northeast corner of YINNETHARRA, is about 65 km^2, but the remainder are less than 10 km^2. Six of the seven intrusions form a southeasterly trending belt from the southeastern corner of EUDAMULLAH to northeastern YINNETHARRA.

Lithology

Foliated, leucocratic muscovite(–biotite) metamonzogranite is, in the main, medium grained and equigranular. It is locally fine grained, and in places contains tourmaline. The monzogranite is commonly accompanied by minor amounts of pegmatite. Locally, there are screens of foliated, medium-grained biotite metamonzogranite. The intrusion around Andrew Bore on northeastern YINNETHARRA is commonly intensely foliated, with some isoclinal folding of quartz or pegmatite veins. This intrusion also contains zones with numerous inclusions or schlieren of pelitic schist, imparting a migmatitic appearance to some exposures.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	–	
2nd qualifier	leucocratic	l
Rock code		**P_-DU-mgml**

Contact relationships

The largest of the three intrusions of foliated, leucocratic muscovite(–biotite) metamonzogranite immediately northwest of Horrigan Well contains scattered screens of foliated, medium-grained biotite monzogranite of the Davey Well Granite (P_-DUda-mgmu). Inclusions of calc-silicate gneiss within foliated, porphyritic, leucocratic metamonzogranite outcrop southeast of Davey Well on EUDAMULLAH. Foliated, leucocratic muscovite(–biotite) metamonzogranite is in contact with schistose mesocratic monzogranite and granodiorite (P_-DU-mgms), but the relative ages of the two units could not be established. The intrusion of foliated leucocratic muscovite(–biotite) metamonzogranite around Andrew Bore appears to be intruded by leucocratic muscovite–tourmaline granite of the Thirty Three Supersuite (P_-TT-gmlt).

Geochronology

P_-DU-mgml	*Maximum*	*Minimum*
Age (Ma)	1678	1619
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2005	Nelson, 2004

Foliated, leucocratic muscovite(–biotite) metamonzogranite has not been dated directly. It appears to be the deformed equivalent of muscovite–biotite granodiorite and monzogranite (P_-DU-gmv), an intrusion of which has been dated on MAROONAH at c. 1620 Ma (Nelson, 2004). Another intrusion of muscovite–tourmaline(–biotite) monzogranite (P_-DU-gmvt) on MAROONAH displays what are interpreted to be mingling textures with an intrusion of porphyritic biotite granodiorite (P_-DU-ggp), which is dated at 1678 ± 6 Ma (Nelson, 2005). Therefore, intrusions of both the muscovite–biotite granodiorite and monzogranite (P_-DU-gmv) and its deformed equivalent (P_-DU-mgml) may be diachronous.

References

Nelson, DR 2004, 169092: biotite–muscovite monzogranite, Red Rock Bore; Geochronology Record 103: Geological Survey of Western Australia, 4p.

Nelson, DR 2005, 178030: biotite granodiorite, Robinson Well; Geochronology Record 539: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-mgms)

Legend narrative

Schistose, mesocratic, biotite metamonzogranite and metagranodiorite; fine- to medium-grained

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	P_-POb-mlsm, P_-PO-mwa (intrusive)

Summary

Schistose, mesocratic, biotite metamonzogranite and metagranodiorite is a very minor component of the Durlacher Supersuite. It has not been directly dated, but it is inferred to be part of the 1680–1620 Ma Durlacher Supersuite.

Distribution

Schistose, mesocratic, biotite metamonzogranite and metagranodiorite is restricted to an irregular-shaped intrusion covering about 25 km^2 across the boundary between EUDAMULLAH and MOUNT PHILLIPS south of the Ti Tree Syncline, and a smaller intrusion about 15 km to the south on northwestern YINNETHARRA and adjacent northeastern LOCKIER.

Lithology

Schistose, mesocratic, biotite metamonzogranite and metagranodiorite is typically fine to medium grained. The rocks are reasonably homogeneous, apart from a few attenuated inclusions of fine-grained metagranodiorite or metamorphosed quartz-diorite. Most of the unit has a strong foliation.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	–	
2nd qualifier	schistose	s
Rock code		**P_-DU-mgms**
Additional lithologies	metagranodiorite	

Contact relationships

Schistose mesocratic metamonzogranite and metagranodiorite contains rafts of amphibolite (P_-PO-mwa) of the Pooranoo Metamorphics along the northern margin of the intrusion. The contact along this margin also truncates the trend of lithological layering in biotite–quartz–muscovite schist (P_-POb-mlsm) of the Biddenew Formation. The intrusion is in contact with the Davey Well Granite, but the relative age of the two units is unknown. Schistose mesocratic metamonzogranite and metagranodiorite is intruded by thin sheets of fine-grained, leucocratic muscovite monzogranite, and by dykes of muscovite–tourmaline pegmatite and granite. The age of these leucocratic granites and pegmatites is not known, but they may be part of the Thirty Three Supersuite.

Geochronology

P_-DU-mgms	*Maximum*	*Minimum*
Age (Ma)	1677	1619
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2005	Nelson, 1998

Schistose, mesocratic, metamonzogranite and metagranodiorite has not been dated directly, and the field relationships with other dated units are not well established. It is inferred to belong to the Durlacher Supersuite. The unit intrudes metasedimentary and meta-igneous rocks of the Pooranoo Metamorphics, which were deposited at c. 1680 Ma.

References

Nelson, DR 1998, 142855: porphyritic monzogranite, Anderson Well; Geochronology Record 371: Geological Survey of Western Australia, 4p.

Nelson, DR 2005, 178027: biotite–muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-mgmt)

Legend narrative

Foliated, leucocratic muscovite(–tourmaline) metamonzogranite; locally coarse grained

Rank	Member
Parent	Durlacher Supersuite (P_-DU-mgml)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MEi-kd (unconformable)
Underlying units	AP_-_ha-mgnl, P_-LS-mhs, P_-LS-mlsm, P_-LS-xmh-mwa, P_-MOru-mgm, P_-POb-mxq (intrusive)

Summary

Foliated, leucocratic muscovite(–tourmaline) metamonzogranite is the deformed equivalent of leucocratic, medium- to fine-grained, muscovite–tourmaline(–biotite) monzogranite (P_-DU-gmvt). The distribution of the two units reflects the absence or presence of Mesoproterozoic to early Neoproterozoic reworking. The foliated muscovite(–tourmaline) metamonzogranite is confined to a belt adjacent to the Ti Tree Syncline where much of this younger reworking is concentrated.

Distribution

Foliated, leucocratic muscovite(–tourmaline) metamonzogranite forms a southeasterly trending belt of intrusions from northeastern YINNETHARRA onto PINK HILLS along the northeastern side of the Ti Tree Syncline. The metamonzogranite comprises four small intrusions, each between about 2.5 and 30 km^2, all of which are elongate parallel to the regional structural grain.

Lithology

Foliated, leucocratic muscovite(–tourmaline) metamonzogranite is mostly fine to medium grained and equigranular, although it is weakly porphyritic in places. The unit contains local coarser grained or pegmatitic zones, which in many instances contain tourmaline. The metamonzogranite commonly has a vague layering defined by subtle variations in grain size and the alignment of drawn out biotite wisps and biotite-rich seams, or by variations in tourmaline abundance. Lithological layering is mostly parallel to the foliation. Parts of the unit contain patchy tourmaline-rich spots, which are typically 5–15 mm in diameter; some featuring a bleached halo. In places tourmaline is distributed throughout the metamonzogranite, and it may be the only mafic phase.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metamonzogranite	m
1st qualifier	–	
2nd qualifier	tourmaline	t
Rock code		**P_-DU-mgmt**

Contact relationships

Foliated, leucocratic, muscovite(–tourmaline) metamonzogranite intrudes the leucocratic phase of the Halfway Gneiss (AP_-_ha-mgnl) and several units of the Morrissey Metamorphics. The metamonzogranite also intrudes the Rubberoid Granite of the Moorarie Supersuite, and is inferred to intrude cobble and boulder metaconglomerate of the Biddenew Formation (P_-POb-mxq). Foliated, leucocratic, muscovite(–tourmaline) metamonzogranite is inferred to be overlain unconformably by the Irregully Formation on northeastern YINNETHARRA, although exposure in the area is poor. The two units may be in faulted contact.

Geochronology

P_-DU-mgmt	*Maximum*	*Minimum*
Age (Ma)	1678	1619
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2005	Nelson, 2004

Foliated, leucocratic, muscovite(–tourmaline) metamonzogranite has not been dated directly, but it is probably the deformed equivalent of leucocratic muscovite–tourmaline(–biotite) monzogranite (P_-DU-gmvt), an intrusion of which has been dated on MAROONAH at c. 1620 Ma (Nelson, 2004). Another intrusion of leucocratic muscovite–tourmaline(–biotite) monzogranite on MAROONAH displays what are interpreted to be mingling textures with an intrusion of porphyritic biotite granodiorite (P_-DU-ggp), which is dated at 1678 ± 6 Ma (Nelson, 2005). Therefore, intrusions of both the foliated, leucocratic, muscovite(–tourmaline) metamonzogranite and its undeformed equivalent may be diachronous.

References

Nelson, DR 2004, 169092: biotite-muscovite monzogranite, Red Rock Bore; Geochronology Record 103: Geological Survey of Western Australia, 4p.

Nelson, DR 2005, 178030: biotite granodiorite, Robinson Well; Geochronology Record 539: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-mgn)

Legend narrative

Gneissic to schistose, biotite metamonzogranite and metasyenogranite; fine- and medium-grained; pegmatite banded

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DUda-mgmu, P_-DU-gmvt (intrusive); CP-LY-sepg (unconformable)
Underlying units	P_-PO-mxq, P_-PO-mwa, P_-PO-mkq (faulted)

Summary

Gneissic to schistose, biotite metamonzogranite and metasyenogranite is a voluminous unit of the Durlacher Supersuite in the western part of the Mutherbukin Zone. The unit extends onto Mount Sandiman, where it is yet to be mapped. The unit comprises several granite phases of differing grain size, composition and texture, which are interleaved on a metre to decametre scale. A sample from the leucocratic member of this unit yielded a SHRIMP U–Pb zircon date of c. 1665 Ma, interpreted as the igneous crystallization age of the precursor leucocratic metamonzogranite.

Distribution

Gneissic to schistose, biotite metamonzogranite and metasyenogranite (P_-DU-mgn), including an un-named leucocratic member (P_-DU-mgnl), underlies much of the Mutherbukin Zone in the southwestern part of Eudamullah. The unit extends to the southeast onto Lockier, Yinnetharra, and Mount Phillips. Scattered outcrops amongst regolith on the western edge of Eudamullah extend westwards onto Mount Sandiman. The metamonzogranite and metasyenogranite form low, undulating sandy country, and typically outcrop as low boulders and pavements.

Lithology

Gneissic to schistose, biotite metamonzogranite and metasyenogranite consists of a several granite phases of differing grain size, composition and texture. These phases are typically interleaved on a metre to decametre scale. The rocks range from gneissic or strongly foliated and pegmatite banded in high-strain zones, to weakly foliated but strongly recrystallized in lower-strain zones. Individual rock types include: leucocratic, fine- to medium grained, equigranular monzogranite to syenogranite; pale-grey, fine-grained monzogranite; and mesocratic, biotite-rich, porphyritic granodiorite or monzogranite. The porphyritic phases contain 5–10% round phenocrysts of K-feldspar up to 3 cm in diameter; locally the rock has a few megacrysts of pegmatitic feldspar. In areas where gneissic to schistose, leucocratic, muscovite–biotite metamonzogranite to metasyenogranite is dominant, it is mapped as a separate unit (P_-DU-mgnl). On the western edge of Eudamullah, scattered outcrops comprise foliated, medium-grained, sparsely porphyritic and coarse-grained, equigranular monzogranites, and granitic gneiss with a very shallowly dipping tectonic fabric.

Gneissic to schistose, biotite metamonzogranite and metasyenogranite contain metre- to decametre-scale folds, unlike other foliated granites of the Durlacher Supersuite (for example, P_-DU-mgml, P_-DU-mgrl, P_-DUda-mgm). The metamonzogranite and metasyenogranite contain thin layers of quartzite, amphibolites, and calc-silicate gneiss.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	meta-igneous felsic intrusive	mg
Lithname	granitic gneiss	n
Rock code		**P_-DU-mgn**
Additional lithologies	metasyenogranite	

Contact relationships

Gneissic to schistose, biotite metamonzogranite and metasyenogranite is tectonically interleaved with several units of the Pooranoo Metamorphics including: cobble and pebble metaconglomerate, and coarse-grained, granule and pebbly quartz metasandstone (P_-POb-mxq); amphibolite (P_-PO-mwa); and calc-silicate gneiss (P_-PO-mkq). The metamonzogranite and metasyenogranite are intruded by a plug of muscovite–tourmaline(–biotite) monzogranite (P_-DU-gmvt) just north of No 11 Bore on southern Eudamullah. Gneissic to schistose metamonzogranite and metasyenogranite is in contact with the Davey Well Granite (P_-DUda-mgmu) over a wide area. Most of the contacts are faulted, but the Davey Well Granite does not contain a folded foliation like the metamonzogranite and metasyenogranite, suggesting that these gneissic to schistose granites are older. This interpretation is supported by the presence of rare inclusions of gneissic, medium-grained monzogranite in foliated, coarse-grained, porphyritic monzogranite of the Davey Well Granite at site SXSEUD6650 (Zone 50, MGA 382158E 7303452N) about 2.5 km south of Peak Bore. Gneissic to schistose, biotite metamonzogranite and metasyenogranite is unconformably overlain by diamictite, sandstone, and siltstone (CP-LY-sepg) of the Lyons Group in the southwestern corner of Eudamullah.

Geochronology

P_-DU-mgn	*Maximum*	*Minimum*
Age (Ma)	1666	1666
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Kirkland et al., 2009	Kirkland et al., 2009

Gneissic to schistose, biotite metamonzogranite and metasyenogranite has not been sampled for geochronology, although a sample from the leucocratic member of this unit (P_-DU-mgnl) yielded an igneous crystallization age of 1666 ± 5 Ma for the monzogranite protolith (Kirkland et al., 2009). This date is within uncertainty of that for the Davey Well Granite.

References

Kirkland, CL, Wingate, MTD, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183212: granitic gneiss, O'Malley Well; Geochronology Record 755: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-mgnl)

Legend narrative

Gneissic to schistose, leucocratic, biotite–muscovite–metamonzogranite and metasyenogranite; fine and medium grained; pegmatite banded

Rank	Formation
Parent	Durlacher Supersuite P_-DU-g
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DUda-mgmu, P_-DU-mgrl, P_DU-gmvt, P_-TT-gmlt, P_-TT-gpvt
Underlying units	P_-PO-mwa

Summary

Gneissic to schistose, leucocratic, biotite–muscovite metamonzogranite and metasyenogranite comprises two irregular shaped intrusions in the Mutherbukin Zone on southern EUDAMULLAH. The leucocratic metamonzogranite and metasyenogranite outcrop along the northern margin of the more voluminous and extensive gneissic to schistose, biotite metamonzogranite and metasyenogranite (P_-DU-mgn). The leucocratic rocks are also tectonically interleaved with the latter on the scale of individual exposures. A specimen from the unit sampled for SHRIMP U–Pb zircon geochronology yielded an igneous crystallization age of c. 1665 Ma.

Distribution

Gneissic to schistose, leucocratic, biotite–muscovite metamonzogranite and metasyenogranite forms a mappable unit in a narrow, east-southeast trending belt on southeastern EUDAMULLAH and in the far southwest corner of MOUNT PHILLIPS, and extending onto YINNETHARRA. Elsewhere these leucocratic rock types form part of the undivided gneissic to schistose, biotite metamonzogranite and metasyenogranite unit (P_-DU-mgn).

Lithology

Gneissic to schistose, leucocratic, biotite–muscovite metamonzogranite and metasyenogranite range from strongly deformed and pegmatite banded, to weakly or moderately foliated. In lower strain zones the leucocratic metamonzogranite and metasyenogranite can be difficult to distinguish from other units of the Durlacher Supersuite, such as foliated, leucocratic, biotite–muscovite metasyenogranite (P_-DU-mgrl) and foliated, leucocratic, muscovite(–biotite) metamonzogranite (P_-DU-mgml). Tectonically interleaved with the leucocratic metamonzogranite and metasyenogranite are minor amounts of fine- to medium-grained, foliated, pale-grey, biotite monzogranite that ranges from equigranular to locally porphyritic.

The majority of the leucocratic rocks are fine to medium grained, but medium- to coarse-grained rocks are also present. Almost all the rocks are equigranular or sparsely porphyritic. Many of the granitic rocks have a banded appearance owing to the presence of schlieren and centimetre-thick layers of coarse-grained biotite–muscovite–quartz(–garnet) schist, in addition to thin, parallel pegmatite layers. Where the amount of interleaved pelitic material and pegmatite veining is negligible, the leucocratic rocks have a flaser fabric. Upright, close to tight, metre-scale folds of the gneissic layering or foliation are widespread, although not always abundant. These folds plunge parallel to tight chevron folds or a crenulation in the interleaved pelitic schists. Rarely, these folds can be seen to have refolded earlier tight to isoclinal folds.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	meta-igneous felsic intrusive	mg
Lithname	granitic gneiss	n
1st qualifier	–	
2nd qualifier	leucocratic	l
Rock code		**P_-DU-mgnl**
Additional lithologies	Metasyenogranite	

Contact relationships

Gneissic to schistose, leucocratic, biotite–muscovite metamonzogranite and metasyenogranite contain abundant interleaved pelitic schist, and minor amounts of interleaved amphibolite (P_-PO-mwa) and calc-silicate gneiss (P_-PO-mkq). In lower strain zones, foliated leucocratic metamonzogranite and metasyenogranite contain inclusions, and veins, of these rock types. These supracrustal rocks contain an S_1 foliation that is truncated by veins of the metamonzogranite or metasyenogranite.

Gneissic to schistose, leucocratic, biotite–muscovite metamonzogranite and metasyenogranite is in contact with the Davey Well Granite (P_-DUda-mgmu) over large distances, but the contacts are typically tectonic. However, the Davey Well Granite does not contain a folded foliation like the metamonzogranite and metasyenogranite, suggesting that these gneissic to schistose granites are older. This interpretation is supported by the presence of rare inclusions of gneissic, medium-grained monzogranite in foliated, coarse grained, porphyritic monzogranite of the Davey Well Granite at site SXSEUD6650 (Zone 50, MGA 382158E 7303452N) about 2.5 km south of Peak Bore. Gneissic to schistose, leucocratic metamonzogranite and metasyenogranite are intruded by veins and dykes of variably foliated, leucocratic, biotite–muscovite metasyenogranite (P_-DU-mgrl) and muscovite–tourmaline(–biotite) monzogranite (P_-DU-gmvt), commonly sub-parallel to the tectonic foliation. In addition, the leucocratic metamonzogranite and metasyenogranite are intruded by veins and dykes of massive muscovite–tourmaline pegmatite (P_-TT-gpvt) and leucocratic, medium-grained, muscovite–tourmaline(–biotite) monzogranite (P_-TT-gmlt) of the Thirty Three Supersuite, particularly in the area about 3–3.5 km west-northwest of New Well on southeastern EUDAMULLAH.

Geochronology

P_-DU-mgnl	*Maximum*	*Minimum*
Age (Ma)	1666 ± 5	1666 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Kirkland et al., 2009	Kirkland et al., 2009

Fine- to medium-grained, leucocratic, biotite–muscovite monzogranite gneiss 1.2 km east-southeast of O'Malley Well (Zone 50, MGA 369872E 7298294N) on EUDAMULLAH was sampled for SHRIMP U–Pb zircon geochronology. The gneiss contains small-scale tight to isoclinal recumbent folds and is pegmatite banded, although the geochronology sample was free of veins. The dated sample (GSWA 183212) is a gneissic micromonzogranite with an anhedral granular texture, containing a few percent dark brown biotite and rare garnet (?almandine) and widespread myrmekite patches. The sample yielded an igneous crystallization age of 1666 ± 5 Ma for the monzogranite protolith (Kirkland et al., 2009). This date is within uncertainty of that for the Davey Well Granite, although field relationships indicate that latter is younger.

References

Kirkland, CL, Wingate, MTD, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183212: granitic gneiss, O'Malley Well; Geochronology Record 755: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-mgrl)

Legend narrative

Foliated, leucocratic, biotite–muscovite metasyenogranite; fine to medium grained; equigranular to sparsely porphyritic

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Underlying units	P_-PO-mxq, P_-DUda-mgmu, P_-DU-mgnl

Summary

Foliated, leucocratic, biotite–muscovite metasyenogranite is restricted to a single pluton in the Mutherbukin Zone on the boundary between Eudamullah and Mount Phillips, along with a swarm of associated dykes. A sample from the unit taken for SHRIMP U–Pb zircon dating yielded an igneous crystallization age of 1666 ± 6 Ma.

Distribution

Foliated, leucocratic, biotite–muscovite metasyenogranite forms a southeast-trending sheet-like intrusion, 5 km long and up to 1 km wide, with a swarm of dykes, on the southern part of the boundary between Eudamullah and Mount Phillips.

Lithology

Foliated, leucocratic, biotite–muscovite metasyenogranite is fine to medium grained, and mostly equigranular to sparsely porphyritic. Some dykes, where they intrude foliated, coarse-grained metamonzogranite of the Davey Well Granite (P_-DUda-mgmu), contain a few percent round K-feldspar phenocrysts that have the same size and shape as phenocrysts in the Davey Well Granite. Many of the rocks contain flattened clots of biotite and muscovite up to 1 cm in diameter. The unit is mostly moderately to weakly foliated, although in local high-strain zones the rocks may be gneissic. A subtle igneous compositional banding, which is subparallel to the tectonic foliation, is present in places.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	meta-igneous felsic intrusive	mg
Lithname	metasyenogranite	r
1st qualifier	–	
2nd qualifier	leucocratic	l
Rock code		**P_-DU-mgrl**

Contact relationships

Foliated, leucocratic biotite–muscovite metasyenogranite intrudes the Davey Well Granite (P_-DUda-mgmu) as well as gneissic to schistose, leucocratic, biotite–muscovite metamonzogranite and metasyenogranite (P_-DU-mgnl). The main sheet-like intrusion also contains at least one raft of cobble and pebble metaconglomerate, and coarse-grained granule and pebbly quartz metasandstone (P_-PO-mxq).

Geochronology

P_-DU-mgrl	*Maximum*	*Minimum*
Age (Ma)	1666 ± 6	1666 ± 6
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Wingate et al., 2009	Wingate et al., 2009

A dyke of foliated, leucocratic biotite–muscovite metasyenogranite was sampled for SHRIMP U–Pb zircon geochronology about 3 km north of New Well on southeastern Eudamullah (Zone 50, MGA 395769E 7296452N). The sample yielded an igneous crystallization age of 1668 ± 6 Ma for the syenogranite protolith (Wingate et al., 2009). Although foliated, leucocratic, biotite–muscovite metasyenogranite intrudes the Davey Well Granite (P_-DUda-mgmu) and gneissic to schistose, leucocratic, biotite–muscovite metamonzogranite and metasyenogranite (P_-DU-mgnl), the igneous crystallization ages of all three units are indistinguishable.

References

Wingate, MTD, Kirkland, CL, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183208: foliated metasyenogranite dyke, New Well; Geochronology Record 770: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-mog)

Legend narrative

Massive metagabbro with xenocrysts of quartz and K-feldspar

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DUdi-grpv, P_-DU-gmp, P_-DU-gpt (intrusive)
Underlying units	P_-PO-mln, P_-PO-mtsf (intrusive)

Summary

Metagabbro is a trivial component of the Durlacher Supersuite. The unit comprises four very small exposures, each less than 0.3 km^2 in area, and scattered inclusions in granites of the supersuite. The presence of quartz and K-feldspar xenocrysts, and local net-vein structures, indicate mingling of gabbroic and granitic magma. The unit has not been directly dated but cross-cutting relationships indicate it has an intrusion age between 1677 and 1674 Ma.

Distribution

On Mangaroon, massive metagabbro (P_-DU-mog) outcrops over an area of only approximately 0.2 km^2 roughly 3 km north-northeast of James Bore, in another outcrop less than 50 m^2 in extent about 2 km to the north-northwest (Zone 50, MGA 372160E 7380270N), and east-northeast of High Range – Daniels prospect. On Maroonah, metagabbro forms two exposures, each about 0.2 – 0.3 km^2, 6 km west-northwest of North Mullara Bore and 3 km west-southwest of Red Rock Bore. Both exposures consist of rocky knolls that rise about 30–35 m above surrounding sheetwash and scattered outcrop.

Lithology

The metagabbro ranges from equigranular to moderately porphyritic. Net-vein structures are present along the contacts of the metagabbro and a pale-grey, fine-grained granite at both localities, implying that the mafic and felsic magmas have mingled. The K-feldspar phenocrysts in the metagabbro are commonly partly rounded, and have the same shape and size as those in the pale-grey granite: therefore, the K-feldspar crystals are probably xenocrysts. The pale-grey granite, and to a lesser extent the metagabbro, is intruded by veins of fine- to medium-grained, strongly porphyritic monzogranite of the Dingo Creek Granite.

The massive metagabbro north-northeast of James Bore is a fine-grained anhedral granular rock composed of very pale green actinolite and sodic plagioclase and minor quartz, with xenocrysts of microcline. Biotite has exsolved ?rutile needles, and recrystallization of plagioclase to more sodic composition was associated with pseudomorphs of titanite and epidote after ilmenite and magnetite, respectively. Apatite and zircon are abundant accessory minerals. Metamorphosed gabbro uncontaminated with granitic melt is composed of decussate actinolite (–straw yellow, β = blue–green, γ = deep green), andesine (An_{35}), epidote, and altered ?titanite. Quartz and microcline are accessory minerals. Actinolite is commonly intergrown with, or rimmed by, tremolite.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	meta-igneous mafic intrusive	mo
Lithname	metagabbro	g
Rock code		**P_-DU-mog**

Contact relationships

West-northwest of North Mullara Bore, the metagabbro is intruded by a sheet of porphyritic biotite(–muscovite) monzogranite (P_-DU-gmp) at the base of the knoll. At both localities on Maroonah, metagabbro is intruded by planar veins and thin dykes of tourmaline–muscovite pegmatite (P_-DU-gpt) that have selvages of epidote and chlorite alteration in the mafic rock. North-northeast of James Bore, metagabbro is intruded by veins of fine- to medium-grained, strongly porphyritic monzogranite of the Dingo Creek Granite (P_-DUdi-grpv).

Geochronology

P_-DU-mog	*Maximum*	*Minimum*
Age (Ma)	1677	1674
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2005a	Nelson, 2002; Nelson, 2005b; Pearson, 1996

Metagabbro of the Durlacher Supersuite has not been dated directly. The massive nature of the rocks, and the absence of high-grade metamorphic assemblages, suggests that the rocks post-date the peak of M_{1m} metamorphism, constrained to between 1680 ± 13 Ma, the maximum depositional age of the Pooranoo Metamorphics (Nelson, 2004), and 1677 ± 5 Ma, the igneous crystallization age of the oldest granite in the Durlacher Supersuite to cut the gneissic fabrics (Nelson, 2005a). The metagabbro is intruded by veins of the Dingo Creek Granite, which is dated at 1674 ± 8 Ma (Pearson, 1996; Nelson, 2002, 2005b).

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Nelson, DR 2004, 169094: quartz–plagioclase–biotite–sillimanite gneiss, Woorkailjia Pool; Geochronology Record 88: Geological Survey of Western Australia, 5p.

Nelson, DR 2005a, 178027: biotite–muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Nelson, DR 2005b, 178028: biotite–muscovite syenogranite dyke, Coorabie Tank; Geochronology Record 537: Geological Survey of Western Australia, 4p.

Durlacher Supersuite; subunit (P_-DU-mu)

Legend narrative

Meta-ultramafic rock; medium- to coarse-grained; includes tremolite–clinopyroxene(–quartz) schist

Rank	Formation
Parent	Durlacher Supersuite (P_-DU-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-DU-ggvs (intrusive); P_-DU-mgnl (faulted)

Summary

Metamorphosed ultramafic rock is a very minor component of the Durlacher Supersuite, being restricted to two very small outcrops, or isolated inclusions in granites of the supersuite.

Distribution

Metamorphosed ultramafic rock is restricted, as a mappable unit, to a single layer of tremolite–clinopyroxene(–quartz) schist about 350 m long, 5 km west-southwest of Styles Bore on southern EUDAMULLAH, and a raft, roughly 200 m long and 100 m wide, 0.5 km south of Pelt Well on northeastern EUDAMULLAH. Metamorphosed ultramafic rock also forms rare inclusions in granitic rocks of the Durlacher Supersuite, and layers too small to be shown on the maps.

Lithology

The raft on northern EUDAMULLAH comprises crystals of pyroxene up to 4 cm long. The tremolite–clinopyroxene(–quartz) schist consists of poikiloblastic crystals of clinopyroxene 2–5mm in diameter (10%) in a matrix of tremolite (89%) defining a schistosity. Tremolite and quartz form inclusions in clinopyroxene. Clinopyroxene is partly replaced by a very fine-grained, pale-brown, fibrous mineral (?serpentine); this forms concentric growth zones with some cores of quartz.

Age code	Proterozoic	P_-
Stratigraphic code	Durlacher Supersuite	DU-
Rock type	meta-igneous ultramafic volcanic or undivided	
Lithname	meta-ultramafic rock, volcanic or undivided	mu
Rock code		**P_-DU-mu**

Contact relationships

The outcrop of coarse-grained, metamorphosed ultramafic rock on northeastern EUDAMULLAH appears to form a raft within schlieric, inclusion-rich granodiorite (P_-DU-ggvs). The layer of tremolite–clinopyroxene(–quartz) schist on southern EUDAMULLAH is tectonically interleaved with gneissic to schistose, leucocratic, biotite–muscovite metamonzogranite and metasyenogranite (P_-DU-mgnl).

Geochronology

P_-DU-mu	*Maximum*	*Minimum*
Age (Ma)	1680	1677
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2004	Nelson, 2005

The outcrop of coarse-grained, metamorphosed ultramafic rock on northeastern EUDAMULLAH appears to form a raft within schlieric, inclusion-rich granodiorite (P_-DU-ggvs), which has an igneous crystallization age of 1677 ± 5 Ma (Nelson, 2005). This date provides a minimum age for crystallization of the ultramafic precursor. There are no constraints on the maximum age of the metamorphosed ultramafic rock, other than it is presumably younger than the maximum depositional age of the Pooranoo Metamorphics at c. 1680 Ma.

References

Nelson, DR 2004, 169094: quartz–plagioclase–biotite–sillimanite gneiss, Woorkailjia Pool; Geochronology Record 88: Geological Survey of Western Australia, 5p.

Nelson, DR 2005, 178027: biotite–muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Mangaroon Orogeny

Event type	Tectonic: intracratonic orogeny. deformation: transpressional. metamorphic: regional
Parent event	Top of Event list (TOL)
Child event	D_{1m}, D_{2m}
Tectonic units affected	Gascoyne Province, Earaheedy Basin, Bresnahan Basin
Tectonic setting	orogen: intracratonic orogen
Metamorphic facies from	greenschist facies: muscovite zone
Metamorphic facies to	amphibolite facies: sillimanite–K-feldspar zone

Summary

The Mangaroon Orogeny encompasses complex and progressive deformation and metamorphism. In the Mangaroon Zone this has been divided into two discrete deformation and regional metamorphic 'events' (D_{1m}/M_{1m}, D_{2m}/M_{2m}), which are probably broadly associated with the intrusion of voluminous granite plutons of the Durlacher Supersuite. Metamorphism in the Mangaroon Zone reached upper amphibolites-facies, and appears to have been low pressure and high temperature in nature. Deformation and metamorphism related to the Mangaroon Orogeny is younger than 1680 ± 13 Ma, the age of the youngest detrital zircon age component in the precursor sediments to the Pooranoo Metamorphics, and continued until c. 1620 Ma, the age of the youngest syntectonic granites in the Durlacher Supersuite. The Mangaroon Orogeny is therefore much younger than tectonic fabrics and metamorphic mineral assemblages related to the 1820–1770 Ma Capricorn Orogeny. The Mangaroon Orogeny represents an important episode of intracontinental reworking of the Capricorn Orogen (Sheppard et al., 2005).

Our understanding of the Mangaroon Orogeny in the Gascoyne Province is largely based on mapping in the Mangaroon Zone. Outside of this zone it is difficult to be confident that any of the tectonic fabrics were formed during the Mangaroon Orogeny, because of overprinting by younger orogenic events, in particular the Edmundian and Mutherbukin Orogenies. Nevertheless, preliminary Ar–Ar ages of c. 1650 Ma for shear zones in the Sylvania Inlier along the northern margin of the Capricorn Orogen, and for a prominent cleavage in the Stanley Fold Belt of the Earaheedy Basin in the southeastern part of the orogen, indicates that the Mangaroon Orogeny is of regional significance.

Distribution

Structures and metamorphic assemblages related to the 1680–1620 Ma Mangaroon Orogeny are best developed in the northern Gascoyne Province, in particular in the Mangaroon Zone. The effects of this orogeny in the central part of the province (that is, south of the Minnie Creek batholith) may have been largely obliterated by deformation and metamorphism related to the Edmundian Orogeny, although no SHRIMP U–Pb ages indicative of the Mangaroon Orogeny have been obtained. Tectonic fabrics and accompanying low-grade mineral assemblages in the Glenburgh Terrane, Errabiddy Shear Zone, and Yarlarweelor Gneiss Complex that have been attributed to the waning stages of the Capricorn Orogeny (e.g. Sheppard and Swager, 1999; Occhipinti and Sheppard, 2000; Occhipinti et al., 2001), may, at least in part, be part of the Mangaroon Orogeny. There is also evidence that deformation related to the Mangaroon Orogeny has affected other tectonic units in the Capricorn Orogen, such as the Earaheedy Basin and the Bresnahan Basin, and other units along the southern margin of the Pilbara Craton.

Description

The oldest fabric in the Mangaroon Zone is a regionally extensive gneissic layering or foliation (S_{1m}) developed in metamorphic rocks of the Pooranoo Metamorphics, as well as in the Gooche Gneiss. Folds associated with D_{1m} are difficult to identify, but local refolded folds and evidence from facing indicates the presence of F_{1m} structures. Mineral assemblages developed during $M_{1\ m}$ are commonly well preserved in the fold hinges of macroscopic F_{2m} folds. Pelitic gneiss and granofels contain assemblages including biotite, muscovite, quartz, plagioclase, and sillimanite; quartz, biotite, cordierite, plagioclase, muscovite, and minor sillimanite; and plagioclase, biotite, quartz, sillimanite, muscovite, and cordierite. The cordierite and sillimanite bearing assemblages noted above are stable at about 600–630°C at 200 MPa or 650–700°C at 500 MPa (Spear, 1993, p. 375–382). The appearance of sillimanite in non-migmatitic pelitic gneiss is consistent with a metamorphic grade equivalent to amphibolite facies.

The migmatites around the Star of Mangaroon mine are associated with pelitic gneisses consisting of: cordierite, biotite, quartz, microcline, sillimanite, and minor muscovite; or quartz, cordierite, biotite, microcline, sillimanite, and minor plagioclase. The major difference with non-migmatitic pelitic gneisses north of the Mangaroon Syncline is the paucity or absence of plagioclase or muscovite, and the appearance of microcline. The co-existence of sillimanite and K-feldspar is consistent with onset of the equivalent of upper amphibolite facies conditions (Bucher and Frey, 2002, p. 110).

The dominant fabric in rocks of the Pooranoo Metamorphics in the Mangaroon Zone is a pervasive, east-southeast striking foliation. This foliation cuts the gneissic layering (S_{1m}), and is parallel to the axial surfaces of metre- to kilometre-scale folds. A widespread lineation defined by the crenulation of S_{1m} by S_{2m} plunges parallel to F_{2m} folds. The F_{2m} folds are upright, and range from close to tight, and plunge moderately to steeply west-northwest or east-southeast. Metamorphism accompanying the folding (M_{2m}) has resulted in widespread retrogression of M_{1m} assemblages to sericite–chlorite–quartz–plagioclase–biotite schist. This assemblage, along with the absence of andalusite, chloritoid, or staurolite is consistent with greenschist facies metamorphism of a low-Al bulk composition (Spear, 1993).

The Earaheedy Basin, at the exposed southeastern end of the orogen, is strongly folded and cut by numerous steeply north-dipping faults on its northern margin in a zone referred to as the Stanley Fold Belt. Sinistral strike-slip and reverse faulting have been recorded in this belt, but its structural history is not well understood. However, a $^{40}Ar/^{39}Ar$ muscovite date of c. 1650 Ma has been determined for muscovite defining the main cleavage in the fold belt (Pirajno et al., 2009), implying that at least some of the deformation is likely to be related to the Mangaroon Orogeny.

The Bresnahan Group along the northern margin of the Capricorn Orogen comprises siliciclastic rocks that lie unconformably on Archean and Paleoproterozoic successions along the southern margin of the Pilbara Craton. Deposition of the Bresnahan Group was controlled by a series of northeast-striking en echelon normal faults linked by sinistral transfer faults that are consistent with an overall southeast-directed extension. An $^{40}Ar/^{39}Ar$ muscovite date of c. 1650 Ma from one of these shear zones that cuts the Archean Sylvania Inlier to the east (D Hollingsworth, 2006, written comm., 10 January) suggests that deposition of the Bresnahan Group is related to the Mangaroon Orogeny. Large, open, west-northwesterly striking folds in the Bresnahan Group, which predate deposition of the Edmund Group, may be related to a later stage of the Mangaroon Orogeny. In iron ore deposits hosted by the Hamersley Group at the northern edge of the Capricorn Orogen, monazite and xenotime intergrown with the hematite ore grew during multiple discrete events, including one at c. 1650 Ma (Rasmussen et al., 2007). Monazite crystals interpreted to have grown during low-grade metamorphism of sedimentary rocks in the central part of the Pilbara Craton also record ages of c. 1650 Ma (Rasmussen et al., 2006). These data suggest that fluid flow associated with the Mangaroon Orogeny may have extended over a very wide area.

Geochronology

Mangaroon Orogeny	*Maximum*	*Minimum*
Age (Ma)	1677 ± 5	1619 ± 15
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2005; Sheppard et al., 2005	Nelson, 1998

The age of the Mangaroon Orogeny within the Mangaroon Zone is tightly constrained. A maximum age for D_{1m}/M_{1m} is provided by the youngest detrital zircon age component, dated at 1680 ± 13 Ma, in pelitic gneiss and granofels, whereas the minimum age is provided by granites of the Durlacher Supersuite that intrude S_{1m}, the oldest of which is 1677 ± 5 Ma (Sheppard et al., 2005). The S_{2m} fabric is present in some of the granites of the Durlacher Supersuite, such as the schlieric inclusion-rich granodiorite (P_-DU-ggvs) dated at 1677 ± 5 Ma. Some of the other granite units dated at c. 1675 Ma contain a magmatic foliation defined by tabular K-feldspar phenocrysts parallel to S_{2m}, and comprise a series of sheets parallel to S_{2m}, suggesting that they were emplaced during D_{2m}.

In iron ore deposits hosted by the Hamersley Group at the northern edge of the Capricorn Orogen, monazite and xenotime intergrown with the hematite ore grew during multiple discrete events, including one at c. 1650 Ma (Rasmussen et al., 2007). Monazite crystals interpreted to have grown during low-grade metamorphism of sedimentary rocks in the central part of the Pilbara Craton also record ages of c. 1650 Ma (Rasmussen et al., 2006). Two $^{40}Ar/^{39}Ar$ muscovite dates of c. 1650 Ma in other tectonic units of the Capricorn Orogen suggest that the Mangaroon Orogeny extended over a very wide area. These latter results were obtained from muscovite defining the main cleavage in the Stanley Fold Belt along the northern edge of the Earaheedy Basin (Pirajno et al., 2009), and muscovite from a sinistral transfer fault that is linked to a series of en echelon normal faults which controlled deposition of the Bresnahan Group (Sheppard et al., 2006).

Tectonic setting

The Mangaroon Orogeny involved pervasive reworking of crust in the Mangaroon Zone at 1680–1660 Ma, and coeval voluminous granitic magmatism, followed by reactivation of faults and shear zones and intrusion of granite plutons over a wide area of the Gascoyne Province until 1620 Ma. On either side of the Mangaroon Zone, the Boora Boora Zone and the Limejuice Zone appear to have similar early geological histories, suggesting that the crust is contiguous under the Mangaroon Zone and that the zone formed roughly in its current position. The lack of any volcanic and plutonic activity immediately preceding the Mangaroon Orogeny, either within or flanking the Mangaroon Zone, also precludes the orogeny being related to closure of an ocean. Instead, the Mangaroon Orogeny represents an episode of intracontinental reworking. Existing geochronology suggests that D_{1m}/M_{1m} and D_{2m}/M_{2m} may have taken place over a short time, and that they closely followed deposition of sediment precursors to the Pooranoo Metamorphics. This suggests a rapid tectonic event, albeit followed by a prolonged period of granite intrusion. The abundance of strongly peraluminous, two-mica granites in the Durlacher Supersuite, and their silicic nature, suggests that they were derived largely by remelting of older crust that included a significant proportion of metasedimentary rock. This conclusion is consistent with the abundance of inherited zircon grains in the dated granites.

The absence of megascopic compressional structures during D_{1m} may be consistent with regional metamorphism related to voluminous granite intrusion. In the northern half of the Mangaroon Zone pelitic rocks commonly have a hornfels texture that suggests the presence of large igneous intrusions just below the current level of exposure. Preliminary gravity modelling suggests that the small exposed gabbro intrusions are not part of much larger subsurface intrusions (GSWA, unpublished data), so that the voluminous granitic rocks probably provided the heat. The Mangaroon Zone shows no substantial change in metamorphic grade along or across strike; there is a change in grade across the Mangaroon Syncline, but this probably reflects differential uplift during the Neoproterozoic Edmundian Orogeny.

The Mangaroon Orogeny and Durlacher Supersuite are the only known tectonic and magmatic events in the West

Australian Craton at this time. However, tectonothermal events of similar age are known from a number of areas elsewhere in Australia; for example, in the southern Arunta region (Wyborn et al., 1998; Close et al., 2002; Scrimgeour et al., 2002) and Mount Isa Inlier and McArthur Basin (Page et al., 2000) of the North Australian Craton, and in the western Gawler Craton (Ferris, 2000), and Broken Hill and Olary Domains (Raetz et al., 2002) of the South Australian Craton. Granitic rocks with igneous crystallization ages of 1700–1600 Ma are also present in the Albany–Fraser Orogen (Nelson et al., 1995; Spaggiari et al., 2009). Nevertheless, the Capricorn Orogen is distinguished from all these other Proterozoic provinces by its lack of earliest Mesoproterozoic tectonic and magmatic activity.

Deposition of protoliths to the Pooranoo Metamorphics overlaps in time with deposition of sedimentary packages in the Mount Isa and Broken Hill regions; however, the latter are distinguished by much longer periods of sedimentation and, in the Mount Isa region, by eruption of extensive mafic magma. The geological history of the Capricorn Orogen during the Late Paleoproterozoic has little in common with the Gawler Craton with one exception: the younger granites in the Durlacher Supersuite of the Capricorn Orogen are of similar age to granites of the St Peter Suite in the western Gawler Craton (Ferris, 2000). The younger granites of the Durlacher Supersuite represent the end stages of a long-lived magmatic event, in contrast to the apparently restricted period of magmatism in the western Gawler Craton.

The Warumpi Province (southern part of the Arunta region) of Close et al. (2002, 2003) and Scrimgeour (2003) shows the greatest degree of similarity a priori to the Capricorn Orogen. Overall, the two have a similar age range of tectonism, metamorphism, and igneous activity, although (not surprisingly given the distance between them) in detail there are notable differences. For example, protoliths to the Pooranoo Metamorphics are older than the sedimentary packages in the Warumpi Province; volcanic rocks are abundant in the Warumpi Province; and the Liebig Orogeny in the Warumpi Province is characterized by high pressure (up to 900 MPa) and temperature (up to 900°C) and is associated with charnockites. The nature of the metamorphism during the Liebig Orogeny and the charnockitic granites contrast with the lower temperatures in the Mangaroon Orogeny (<750°C) and the peraluminous, xenocryst-rich granites of S-type or mixed S/I-type affinity in the Durlacher Supersuite.

In their plate-tectonic reconstruction of Proterozoic Australia, Myers et al. (1996) suggested that the West Australian, North Australian, and South Australian Cratons did not amalgamate until 1300–1000 Ma. However, recent work suggests that the three cratons were joined before c. 1500 Ma or possibly even c. 1600 Ma (Wingate and Evans 2003; Giles et al., 2004). Giles et al. (2004) proposed a model in which north- or northeast-directed subduction and progressive accretion to the southern margin of the combined craton took place between c. 1800 and c. 1600 Ma. The Warumpi Province in the Arunta Inlier is interpreted to have developed outboard of the craton, and to have been accreted to it during the 1640–1630 Ma Liebig Orogeny (Scrimgeour, 2003). If these interpretations of a contiguous latest Paleoproterozoic craton are correct, then the Mangaroon Orogeny may well be linked to tectonic events along the southern margin of the craton.

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Mangaroon Orogeny D_{1m}/M_{1m}

Event type	deformation: undivided; metamorphic: regional
Parent event	Mangaroon Orogeny
Tectonic units affected	Gascoyne Province, Earaheedy Basin, Bresnahan Basin
Tectonic setting	orogen: reactivated orogen
Metamorphic texture/ tectonic feature	foliated, gneissose, diatexitic, granofelsic, metatexitic
Metamorphic facies from	amphibolite facies: sillimanite zone
Metamorphic facies to	amphibolite facies: sillimanite–K-feldspar zone

Summary

In the Mangaroon Zone, D_{1m} was responsible for a regionally extensive gneissic layering or foliation that developed at amphibolite facies or upper amphibolites-facies metamorphic grade. There are few other structures, apart from some small, recumbent folds, that can be attributed to D_{1m}. In the northern half of the Mangaroon Zone diatexites and metatexites are rare. Many of the rocks in this region have granofelsic or hornfelsic textures, suggesting that M_{1m} may be related to intrusion of voluminous granites. In the southern half of the Mangaroon Zone, diatexites and metatexites are widespread and voluminous.

Distribution

All of the information on the discrete deformational and metamorphic events related to the Mangaroon Orogeny comes from the Mangaroon Zone in the Gascoyne Province. Outside of this zone it is difficult to be confident that any of the mineral assemblages were formed during the Mangaroon Orogeny, because of the pervasive effects of younger orogenic events, in particular the Edmundian Orogeny. In other tectonic units thought to be affected by the Mangaroon Orogeny, the age constraints are insufficient to assign any particular fabric to D_{1m} or D_{2m}. SHRIMP U–Pb dating of metamorphic monazite and xenotime in situ from the Mutherbukin Zone has failed to yield any ages corresponding with the Mangaroon Orogeny despite the presence of voluminous granites of the Durlacher Supersuite.

Description

The oldest fabric in the Mangaroon Zone is a regionally extensive gneissic layering or foliation (S_{1m}) developed in metamorphic rocks of the Pooranoo Metamorphics, as well as in the Gooche Gneiss. In the area around the Star of Mangaroon mine this fabric includes stromatic leucosomes in metatexite migmatite and diatexite melts. The S_{1m} gneissic layering is cut by an upright foliation associated with F_{2m} folds. Folds associated with D_{1m} are difficult to identify, but about 5 km northwest of James Bore (Zone 50, MGA 368020E 7380090N) a steeply inclined, metre-scale isoclinal F_{1m} fold in pelitic gneiss in the hinge of a large F_{2m} fold is exposed. Other evidence for F_{1m} folds comes from small-scale F_{1m}/F_{2m} fold interference structures in psammite near the Star of Mangaroon mine (Zone 50, MGA 372200E 7360090N). However, there are also larger scale fold interference structures in Gooche Gneiss about 4 km northeast of Six Mile Well and 6 km east of Burridges Well. In addition, F_{1m} inclined folds are inferred from downward facing metamorphosed feldspathic sandstone beds in the hinge of an F_{2m} fold west of Doorawarrah Well (Zone 50, MGA 355550E 7376850N). The dominant foliation or gneissic layering in granodioritic to monzogranitic rocks of the Gooche Gneiss is also interpreted to have formed during D_{1m}. Augen of microcline and quartz are wrapped by fine-grained quartz, plagioclase, biotite, and muscovite. The micas have a strong preferred orientation and define the foliation.

Mineral assemblages developed during M_{1m} are commonly well preserved in the fold hinges of macroscopic F_{2m} folds. Pelitic gneiss and granofels contain assemblages including; biotite–muscovite–quartz–plagioclase–sillimanite, quartz–biotite–cordierite–plagioclase–muscovite(–sillimanite), and plagioclase–biotite–quartz–sillimanite–muscovite–cordierite. All assemblages include accessory tourmaline and iron oxide minerals. Sillimanite consists of seams and patches of fibrolite that typically nucleate on biotite crystals or large muscovite plates. In some rocks sillimanite also forms small prismatic crystals intergrown with plagioclase and quartz.

On MANGAROON, garnet formation during D_{1m} is restricted to two small areas: in the area around Mount Thompson near the southern edge of the sheet area, and about 4 km northwest of Bookatharra Well in the northwestern part of the sheet area. Southeast of Mount Thompson (Zone 50, MGA 379090E 7345630N) pelitic gneiss consists of sillimanite–biotite–quartz–muscovite–garnet(–cordierite), in association with diatexite migmatite. Northwest of Bookatharra Well non-migmatitic pelitic gneiss consists of cordierite–biotite–muscovite–sillimanite with minor layers of garnet–quartz–cordierite–biotite–sillimanite.

Non-migmatitic pelitic gneiss and granofels in the area north and northwest of James Bore commonly have layers rich in porphyroblasts up to 1 cm in diameter. The porphyroblasts overprint S_{1m} and give rise to prominent pits on weathered surfaces. The porphyroblasts consist of fine-grained polygonal plagioclase, biotite, prismatic sillimanite, and minor muscovite.

The assemblages outlined above are typical of high-Al and low-Al pelites regionally metamorphosed at low pressures (Spear, 1993, p. 374–382). The absence of garnet (other than locally where it may have been stabilized by high whole-rock MnO) and staurolite, or kyanite, combined with the abundance of cordierite, suggests that the rocks were not metamorphosed at intermediate to high pressures. The cordierite and sillimanite bearing assemblages noted above are stable at about 600–630°C at 2 kbar or 650–700°C at 5 kbar (Spear, 1993, p. 375–382). The appearance of sillimanite in non-migmatitic pelitic gneiss is consistent with a metamorphic grade equivalent to amphibolite facies.

The migmatites around the Star of Mangaroon mine are associated with pelitic gneisses consisting of cordierite–biotite–quartz–microcline–sillimanite(–muscovite), or quartz–cordierite–biotite–microcline–sillimanite(–plagioclase). The major difference with non-migmatitic pelitic gneisses north of the Mangaroon Syncline is the paucity or absence of plagioclase or muscovite, and the appearance of microcline in gneisses associated with the migmatites. The co-existence of sillimanite and K-feldspar is consistent with onset of the equivalent of upper amphibolite facies conditions (Bucher and Frey, 2002, p. 110). These changes suggest that melt formed due to either of the following reactions:

muscovite + plagioclase + quartz = sillimanite + K-feldspar + melt (1)

muscovite + plagioclase + quartz = sillimanite + K-feldspar + biotite + melt (2).

The temperatures at which these reactions take place are strongly dependent on pressure, but a minimum temperature of approximately 650°C is required (Spear, 1993, p. 368). These reactions do not produce more than about 5% partial melting (Clemens and Vielzeuf, 1987) and are unlikely to be the reaction responsible for the diatexite migmatites, which correspond to large degrees of melt. The diatexite melts are a medium-grained, muscovite- and biotite-bearing granodiorite to tonalite that also contain cordierite, with or without minor garnet and sillimanite. Paleosomes consist of: biotite, cordierite, sillimanite, muscovite, and plagioclase; or cordierite, plagioclase, quartz, sillimanite, and muscovite. The diatexites may have been derived from farther below at higher temperatures by biotite dehydration, which, on both theoretical and experimental grounds, can produce large amounts of melting (Clemens and Vielzeuf, 1987).

Psammitic schist and feldspathic metasandstone is a widespread rock type, but is a poor indicator of metamorphic grade. Some layers of psammitic schist west and northwest of James Bore contain rosettes of fine-grained magnetite and biotite, commonly with leucocratic haloes. The rosettes overprint the S_{1m} fabric, but are commonly flattened within the compositional layering and are cut by the S_{2m} foliation. Rosettes range from nearly spherical and 2 cm in diameter, to oblate and more than 10 cm long. Leucocratic haloes are mostly a few millimetres wide but may exceed 10 mm. The origin of these rosettes is unclear. Garnet is also locally present in psammitic schist on EDMUND.

The dominant foliation or gneissic layering in granodioritic to monzogranitic rocks of the Gooche Gneiss is also interpreted to have formed during D_{1m}. Augen of microcline and quartz are wrapped by fine-grained quartz, plagioclase, biotite, and muscovite. The micas have a strong preferred orientation and define the foliation.

Geochronology

Mangaroon Orogeny D_1	*Maximum*	*Minimum*
Age (Ma)	1680 ± 13	1677 ± 5
Age	Paleoproterozoic	Paleoproterozoic
Source	Isotopic	Isotopic
References	Nelson, 2004; Sheppard, et al., 2005	Nelson, 2005; Sheppard et al., 2005

The age of D_{1m}/M_{1m} in the Mangaroon Zone is tightly constrained by the youngest detrital zircon age component, dated at 1680 ± 13 Ma, in the pelitic gneiss and granofels (Nelson, 2004), and by granites of the Durlacher Supersuite, the oldest of which is 1677 ± 5 Ma (Nelson, 2005) that intrude S_{1m}. There are no geochronological constraints on the age of the Mangaroon Orogeny outside the Mangaroon Zone.

Tectonic setting

See **Mangaroon Orogeny**

References

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Clemens, JD and Vielzeuf, D 1987 Constraints on melting and magma production in the crust: Earth and Planetary Science Letters, v. 86, p. 287–306.

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Nelson, DR 2005, 178027: biotite–muscovite granodiorite, Mangaroon Homestead; Geochronology Record 536: Geological Survey of Western Australia, 4p.

Sheppard, S, Occhipinti, SA and Nelson, DR 2005, Intracontinental reworking in the Capricorn Orogen, Western Australia: the 1680–1620 Ma Mangaroon Orogeny: Australian Journal of Earth Sciences, v. 52, p. 443–460.

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Mangaroon Orogeny D_{2m}/M_{2m}

Event type	tectonic: intracratonic orogeny; metamorphic: regional
Parent event	Mangaroon Orogeny
Tectonic units affected	Gascoyne Province, Earaheedy Basin, Bresnahan Basin
Tectonic setting	orogen: reactivated orogen
Metamorphic texture/ tectonic feature	folded, foliated, sheared, retrogressed, schistose
Metamorphic facies from	greenschist facies: chlorite zone
Metamorphic facies to	greenschist facies: biotite zone

Summary

In the Mangaroon Zone, D_{2m} was responsible for a pervasive east-southeast striking upright schistosity or crenulation schistosity. Metre- to kilometre-scale folds associated with the schistosity are upright, and range from close to tight, and plunge moderately or steeply to the west-northwest or east-southeast. Older granites of the Durlacher Supersuite (that is, those emplaced at or before c. 1675 Ma) have an S_{2m} schistosity of variable intensity; this is commonly developed parallel to an igneous layering. Metamorphism (M_{2m}) accompanying D_{2m}, was responsible for widespread retrogression of medium- to high-grade M_{1m} assemblages to a common assemblage of sericite, chlorite, quartz plagioclase, with or without biotite.

Distribution

Deformation and metamorphism attributed to D_{2m}/M_{2m} is known only from the Mangaroon Zone. The extent of this event elsewhere in the Gascoyne Province is unclear, largely owing to the effects of younger orogenic events, mainly the Edmundian Orogeny. SHRIMP U–Pb dating of metamorphic monazite and xenotime in situ from the Mutherbukin Zone has failed to yield any ages corresponding with the Mangaroon Orogeny despite the presence of voluminous granites of the Durlacher Supersuite.

Description

The dominant fabric in rocks of the Pooranoo Metamorphics in the Mangaroon Zone is a pervasive, east-southeast striking foliation. This foliation cuts the gneissic layering (S_{1m}), and is parallel to the axial surfaces of metre- to kilometre-scale folds. A widespread lineation defined by the crenulation of S_{1m} by S_{2m} plunges parallel to F_{2m} folds. The F_{2m} folds are upright, and range from close to tight, and plunge moderately to steeply to the west-northwest or east-southeast. There are locally large variations in plunge direction over short distances, but there is no crosscutting fabric to suggest a later phase of folding or shearing, and there are no large swings in the strike of the F_{2m} axial surfaces.

In the hinges of F_{2m} folds, M_{1m} mineral assemblages are commonly preserved, but on the limbs, these assemblages are overprinted partly or wholly by M_{2m} metamorphism. This has resulted in replacement of sillimanite by sericite, and recrystallization of cordierite to sericite and chlorite. Microcline is replaced by sericite, and biotite is commonly recrystallized to a greenish variety and exhibits exsolution of fine ?rutile needles. Plagioclase is partly sericitized. The result is typically a sericite–chlorite–quartz–plagioclase–biotite schist. This assemblage, along with the absence of andalusite, chloritoid, or staurolite, is consistent with greenschist facies metamorphism of a low-Al bulk composition (Spear, 1993).

Metamorphosed mafic rocks are rare in the Pooranoo Metamorphics, and where present they do not seem to contain high-grade M_{1m} assemblages. Assemblages of actinolite, plagioclase, epidote, and titanite suggest upper greenschist-facies metamorphism during M_{2m}. Some actinolite crystals have cores of clinopyroxene. Metamorphosed ultramafic rock contains cummingtonite and serpentine with minor green spinel. Lenticular patches of coarser grained cummingtonite contain cores of orthopyroxene with a relict subophitic texture.

The S_{2m} fabric is present in some of the granites of the Durlacher Supersuite, particularly in the schlieric inclusion-rich granodiorite (P_-DU-ggvs). In addition, some of the granite units, most commonly the Pimbyana Granite and the Dingo Creek Granite, contain a magmatic foliation defined by tabular K-feldspar phenocrysts parallel to S_{2m}. Both granites are composed of a series of sheets parallel to S_{2m} suggesting that they were emplaced during D_{2m}. However, other granite plutons cut across S_{2m}, and contact metamorphism associated with the granites has recrystallized M_{2m} mineral assemblages. These observations suggest that D_{2m}/M_{2m} in the Mangaroon Zone is the same age as the granites of the Durlacher Supersuite; that is c. 1675 Ma. The effects of M_{2m} are most pronounced in the schlieric granodiorite (P_-DU-ggvs), which field relationships suggest is the oldest of the granites in the supersuite. Mineralogical changes during M_{2m} consist of epidote and titanite replacement of magnetite and ilmenite in conjunction with plagioclase recrystallization, as well as recrystallization of biotite to a green variety with exsolved rutile needles. Plagioclase is recrystallized to albite–oligoclase, sericite, and epidote.

Along the western edge of MANGAROOON adjacent to the Minga Bar Fault, medium-grained, porphyritic biotite monzogranite (P_-MO-gmp) is moderately to strongly foliated. The foliation strikes southeast and dips steeply to the southwest, and becomes more intense toward the northeast. About 1.7 km west and 3.6 km south of Minga Bar Well (Site SXSMAN6181; Zone 50, MGA 347930E 7373710N and Site SXSMAN6158; Zone 50, MGA 350070E 7370420N) a phyllonite derived from porphyritic biotite monzogranite is juxtaposed against medium- to coarse-grained and pebbly sandstone of the Edmund Group. The Edmund Group rocks are folded about open to close upright folds, but are otherwise weakly strained. At the latter locality, a folded unconformity is preserved between the Edmund Group rocks and the phyllonite. The majority of the deformation in the shear zone must have pre-dated deposition of the Edmund Group, and may relate to the Mangaroon Orogeny. The general absence of a stretching lineation suggests that the rocks underwent non-rotational strain. Locally, a steeply dipping stretching lineation defined by biotite or chlorite is developed, and is associated with asymmetric K-feldspar porphyroclast tails implying southwest side up on steep normal or reverse faults.

Narrow shear zones (<2 m wide) in granites on the southwestern side of the Minga Bar Fault locally contain S–C fabrics suggesting dextral strike-slip movement. Deformed porphyritic biotite monzogranite consists of microcline and quartz porphyroclasts wrapped by fine-grained quartz, muscovite, chlorite, untwinned ?albite, titanite, and minor green–brown biotite. This assemblage is consistent with recrystallization under lower greenschist facies conditions. However, the age of this deformation and recrystallization is unknown. It may relate to D_{2m}/M_{2m} or, alternatively, it may relate to the Neoproterozoic Edmundian Orogeny (see Neoproterozoic Edmundian Orogeny).

In the areas between the Yannarie River on northwestern Mangaroon and outcrop of the Edmund Group to the northeast, and along the western side of the fault that runs near Old Deep Well and Middle Well, granites of the Durlacher Supersuite are cut by narrow zones of shearing. This tectonic fabric strikes southeast and mostly dips steeply to the southwest. It is commonly parallel to an igneous foliation in the granites defined by the alignment of tabular K-feldspar phenocrysts. At one locality (Site SXSMAN5864; Zone 50, MGA 382980E 7373950N), weakly to moderately foliated, porphyritic biotite granodiorite (P_-DU-ggb) is intruded by northeast-striking dykes of muscovite–biotite granite and pegmatite (P_-DU-gmv). The latter contain a foliation, but are not offset, suggesting that they have undergone non-rotational strain. Therefore, granites of the Durlacher Supersuite both intrude the shear zones and are overprinted by them, indicating that supersuite emplacement, at least in part, accompanied the deformation. Most sense-of-shear criteria indicate reverse movement (that is, southwest side up), although normal movement is indicated in places.

Geochronology

Mangaroon Orogeny D_2	*Maximum*	*Minimum*
Age (Ma)	1677	1659
Age	Paleoproterozoic	Paleoproterozoic
Source	Inferred	Inferred
References	Nelson, 2005	Nelson, 2002

The S_{2m} fabric is present in some granites of the Durlacher Supersuite, particularly in the schlieric inclusion-rich granodiorite (P_-DU-ggvs). This granodiorite has an igneous crystallization age of 1677 ± 5 Ma, and is the oldest dated in the supersuite (Nelson, 2005; Sheppard et al., 2005). Therefore, the age of the granodiorite provides a maximum age for D_{1m}/M_{2m}. In addition, some of the granite units, in particular the c. 1675 Ma Pimbyana Granite and Dingo Creek Granite, contain a magmatic foliation defined by tabular K-feldspar phenocrysts parallel to S_{2m}. Both granites comprise a series of sheets parallel to S_{2m} suggesting that they were emplaced during D_{2m}. Other granite plutons, such as the Yangibana Granite, which has an igneous crystallization age of 1659 ± 10 Ma (Nelson, 2002), cut across S_{2m}, and contact metamorphism associated with some of the granites (for example, parts of the Dingo Creek Granite) has recrystallized M_{2m} mineral assemblages. These observations suggest that D_{2m}/M_{2m} is the same age as the bulk of the granites of the Durlacher Supersuite in the Mangaroon Zone: that is, c. 1675 Ma.

Tectonic setting

See **Mangaroon Orogeny**

References

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KIANGI CREEK FORMATION; subunit (P_-MEk-mh)

Legend narrative

Interbedded metasiltstone and fine-grained metasandstone

Rank	Member
Parent	KIANGI CREEK FORMATION (P_-MEk-sf)
Tectonic units	Edmund Basin; Edmund Fold Belt
Overlying units	P_-MEd-ml, P_-MEv-mk, P_-MEl-mlsd (nonconformable)
Underlying units	AP_-_ha-mgnw, P_-MGm-mtsf, P_-MGm-mtq, P_-DU-mgm, P_-DU-mgmb, P_-MO-mgnl, P_-LS-mhs, P_-MEy-st (fault)

Summary

Interbedded metasiltstone and fine-grained metasandstone of the Kiangi Creek Formation is poorly exposed within a 115 km^2 lens-shaped outcrop of metamorphosed Edmund Group on central southern Pink Hills. The rocks have been metamorphosed at low to medium grade, are commonly silicified, and locally contain two penetrative foliations. The unit is relatively uniform across the extent of exposure, consisting of interbedded pale-coloured metasiltstones and fine-grained metasandstones with minor metamudstone and recrystallized sericitic quartzite. The unit is interpreted as Kiangi Creek Formation that was metamorphosed to lower amphibolite facies during the Edmundian Orogeny. This unit has not been directly dated but is inferred to have been deposited sometime between 1620 and 1460 Ma.

Distribution

Interbedded metasiltstone and fine-grained metasandstone of the Kiangi Creek Formation occurs within a 115 km^2 lens-shaped outcrop of metamorphosed Edmund Group on central southern Pink Hills. These rocks form the majority of this outcrop along the southern and south-eastern parts, but they are poorly exposed, being covered by extensive colluvial deposits. The unit is best exposed along the southern margin of this area around Big Bend Bore.

Lithology

Interbedded metasiltstone and fine-grained metasandstone has been metamorphosed at low grade and is commonly silicified. The unit is relatively uniform across the extent of exposure, consisting of interbedded pale-coloured metasiltstone and fine-grained metasandstone. Finer grained, white to pale-coloured metamudstone and recrystallized medium- to coarse-grained sericitic quartzite are locally common. Fine-grained metasandstone can locally dominate the finer grained lithologies by up to 70%. Relict bedding is commonly on the 20–30 cm scale but locally may contain quartzite horizons up to 1 m thick. The fine-grained metasandstone is well sorted and may locally contain up to 10% sericite. Rare 20–30 cm cross-bedding is present in some quartzite units. All lithologies commonly contain a penetrative foliation which is locally truncated at a low angle by a second, weak cleavage/ foliation.

Age code	Proterozoic	P_-
Startigraphic code	Edmund Group, KIANGI CREEK FORMATION	MEk-
Rock type	metasedimentary siliciclastic: psammite and pelite; interlayered	
Lithname	psammite and pelite; interlayered	mh
Rock code		**P_-MEk-mh**

Contact relationships

Contacts between interbedded metasiltstone and fine-grained metasandstone and the surrounding units are not exposed. However, this unit is interpreted to be in faulted contact with all older lithologies including those of the Halfway Gneiss (AP_-_ha-mgnw), Moogie Metamorphics (P_-MGm-mtsf and P_-MGm-mtq), Leake Spring Metamorphics (P_-LS-mhs), Moorarie Supersuite (P_-MO-mgnl), Durlacher Supersuite (P_-DU-mgm, P_-DU-mgmb), and unmetamorphosed rocks of the Edmund Group (P_-MEy-st). The unit is overlain by more strongly deformed and metamorphosed rocks of the Edmund Group that are equivalent to depositional package 4 including the Discovery Formation (P_-MEd-ml), the Devil Creek Formation (P_-MEv-mk), and the Ullawarra Formation (P_-MEl-mlsd). These rocks appear to onlap the underlying Kiangi Creek rocks suggesting that the original relationship may have been unconformable; however, due to the intense folding and deformation these contacts may now be tectonic.

Geochronology

P_-MEk-mh	*Maximum*	*Minimum*
Age (Ma)	1619	1460
Age	Mesoproterozoic	Mesoproterozoic
Source	Inferred	Inferred
References	Nelson, 1998	Wingate et al., 2010

Interbedded metasiltstone and fine-grained metasandstone of the Kiangi Creek Formation has not been dated directly. The Edmund Group unconformably overlies deformed granites of the Durlacher Supersuite and therefore must be younger than c. 1620 Ma (Nelson, 1998). A horizon of felsic volcanic sandstone in the Ullawarra Formation of the Upper Edmund Group farther east on Milgun has been dated directly using SHRIMP U–Pb zircon geochronology at 1460 ± 9 Ma (Wingate et al., 2010), providing a reliable minimum age for deposition of the unit. This date is within uncertainty of the age of the c. 1465 Ma Narimbunna Dolerite Sills (Wingate, 2002) that intrude Edmund Group depositional package 3.

References

Nelson, DR 1998, 142855: porphyritic monzogranite, Anderson Well; Geochronology Record 371: Geological Survey of Western Australia, 4p.

Wingate, MTD 2002. Age and palaeomagnetism of dolerite sills of the Bangemall Supergroup on the Edmund 1:250,000 map sheet, WA: Geological Survey of Western Australia, Record 2002/4, 48p.

Wingate, MTD, Kirkland, CL and Thorne, AM 2010, 149031; quartzofeldspathic gneiss, Salt Creek; Geochronology Record 867: Geological Survey of Western Australia, 5p.

DISCOVERY FORMATION; subunit (P_-MEd-ml)

Legend narrative

Metamorphosed silicified mudstone; locally with abundant pyrite

Rank	Member
Parent	DISCOVERY FORMATION (P_-MEd-cl)
Tectonic units	Edmund Basin; Edmund Fold Belt
Overlying units	P_-MEv-mk (conformable); P_-_nr-moa (intrusive)
Underlying units	P_-MEk-mh (unconformity – overstep); AP_-_ha-mgnw (fault)

Summary

Metamorphosed silicified mudstone of the Discovery Formation occurs as a series of thin discontinuous poorly exposed outcrops within a 115 km^2 lens-shaped region of metamorphosed Edmund Group rocks on central southern Pink Hills. The lithology is light-blue–grey, very fine grained, and intensely silicified showing a conchoidal and feathery fracture. The unit contains <5%, 10–15 mm, randomly oriented and distributed pyrite crystals. The unit is interpreted as Discovery Formation that was metamorphosed to lower amphibolite facies during the Edmundian Orogeny. Although this unit has not been directly dated it is inferred to have been deposited sometime between 1620 and 1460 Ma.

Distribution

Metamorphosed silicified mudstone of the Discovery Formation forms a series of thin, discontinuous, poorly exposed outcrops within a 115 km^2 lens-shaped region of metamorphosed Edmund Group rocks on central southern Pink Hills. The outcrops define a regional-scale synform, and this unit outcrops predominantly around the northern nose of the synform. The metamorphosed silicified mudstone has only been observed at a single locality (SPJPKH000796); map outcrop was interpreted from both aerial photography and LANDSAT images. The total length of discontinuous outcrops is 14 km with the thickest exposure interpreted to be 300 m.

Lithology

At SPJPKH000796, the metamorphosed silicified mudstone (P_-MEd-ml) is very fine grained showing a conchoidal and feathery fracture. The lithology is light-blue–grey, intensely silicified, and contains <5%, 10–15 mm, randomly oriented and distributed pyrite crystals, most of which have been weathered out. Individual beds are about 10–15 cm in thickness, and are defined principally by variations in colour.

Age code	Proterozoic	P_-
Stratigraphic code	Edmund Group, DISCOVERY FORMATION	MEd-
Rock type	metasedimentary siliciclastic: pelite	ml
Lithname	pelite	ml
Rock code		**P_-MEd-ml**

Contact relationships

Contacts between interbedded metasiltstone and fine-grained metasandstone and the surrounding units are not exposed. However, this unit is interpreted to unconformably overly interbedded metasiltstones and fine grained metasandstones of the Kiangi Creek Formation (P_-MEk-mh). This contact is interpreted as an overstep as the overlying lithologies of the Devil Creek Formation and Ullawarra Formation are in contact with the Kiangi Creek Formation progressively to the southeast. The unit is interpreted to be conformably overlain by the Devil Creek Formation (P_-MEv-mk; unexposed). At the northern tip of the regional synform, metamorphosed Narimbunna Dolerite (P_-_nr-moa) intruded between the Discovery Formation and Devil Creek Formation.

Geochronology

P_-MEd-ml	*Maximum*	*Minimum*
Age (Ma)	1619	1460
Age	Mesoproterozoic	Mesoproterozoic
Source	Inferred	Inferred
References	Nelson, 1998	Wingate, et al., 2010

Metamorphosed silicified mudstone of the Discovery Formation has not been dated directly. The Edmund Group unconformably overlies deformed granites of the Durlacher Supersuite and therefore must be younger than c. 1620 Ma (Nelson, 1998). A horizon of felsic volcanic sandstone in the Ullawarra Formation of Package 3 farther east on Milgun has been dated directly using SHRIMP U–Pb zircon geochronology at 1460 ± 9 Ma (Wingate et al., 2010), providing a reliable minimum age for deposition of the unit. The Discovery Formation is intruded by a 1465 ± 3 Ma dolerite sill north of Coolinbah Well in the Mangaroon Syncline (Wingate, 2002).

References

Nelson, DR 1998, 142855: porphyritic monzogranite, Anderson Well; Geochronology Record 371: Geological Survey of Western Australia, 4p.

Wingate, MTD 2002. Age and palaeomagnetism of dolerite sills of the Bangemall Supergroup on the Edmund 1:250,000 map sheet, WA: Geological Survey of Western Australia, Record 2002/4. 48p.

Wingate, MTD, Kirkland, CL and Thorne, AM 2010, 149031: quartzofeldspathic gneiss, Salt Creek; Geochronology Record 867: Geological Survey of Western Australia, 5p.

DEVIL CREEK FORMATION; subunit (P_-MEv-mk)

Legend narrative

Metacarbonate rock

Rank	Member
Parent	DEVIL CREEK FORMATION (P_-MEv-kd)
Tectonic units	Edmund Group; Edmund Fold Belt
Overlying units	P_-MEl-mlsd (conformable)
Underlying units	P_-MEd-ml (conformable); P_-MEk-mh (unconformable)

Summary

Metacarbonate of the Devil Creek Formation is interpreted to form a discontinuous train of exposures within a 115 km^2 lens-shaped region of metamorphosed Edmund Group rocks on central southern Pink Hills. This formation has not been identified in outcrop, but from the presence of a prominent gap in exposure between the underlying Discovery Formation and overlying Ullawarra Formation. The unit is interpreted as Devil Creek Formation that was metamorphosed to amphibolite facies during the Edmundian Orogeny. Although this unit has not been directly dated it is inferred to have been deposited sometime between 1620 and 1460 Ma.

Distribution

Metacarbonate of the Devil Creek Formation is interpreted to form a discontinuous train of exposures within a 115 km^2 lens-shaped region of metamorphosed Edmund Group rocks on central southern Pink Hills. Currently this formation has not been identified in outcrop, but is interpreted to be present under extensive colluvium between the outcropping Discovery Formation and overlying Ullawarra Formation. The unit very locally displays a distinct striped air-photo pattern. In common with the metamorphosed Discovery Formation in this region, metamorphosed Devil Creek Formation is restricted to the northern part of the regional scale synform.

Lithology

See **Distribution**

Age code	Proterozoic	P_-
Stratigraphic code	Edmund Group, DEVIL CREEK FORMATION	MEv-
Rock type	metasedimentary carbonate	
Lithname	metacarbonate	mk
Rock code		**P_-MEv-mk**

Contact relationships

Because this unit is not exposed the nature of its contacts with other units is unclear. However; based on the regional interpretation, the Devil Creek Formation is presumably in conformable contact with other metamorphosed Edmund Group rocks in the area (P_-MEd-ml and P_-MEl-mlsd) and sits unconformably on interbedded metasiltstone and fine grained metasandstones of the Kiangi Creek Formation (P_-MEk-mh).

Geochronology

P_-MEv-mk	*Maximum*	*Minimum*
Age (Ma)	1619	1460
Age	Mesoproterozoic	Mesoproterozoic
Source	Inferred	Inferred
References	Nelson, 1998	Wingate et al., 2010

Metacarbonates of the Devil Creek Formation have not been dated directly. The Edmund Group unconformably overlies deformed granites of the Durlacher Supersuite and therefore must be younger than c. 1620 Ma (Nelson, 1998). A horizon of felsic volcanic sandstone in the overlying Ullawarra Formation of Package 3 farther east on Milgun has been dated directly using SHRIMP U–Pb zircon geochronology at 1460 ± 9 Ma (Wingate et al., 2010), providing a reliable minimum age for deposition of the unit.

References

Nelson, DR 1998, 142855: porphyritic monzogranite, Anderson Well; Geochronology Record 371: Geological Survey of Western Australia, 4p.

Wingate, MTD, Kirkland, CL and Thorne, AM 2010, 149031: quartzofeldspathic gneiss, Salt Creek; Geochronology Record 867: Geological Survey of Western Australia, 5p.

ULLAWARRA FORMATION; subunit (P_-MEl-mlsd)

Legend narrative

Pelitic and psammitic schist; andalusite–garnet–biotite–muscovite schist

Rank	Member
Parent	ULLAWARRA FORMATION (P_-MEl-sl)
Tectonic units	Edmund Basin; Edmund Fold Belt
Overlying units	P_-_nr-moa (intrusive)
Underlying units	P_-MEv-mk, P_-MEd-ml (conformable); P_-MEk-mh (unconformable); P_-MGm-mtq, P_-DU-mgm (fault)

Summary

Pelitic and psammitic schist of the Ullawarra Formation lies within a 115 km^2 lens-shaped region of metamorphosed Edmund Group rocks on central southern Pink Hills. The unit consists predominantly of interbedded andalusite- and garnet-bearing schist with minor interbeds of fine-grained metasandstone or psammitic schist. The unit is interpreted as Ullawarra Formation that was metamorphosed to amphibolite facies during the Edmundian Orogeny. Although this unit has not been directly dated, a felsic volcanoclastic horizon from Milgun to the east has been dated at 1460 ± 9 Ma.

Distribution

Pelitic and psammitic schist of the Ullawarra Formation lies within a 115 km^2 lens-shaped region of metamorphosed Edmund Group rocks on central southern Pink Hills. The rocks form part of a regional-scale synform of which the pelitic and psammitic schists form the core. Exposure is poor in most parts due to extensive colluvial deposits, but the pelitic and psammitic schist is interpreted to cover some 37 km^2. The unit is best exposed in the central to northern part of its outcrop where it forms a series of small, undulating hills.

Lithology

Metamorphosed Ullawarra Formation consists predominantly of interbedded, andalusite- and garnet-bearing schist or metamudstone and fine-grained, silicified, schist or metasiltstone with minor interbeds of fine-grained, psammitic schist or metasandstone. Typically andalusite- and garnet-bearing schist after mudstone is the predominant rock type, although schist after siltstone may predominate locally. Bedding is typically on a 5–10 cm scale but where fine-grained metasandstones are present, bedding can be on a 1–2 m scale. Sedimentary features, such as cross-bedding, are rare; presumably having been obliterated during the medium-grade metamorphic event. At SPJPKH000794, fine grained metasandstones become predominant and are bedded on a 20–30 cm scale. These units grade up into 10–15 cm-thick metasiltstones, the tops of which have sharp boundaries with the overlying metasandstone unit. This grading suggests that, although folded within a tight regional-scale syncline, the beds are the right way up.

Pelitic and psammitic schist of the Ullawarra Formation is characterized by an abundance of randomly oriented (although locally aligned) 1–10 mm long andalusite porphyroblasts within the metamudstone units and, to a lesser degree, the metasiltstones. Garnet porphyroblasts are common but not present throughout the entire formation. Where present, the garnet is randomly distributed, between 1–10 mm diameter, and typically idioblastic. All units contain at least one penetrative foliation but the relationship of this fabric to the timing of growth of the garnet and andalusite porphyroblasts is uncertain. At some localities, garnet is wrapped by this fabric but at others appears to have grown over it. Similarly, andalusite has generally grown randomly within the foliation plane, but at some localities has grown across it. This would appear to suggest that fabric formation and porphyroblast growth occurred at a similar time but over a protracted period. At SPJPKH000795, a riverbank exposure reveals a 1–2 m thick, more massive, medium grained rock comprising 10–20% 1–2 mm garnet porphyroblasts and 5–10% 1–2 mm staurolite porphyroblasts that are set within a fine grained matrix of quartz and muscovite; suggesting that the temperature of metamorphism was approaching that of equivalent rocks around the Nardoo Hills in the northern part of the Mutherbukin Zone (500–600°C). The rock has been overprinted by a lower grade metamorphic assemblage so that the garnet has been variably replaced by chlorite, the staurolite by chloritoid (and subsequently by fine grained muscovite and chlorite), and an unknown mineral by radiating masses of acicular amphibole (presumably tremolite).

Age code	Proterozoic	P_-
Stratigraphic code	Edmund Group, ULLAWARRA FORMATION	MEl-
Rock type	metasedimentary siliciclastic: pelite	ml
Lithname	pelitic schist	s
Qualifier	andalusite	d
Rock code		**P_-MEl-mlsd**

Contact relationships

Due to the poor exposure of this and other units in the region, its contacts with the surrounding units are not observed. However, this unit is interpreted to conformably overly metacarbonate rocks of the Devil Creek Formation (P_-MEd-mk) and metamorphosed silicified mudstones of the Discovery Formation (P_-MEd-ml). The central and southern parts of the formation are interpreted to unconformably overly interbedded metasiltstones and fine grained metasandstones of the Kiangi Creek Formation (P_-MEk-mh). In the northern part of the outcrop the unit is in faulted contact with much older rocks of the Gascoyne Province including the Halfway Gneiss (AP_-_ha-mgnw) and Durlacher Supersuite (P_-DU-mgm). This formation forms the core of the regional synform and is the youngest part of the metamorphosed Edmund Group that is exposed; however, it is intruded by voluminous sills of metamorphosed (amphibolite facies) Narimbunna Dolerite (P_-_nr-moa).

Geochronology

P_-MEl-mlsd	*Maximum*	*Minimum*
Age (Ma)	1460	1449
Age	Mesoproterozoic	Mesoproterozoic
Source	Inferred	Inferred
References	Wingate et al., 2010	Wingate, 2002

Pelitic and psammitic schist (P_-MEl-mlsd) from this region have not been dated directly. However, a horizon of felsic volcanic sandstone in the Ullawarra Formation farther east on MILGUN has been dated directly using SHRIMP U–Pb zircon geochronology at 1460 ± 9 Ma (Wingate et al., 2010), providing a reliable age for deposition of the unit. The Ullawarra Formation is intuded by a dolerite sill at Coodardo Well, which has a minimum age of 1449 ± 5 Ma, and may be as old as c. 1470 Ma (Wingate, 2002).

References

Wingate, MTD 2002, Age and palaeomagnetism of dolerite sills of the Bangemall Supergroup on the Edmund 1:250,000 map sheet, WA: Geological Survey of Western Australia, Record 2002/4, 48p.

Wingate, MTD, Kirkland, CL and Thorne, AM 2010, 149031: quartzofeldspathic gneiss, Salt Creek; Geochronology Record 867: Geological Survey of Western Australia, 5p.

GIFFORD CREEK CARBONATITE COMPLEX (P_-_gc-xrf-z)

Legend narrative

Sills and dykes of ferroan carbonatite; associated with haloes and veins of fenitic alteration

Rank	Formation
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA

Summary

The Gifford Creek Carbonatite Complex comprises sills, dykes, and veins of ferroan carbonatite and hydrothermally-altered rocks (fenites) intruding the Pimbyana Granite and Yangibana Granite. The ferroan carbonatites are associated with complex and irregularly distributed zones of fenitic alteration. Also associated with the carbonatites and fenites are veins of Fe oxide minerals and quartz that were likely formed during post-magmatic alteration processes, which caused dissolution of Fe carbonates and redistribution as Fe oxide minerals. The Gifford Creek Carbonatite Complex has the characteristics of igneous systems generally related to alkaline magmatism in extensional settings, which may imply deep mantle melting and/or interaction of mantle melts with metasomatized subcontinental lithospheric mantle (Mitchell, 2005). These igneous systems may host REE, U, and/or polymetallic mineralization. The age of the complex is unknown but is interpreted to be Neoproterozoic.

Distribution

Gifford Creek ferroan carbonatites and associated fenites outcrop in the southern part of EDMUND, where they occupy a 25 × 20 km zone. Sills are predominant in a northwest-trending belt, along the southern margin of the Complex; the carbonatites tend to be distributed in a series of subparallel west-northwest-trending linear belts, whereas the Fe oxide veins tend to have trends that are almost perpendicular to that of the carbonatites.

Derivation of name

The name Gifford Complex was first used by Pearson et al. (1996). Gifford Creek is a tributary of the Lyons River, which marks the southern boundary of the complex. The igneous complex is renamed Gifford Creek Carbonatite Complex (Pirajno et al., in prep.), based on the lack of alkaline igneous rocks other than carbonatite.

Lithology

Ferroan carbonatites are composed of predominantly ankerite–dolomite, magnetite, pyrochlore, arfvedsonite–riebeckite, and lesser calcite. Sills and dykes north of, and along the Lyons River right bank, are, according to Pearson et al. (1996), olivine phyric within a carbonate-rich matrix, and contain apatite, barite, monazite, and phlogopite. On the basis of Pearson and co-workers' data, it can be surmised that this mineral assemblage, where present, resembles that of lamprophyres and may be transitional from lamprophyric to carbonatitic melts. However, recent field and petrographic work shows that these rocks range from ankeritic carbonatites (> 50 vol% ankerite–dolomite) to silicocarbonatite (arfvedsonite-rich). Fenitic alteration is generally spatially associated with the carbonatites, but it also forms discrete veins and veinlets in basement granitic rocks (Pimbyana and Yangibana Granites).

Age code	Proterozoic	P_-
Stratigraphic code	Not assigned to a Suite, GIFFORD CREEK CARBONATITE COMPLEX	_gc-
Mixed or xenolith-bearing	Mixed	x
Rock type 1	Igneous carbonatite	r
Lithname 1	ferroan carbonatite	f
Rock type 2	hydrothermal	-z
Rock code		**P_-_gc-xrf-z**

Contact relationships

Carbonatite sills, dykes and veins of the Gifford Creek Carbonatite Complex intrude various granitic rocks of the Durlacher Supersuite.

Geochronology

P_-_gc-xrf-z	*Maximum*	*Minimum*
Age (Ma)	1619	600
Age	Paleoproterozoic	Neoproterozoic
Source	Inferred	Inferred
References	Nelson, 1998	

Age is unknown, but field relationships indicate that the carbonatites must be younger than the Pimbyana and Yangibana Granites (Durlacher Supersuite; 1680–1620 Ma); it can be speculated that the Gifford Creek Carbonatite Complex could have been emplaced during tectonothermal reworking of the Capricorn Orogen (e.g. Edmundian Orogeny 1030–955 Ma) or the 755 Ma thermal event (Sheppard et al., 2007).

References

Mitchell, RH 2005, Carbonatites and carbonatites and carbonatites: The Canadian Mineralogist, v. 43, p. 2049–2068.

Nelson, DR 1998, 142855: porphyritic monzogranite, Anderson Well; Geochronology Record 371: Geological Survey of Western Australia, 4p.

Pearson, JM, Taylor WR, Barley ME 1996, Geology of the alkaline Gifford Creek Complex, Gascoyne Complex, Western Australia. Australian Journal of Earth Sciences, v. 43, p. 299–309.

Pirajno F, Sheppard S, Johnson SP and Mao, JW in prep., The Minnie Springs Mo–Cu–W multiphase greisen system: Geological Survey of Western Australia, Record.

Sheppard S, Rasmussen B, Muhling JR, Farrell, TR, Fletcher IR 2007, Grenvillian-aged orogenesis in the Palaeoproterozoic Gascoyne Complex, Western Australia: 1050-950 Ma reworking of the Proterozoic Capricorn Orogen. Journal of Metamorphic Geology, v. 25, p. 477–494.

GIFFORD CREEK CARBONATITE COMPLEX; subunit (P_-_gc-rf)

Legend narrative

Ferroan carbonatite; sills and dykes of Fe-carbonate, phlogopite, and sodic amphibole, and variable amounts of quartz

Rank	Member
Parent	GIFFORD CREEK CARBONATITE COMPLEX (P_-_gc-xrf-z)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA

Summary

Sills, dykes, and veins of ferroan carbonatite intrude rocks of the Durlacher Supersuite. The carbonatites are generally poorly exposed, but reasonably good outcrops can be seen along a west-northwest-trending belt of dykes and sills on the northwestern side of the Lyons River (see EDMUND). Previous exploration and limited drilling focused on Yangibana North, Yangibana South, Bald Hill North Fe oxide and carbonatite veins (see EDMUND), (e.g. Hurlston Pty Ltd,, 1988). The age of the unit is not known but it is inferred to be Neoproterozoic.

Distribution

Gifford Creek Carbonatite Complex ferroan carbonatites and associated fenites outcrop in the southern part of EDMUND, where they occupy a 25 × 20 km zone; sills are predominantly in a northwest-trending belt along the southern margin of the Complex

Lithology

Ferroan carbonatites are composed predominantly of Fe carbonates (siderite and ?ankerite), and accessory monazite, barite, magnetite, bastanasite, pyrochlore, ferrocolumbite, and an unidentified Ce-La oxide.

Age code	Proterozoic	P_-
Stratigraphic code	Not assigned to a Suite, GIFFORD CREEK CARBONATITE COMPLEX	_gc-
Rock type	Igneous carbonatite	r
Lithname	ferroan carbonatite	f
Rock code		**P_-_gc-rf**

Contact relationships

Veins, dykes and sills of ferroan carbonatite intrude the Pimbyana Granite and Yangibana Granite of the Durlacher Supersuite.

Geochronology

P_-_gc-rf	*Maximum*	*Minimum*
Age (Ma)	1619 ±	600
Age	Paleoproterozoic	Neoproterozoic
Source	Inferred	Inferred
References	Nelson, 1998	

References

Hurlston Pty Ltd, Yangibana rare earths prospect, Gascoyne Mineral Field, Western Australia, Reconnaissance Drilling Programme and indicated rare earth element potential. Annual Report 1988; Accession No. 25937; M 5479.

Nelson, DR 1998, 142855: porphyritic monzogranite, Anderson Well; Geochronology Record 371: Geological Survey of Western Australia. 4p.

GIFFORD CREEK CARBONATITE COMPLEX;
subunit (P_-_gc-zi)

Legend narrative

Hematite–magnetite veins, locally altered to massive goethite; fenite alteration comprises variable amounts of K-feldspar, albite, sodic amphibole, cancrinite, pyrochlore, phlogopite, and lamprophyllite

Rank	Member
Parent	GIFFORD CREEK CARBONATITE COMPLEX (P_-_gc-xrf-z)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA

Summary

Hematite–magnetite veins of the Gifford Creek Carbonatite Complex comprise hematite, magnetite, and goethite. Exploration drilling shows that these veins have very shallow (~10°) to moderate (>45°) dips (Hurlston Pty Ltd, 1988). Only REE oxide minerals have been detected by geochemical analyses. No uranium minerals have been identified. Estimated resources are about 2.77 Mt, grading 1.52% REE oxides (Flint and Abeysinghe, 2000). The age of this unit is not known but it is inferred to be Neoproterozoic.

Distribution

The Fe-oxide and quartz veins are distributed throughout the extent of the Gifford Creek Carbonatite Complex. Hematite–magnetite in places is altered to massive goethite. The Fe-oxide veins are curved to locally sinuous and have variable trends, although in many instances they tend to be almost perpendicular to the trend of the carbonatites.

Lithology

Hematite–magnetite and quartz veins, in places altered to massive goethite, range in width from less than 1 m to about 20 m. Fe-oxide veins are locally sinuous and have variable trends, although in many instances they tend to be almost perpendicular to the trend of the carbonatites.

Age code	Proterozoic	P_-
Stratigraphic code	Not assigned to a Suite, GIFFORD CREEK CARBONATITE COMPLEX	_gc-
Rock type	hydrothermal	z
Lithname	goethite/hematite vein	i
Rock code		**P_-_gc-zi**

Contact relationships

Fe oxide veins cut the carbonatite and associated fenitised granitic rocks of the Durlacher Supersuite.

Geochronology

P_-_gc-zi	*Maximum*	*Minimum*
Age (Ma)	1619	600
Age	Paleoproterozoic	Neoproterozoic
Source	Inferred	inferred
References	Nelson, 1998	

The age of the hematite–magnetite veins is unknown, but their attitudes, field relationships, and petrographic data suggest that the veins post-date carbonatite emplacement and associated fenitic alteration of the complex.

References

Flint, D and Abeysinghe, PB 2000, Geology and mineral resources of the Gascoyne Region. Geological Survey of Western Australia, Record 2000/7, 29p.

Hurlston Pty Ltd, Yangibana rare earths prospect, Gascoyne Mineral Field, Western Australia, Reconnaissance Drilling Programme and indicated rare earth element potential. Annual Report 1988; Accession No. 25937; M 5479.

Nelson, DR 1998, 142855: porphyritic monzogranite, Anderson Well; Geochronology Record 371: Geological Survey of Western Australia, 4p.

GIFFORD CREEK CARBONATITE COMPLEX; subunit (P_-_gc-zn)

Legend narrative

Fenite, comprising nepheline, sodalite, sodic amphibole, and microcline

Rank	Member
Parent	GIFFORD CREEK CARBONATITE COMPLEX (P_-_gc-xrf-z)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA

Summary

Fenitic alteration of the carbonatitic rocks of the Gifford Creek Igneous Complex consists of variable amounts of orthoclase (locally forming monomineralic orthoclasite), albite, lamprophyllite, cancrinite, nepheline, sodalite, aegirine, and riebeckite. The age of this alteration is not precisely known but is interpreted to be Neoproterozoic.

Distribution

Fenitic alteration forms irregular zones surrounding the carbonatites, but also as veins and veinlets in Pimbyana and Yangibana granites.

Lithology

The fenite comprises variable amounts of orthoclase (locally forming monomineralic orthoclasite), albite, lamprophyllite, cancrinite, nepheline, sodalite, aegirine, and riebeckite.

Age code	Proterozoic	P_-
Stratigraphic code	Not assigned to a Suite, GIFFORD CREEK CARBONATITE COMPLEX	_gc-
Rock type	hydrothermal	z
Lithname	hydrothermal rock, undivided	n
Rock code		**P_-_gc-zn**

Geochronology

P_-_gc-zn	*Maximum*	*Minimum*
Age (Ma)	1619	600
Age	Neoproterozoic	Neoproterozoic
Source	Inferred	Inferred
References	Nelson, 1998	

The age of the Complex is unknown, but the spatial association of fenite alteration zones with carbonatites suggests the fenitization process is closely associated with carbonatite emplacement.

NARIMBUNNA DOLERITE (P_-_nr-moa)

Legend narrative

Amphibolite

Rank	Formation
Parent	NARIMBUNNA DOLERITE (P_-_nr-od)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MW-od (intrusive)
Underlying units	P_-MEl-mlst and P_-MEl-mlsd (intrusive)

Summary

Metamorphosed Narimbunna Dolerite is widespread, although never voluminous, along the northern edge of the Mutherbukin Zone. The vast majority of the amphibolite is too deformed and recrystallized to preserve any evidence of either an extrusive or intrusive origin, but by analogy with their unmetamorphosed and relatively undeformed counterparts in the main part of the Edmund Group , they are interpreted as sills. Unmetamorphosed Narimbunna Dolerite sills (P_-_nr-od) have been dated at c. 1465 Ma.

Distribution

Amphibolite representing metamorphosed Narimbunna Dolerite is common along the northern edge of the Mutherbukin Zone within the metamorphosed Ullawarra Formation. The amphibolite comprises thin layers; the largest of which can be traced for nearly 3.5 km along strike on the southern edge of Mount Phillips and adjacent Yinnetharra. Metadolerite ?sills are also present within andalusite-bearing schists that form part of a 115 km^2 lens-shaped outcrop of metamorphosed Edmund Group rocks on central, southern Pink Hills.

Lithology

Amphibolites of the metamorphosed Narimbunna Dolerite are strongly foliated. In the area between White Well and Nardoo Well in the southwestern corner of Mount Phillips, amphibolite is strongly foliated and in places contains thin wispy leucosomes and irregular quartz–feldspar veins and patches. Most of the amphibolites are fine-grained rocks with a polygonal texture, comprising hornblende (straw-yellow–green–dark-green), plagioclase, quartz, and titanomagnetite. Where the amphibolites have been overprinted by lower grade events, hornblende is partially replaced by a bluish-green actinolitic hornblende or actinolite, plagioclase is recrystallized to a more sodic variety with fine-grained epidote and sericite, and titanomagnetite is pseudomorphed by epidote and titanite.

Age code	Proterozoic	P_-
Stratigraphic code	Not assigned to a Suite, NARIMBUNNA DOLERITE	_nr
Rock type	meta-igneous mafic intrusive	mo
Lithname	amphibolite derived from intrusive rock	a
Rock code		**P_-_nr-moa**
Additional lithologies	mafic schist	

Contact relationships

Amphibolite of the metamorphosed Narimbunna Dolerite is in faulted contact with metamorphosed Ullawarra Formation (P_-MEl-mlst and P_-ME-mlsd). For many of the mafic rocks it is difficult to determine an intrusive or extrusive origin, as contacts are not exposed, or are faulted. However, by analogy with the main outcrop of unmetamorphosed Ullawarra Formation, the amphibolites are interpreted as the higher grade equivalents of the Narimbunna Dolerite sills.

Geochronology

P_-_nr-moa	*Maximum*	*Minimum*
Age (Ma)	1465	1465
Age	Mesoproterozoic	Mesoproterozoic
Source	Inferred	Inferred
References	Wingate, 2002	Wingate, 2002

Amphibolite of the metamorphosed Narimbunna Dolerite has not been dated directly. The unmetamorphosed equivalents, the Narimbunna Dolerite (P_-_nr-od), in the main Edmund Group outcrops have been dated at c. 1465 Ma (Wingate, 2002).

References

Wingate, MTD 2002, Age and palaeomagnetism of dolerite sills of the Bangemall Supergroup on the Edmund 1:250 000 map sheet, WA: Geological Survey of Western Australia, Record 2002/4, 48p.

Unassigned Proterozoic unit (P_-mod-GA)

Legend narrative

Massive metadolerite and foliated amphibolite; fine and medium grained

Rank	Suite
Parent	Unassigned Proterozoic unit (P_-mo-GA)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MW-od (intrusive)
Underlying units	P_-DU-mgn, P_-DU-mgnl, P_-DUda-mgmu (intrusive)

Summary

Massive, metamorphosed dolerite and foliated amphibolite outcrop over much of the Mutherbukin Zone, comprising tectonized, discontinuous dykes or a series of plug-like bodies. Many of the dykes and plugs consist of massive metadolerite with margins of amphibolite with an L-tectonite fabric. The metamorphosed dolerite and amphibolite are probably Mesoproterozoic in age, and may correlate with the Narimbunna Dolerite which forms extensive sills in the Edmund Group.

Distribution

Massive metamorphosed dolerite and foliated amphibolite outcrop over much of the Mutherbukin Zone on southern EUDAMULLAH and central YINNETHARRA. There are two main concentrations of these rock types; the first, east-southeast of Four Corners Well, and the second, east-southeast of No. 11 Bore. The metadolerite and amphibolite form tectonized, discontinuous dykes or a series of plug-like bodies. The dykes may be traced along strike for nearly 5 km and reach a maximum of nearly 200 m wide, although most are considerably narrower.

Lithology

Massive, metamorphosed dolerite and foliated amphibolite are homogeneous, fine and medium grained, equigranular rocks. Many of the dykes and plugs comprise massive metadolerite with margins of amphibolite with an L-tectonite fabric. Amphibolite comprises plagioclase(labradorite)–green-hornblende–quartz–ilmenite; ilmenite is locally replaced by titanite.

Age code	Proterozoic	P_-
Rock type	meta-igneous mafic intrusive	mo
Lithname	metadolerite	d
Tectonic unit code	Gascoyne Province	-GA
Rock code		**P_-mod-GA**

Contact relationships

Massive, metamorphosed dolerite and foliated amphibolite intruded several granitic phases of the Durlacher Supersuite namely: the Davey Well Granite (P_-DUda-mgmu); gneissic to schistose, biotite metamonzogranite and metasyenogranite (P_-DU-mgn); and gneissic to schistose, leucocratic, biotite–muscovite metamonzogranite and metasyenogranite (P_-DU-mgnl). Locally the contacts are commonly parallel to the main tectonic foliation. Massive, metamorphosed dolerite and foliated amphibolite are intruded by dykes of the Mundine Well Dolerite Suite (P_-MW-od).

Geochronology

P_-mod-GA	*Maximum*	*Minimum*
Age (Ma)	1667	1026
Age	Paleoproterozoic	Mesoproterozoic
Source	Inferred	Inferred
References	Wingate et al., 2009	Sheppard et al., 2007

The age of the massive, metamorphosed dolerite and foliated amphibolite is poorly constrained. Rocks of this unit intrude granitic rocks of the Durlacher Supersuite, including the Davey Well Granite, which is dated at 1667 ± 4 Ma (Wingate et al., 2009), thus placing an older limit for crystallization of the dolerite protolith. Metamorphosed dolerite and foliated amphibolite is overprinted by the 1280–1250 Ma Mutherbukin Tectonic Event, which provides a minimum age for emplacement of the metamorphosed dolerite and amphibolite.

References

Wingate, MTD, Kirkland, CL, Bodorkos, S, Sheppard, S and Farrell, TR 2009, 183215: porphyritic metamonzogranite, Davey Well; Geochronology Record 771: Geological Survey of Western Australia, 4p.

Mutherbukin Tectonic Event

Event type	tectonic: intracratonic event, deformation: transpressional
Parent event	Top of Event list (TOL)
Child event	D_{1u}, D_{2u}
Tectonic units affected	Gascoyne province
Tectonic setting	orogen: reactivated orogen
Metamorphic texture/ tectonic feature	folded, gneissose, schistose, sheared
Metamorphic facies from	amphibolite facies: staurolite zone
Metamorphic facies to	amphibolite facies: sillimanite zone

Summary

The Mutherbukin Tectonic Event is presently a poorly defined tectonothermal event, known primarily from the Mutherbukin Zone in the central Gascoyne Province. Preliminary SHRIMP U–Pb geochronology of monazite from pelitic schists and of titanate from metamorphosed alkaline granites, indicates an age between c. 1280 Ma and c. 1250 Ma. The primary expression of the orogeny is a strong upright schistosity or crenulation schistosity in metasedimentary rocks, and a widely developed foliation or gneissic banding in metamorphosed granites throughout much of the Mutherbukin Zone. The tectonic setting of the event and its significance is not well understood.

Distribution

Mineral assemblages and tectonic fabrics related to the 1280–1250 Ma Mutherbukin Tectonic Event are apparently confined to the Mutherbukin Zone in the central part of the Gascoyne Province, although their precise distribution within the zone is not known for two main reasons: first, a lack of geochronology to constrain the ages of fabrics and assemblages in the zone; and second, the grade of metamorphism during the Mutherbukin Tectonic Event was similar to that during both the Capricorn Orogeny and Edmundian Orogeny. Metamorphism and deformation related to the orogeny is mainly known from SHRIMP U–Pb monazite dating on pelitic schists from the Leake Spring Metamorphics along the northern edge of the Mutherbukin Zone. Schists with metamorphic monazite ages between 1280 and 1210 Ma are located on eastern Mount Sandiman and on southeastern Eudamullah around Tommie Well. On southwestern Mount Phillips and northern Yinnetharra, the same package of schists contains similar metamorphic assemblages and structural fabrics but these have been dated using metamorphic monazite and xenotime to be of Edmundian age (1030–955 Ma; Sheppard et al., 2007). The location and nature of the boundary between the area affected by the Mutherbukin Tectonic Event and the Edmundian Orogeny in the Nardoo Hills area is currently unclear. Farther south, the dating of metamorphic titanate within the Tetlow Granite (P_-DUtl-mgt) has demonstrated that the main penetrative foliation or gneissic fabric present within granites of the Durlacher Supersuite (specifically the Davey Well Granite) is related to the Mutherbukin Tectonic Event. Further geochronology is required to better establish the distribution of these two events.

Description

The main expression of the Mutherbukin Tectonic Event is a strong upright schistosity (S_{2u}) in pelitic and semi-pelitic rocks of the Leake Springs Metamorphics. Locally, where S_{1u} is preserved, S_{2u} forms a crenulation schistosity. West of Tommie Well on southeastern Eudamullah, this crenulation schistosity is parallel to a strong foliation or gneissic fabric in the enclosing Davey Well Granite. In the absence of evidence in monazite from the pelite for reworking during the Edmundian Orogeny, we infer that the fabric in the granite also formed during D_{2u}. A similar fabric is present in granites of the Durlacher and Moorarie Supersuites across much of the Mutherbukin Zone on Yinnetharra.

Geochronology

Mutherbukin Orogeny	*Maximum*	*Minimum*
Age (Ma)	1280	1250
Age	Mesoproterozoic	Mesoproterozoic
Source	Inferred	Inferred
References	B Rasmussen (2007, written comm.)	B Rasmussen (2007, written comm.)

Samples from four widely spaced localities along the northern edge of the Mutherbukin Zone have yielded preliminary SHRIMP U–Pb monazite dates between c. 1280 Ma and c. 1250 Ma (B Rasmussen, 2007, written comm.). Preliminary SHRIMP U–Pb dating of metamorphic titanite from the Tetlow Granite on southeastern Eudamullah, suggests an age of c. 1250 Ma for the metamorphism and deformation (B Rasmussen, 2007, written comm.).

Tectonic setting

Very little can be said at present about the tectonic setting of the Mutherbukin Tectonic Event owing to; (1) the preliminary nature of the geochronology defining the event, (2) uncertainty about the spatial extent of the event, and (3) a lack of information regarding kinematics and grade of the metamorphism. The event represents another episode of intracontinental reworking of the Capricorn Orogen, but the causes of the tectonism are unclear.

References

Sheppard, S, Rasmussen, B, Muhling, JR, Farrell, TR, and Fletcher, IR 2007, Grenvillian-aged orogenesis in the Palaeoproterozoic Gascoyne Complex, Western Australia: 1030–950 Ma reworking of the Proterozoic Capricorn Orogen: Journal of Metamorphic Geology, v. 25, p. 477–494.

Mutherbukin Tectonic Event D_{1u}/M_{1u}

Event type	tectonic: intracratonic orogeny, metamorphic regional, deformation: transpressional
Parent event	Mutherbukin Tectonic Event
Tectonic units affected	Gascoyne Province
Tectonic setting	orogen: reactivated orogen
Metamorphic texture/ tectonic feature	folded, gneissose, schistose, sheared
Metamorphic facies from	amphibolite facies: sillimanite zone
Metamorphic facies to	amphibolite facies: sillimanite zone

Summary

The first event attributed to the Mutherbukin Tectonic Event, D_{1u}/M_{1u}, is preserved only as a relict schistosity in porphyroblasts or in schists of the Leake Spring Metamorphics which are strongly crenulated by D_{2u}. The confirmed extent of D_{1u} is restricted to isolated localities along the northern margin of the Mutherbukin Zone. Preliminary SHRIMP U–Pb geochronology on monazite crystals aligned within S_{1u} yield ages of c. 1280 Ma. Local sillimanite (fibrolite) inclusions within garnet porphyroblasts wrapped by S_{2u} imply metamorphism in the sillimanite zone of the amphibolite facies.

Distribution

The first fabric formed during D_{1u} is largely restricted to porphyroblasts of staurolite or as a relict schistosity within a strong S_{2u} crenulation schistosity west of Tommie Well on southeastern EUDAMULLAH.

Description

Monazite from pelitic schists (Leake Spring Metamorphics) in a fault slice within the Davey Well Granite on southeastern EUDAMULLAH gives a SHRIMP U–Pb age of c. 1280 Ma. The monazite is aligned with an S_{1u} fabric that is crenulated and folded by an easterly trending, upright schistosity, which is the dominant fabric in the rocks. In some instances S_{1u} is obliterated in the matrix, being preserved only as folded inclusion trails within staurolite porphyroblasts. The S_{1u} fabric is best preserved in fold hinges on pavements as a millimetre- to centimetre-scale compositional layering; it is commonly obscured in rocks with a strong S_{2u} schistosity that has been precisely dated at c. 1250 Ma.

The grade of metamorphism developed during the Mutherbukin Tectonic Event, and the resulting mineral assemblages, is little different to that which prevailed during the Capricorn Orogeny and the younger Edmundian Orogeny in the Nardoo Hills area. It is therefore very difficult, in the absence of datable younger intrusive rocks, to be confident about the likely age of the metamorphism in any given area. It is only by SHRIMP U–Pb dating of metamorphic monazite in situ, that one can be confident about the age of metamorphism.

In the 'Nick belt' on MOUNT SANDIMAN and the western edge of EUDAMULLAH, schists of the Leake Spring Metamorphics formed staurolite–biotite–garnet during the Mutherbukin Tectonic Event. These rocks are typically quartz rich and fine grained, with randomly oriented prisms of staurolite up to 2 cm long, garnet porphyroblasts around 1 cm in diameter, and flakes of biotite 3 mm in diameter. In some layers, staurolite porphyroblasts are up to 6 cm long. On central EUDAMULLAH, some of the pelites contain fibrolitic sillimanite — mainly preserved as inclusions within garnet porphyroblasts. Garnet porphyroblasts are typically wrapped by the S_{2u} schistosity, suggesting that at least some of the garnet formed during D_{1u}/M_{1u}. In contrast, staurolite porphyroblasts are commonly aligned within S_{2u}, suggesting growth during D_{2u}/M_{2u}. These relationships imply that the D_{1u}/M_{1u} event was of higher grade (garnet–sillimanite) than the D_{2u}/M_{2u} event (staurolite–garnet) that is dominant in outcrop.

Geochronology

Mutherbukin Tectonic Event D_{1u}	*Maximum*	*Minimum*
Age (Ma)	1280	1280
Age	Mesoproterozoic	Mesoproterozoic
Source	Inferred	Inferred
References	B Rasmussen (2007, written comm.)	B Rasmussen (2007, written comm.)

Samples from four widely spaced localities in the Mutherbukin Zone have yielded SHRIMP U–Pb monazite dates of c. 1280 Ma. In the 'Nick belt' on MOUNT SANDIMAN, a staurolite–biotite–garnet schist (GSWA 36493) contains monazite in the matrix and within staurolite porphyroblasts that give dates of c. 1280 Ma (B Rasmussen, 2007, written comm.). Near Tommie Well on southeastern EUDAMULLAH, a sample of garnet–staurolite–biotite schist has yielded dates of c. 1280 Ma (B Rasmussen, 2007, written comm.). The staurolite porphyroblasts contain curved and folded inclusion trails of quartz and rutile, which are oblique or perpendicular to the schistosity in the matrix suggesting that the schistosity is a transposition of an earlier fabric preserved in the porphyroblasts.

Xenotime from an andalusite–chlorite–biotite–quartz–muscovite schist (GSWA 46981) from about 4 km south-southeast of Louden Well on southwestern MOUNT PHILIPS also yielded an date of c. 1280 Ma (B Rasmussen, 2007, written comm.), in addition to results indicative of the Edmundian Orogeny.

Tectonic setting

See **Mutherbukin Tectonic Event**

Mutherbukin Tectonic Event D_{2u}/M_{2u}

Event type	tectonic: intracratonic orogeny, metamorphic: regional, deformation: transpressional
Parent event	Mutherbukin Tectonic Event
Tectonic units affected	Gascoyne Province
Tectonic setting	orogen: reactivated orogen
Metamorphic texture/ tectonic feature	schistose, crenulated
Metamorphic facies from	amphibolite facies: staurolite zone
Metamorphic facies to	amphibolite facies: staurolite zone

Summary

The second event attributed to the Mutherbukin Tectonic Event, D_{2u}/M_{2u}, is represented as an upright schistosity or crenulation schistosity in pelites along the northern margin of the Mutherbukin Zone and as a pervasive tectonic foliation to gneissic banding within metagranitic rocks of the Durlacher and Moorarie Supersuites throughout the Mutherbukin Zone. Preliminary SHRIMP U–Pb geochronology on monazite crystals aligned within S_{2u} within pelitic schists of the Leake Spring Metamorphics, and metamorphic titanite from within strongly deformed metamorphosed alkaline granites (Tetlow Granite) yield ages of c. 1250 Ma. Garnet and staurolite porphyroblasts in the pelitic rocks grew synchronously with S_{2u} imply metamorphism in the staurolite zone of the amphibolite facies. Adjacent to the Ti Tree Shear Zone, locally developed shear sense indicators associated with the S_{2u} foliation in the Davey Well Granite imply sinistral strike-slip movement. More geochronological work is needed to confirm the age of the foliation or gneissic banding in the metagranitic rocks.

Distribution

Mineral assemblages and tectonic fabrics related to D_{2u}/M_{2u} are apparently confined to the Mutherbukin Zone in the central part of the Gascoyne Province, although their precise distribution within the zone is not known for two main reasons: first, a lack of geochronology to constrain the ages of fabrics and assemblages in the zone, and second, the grade of metamorphism during the Mutherbukin Tectonic Event was similar to that which prevailed during both the older Capricorn Orogeny and younger Edmundian Orogeny. On southwestern Mount Phillips and northern Yinnetharra, the same package of schists including those of the Pooranoo Metamorphics contains similar fabrics and assemblages, but have been dated (using metamorphic monazite and xenotime) as younger than 990 Ma (Sheppard et al., 2007), i.e. the Edmundian Orogeny. The location and nature of the boundary between the area affected by the Mutherbukin Tectonic Event and the Edmundian Orogeny in the Nardoo Hills area is currently unclear.

Farther south, the main penetrative foliation or gneissic fabric present within granites of the Durlacher Supersuite (specifically the Davey Well Granite and Tetlow Granite) is related to the D_{2u} event of the Mutherbukin Tectonic Event, but further geochronology is required to better establish the timing and distribution of this fabric forming event.

Description

The main expression of D_{2u} is an upright schistosity or crenulation schistosity in pelitic rocks of the Leake Spring Metamorphics on eastern Mount Sandiman and within a fault slice on southeastern Eudamullah west of Tommie Well. This S_{2u} foliation is parallel to the axial surfaces of upright, tight folds that typically plunge shallowly or moderately to the southeast or east-southeast. Large-scale folds are difficult to identify, in part because of the fragmentary nature of the pelitic units within the granitic rocks. Overall, the metamorphic assemblages developed in the pelites during D_{2u}/M_{2u} are characteristically staurolite–garnet–biotite–muscovite–quartz. In the Nick belt on Mount Sandiman and the western edge of Eudamullah, staurolite–biotite–garnet schists contain randomly oriented prisms of staurolite up to 2 cm long, garnet porphyroblasts around 1 cm in diameter, and flakes of biotite 3 mm in diameter. In some layers, staurolite porphyroblasts are up to 6 cm long.

Preliminary U–Pb dating of metamorphic titanite from the Tetlow Granite (Durlacher Supersuite) indicates that the schistosity in the pelitic rocks correlate with a foliation or, locally, a gneissic fabric in the enclosing Davey Well Granite. On the north side of the fault slice west of Tommie Well, the granite has a subhorizontal lineation and well-developed S–C fabrics and sigma porphyroclasts consistently indicating sinistral shear and is consistent with patterns in aeromagnetic images for the Davey Well Granite. In the pelites, asymmetric tails on garnet porphyroblasts within S_{2u} also indicate a sinistral sense of shear. The S_{2u} fabric in the Davey Well Granite is commonly an L-tectonite, which is defined by biotite and quartz flattening. In the main pluton of Davey Well Granite on central Yinnetharra, the foliation/gneissic fabric dips steeply north-northeast along its northern margin before swinging around and dipping steeply to the south-southwest near the Chalba Fault, thus defining a broad dome about 30 km across. In the granitic rocks, M_{2u} is associated with polygonal granoblastic textures and a foliation defined by biotite and to a lesser extent muscovite.

Boudinaged lenses and layers of aegirine-augite- or hornblende-bearing metamorphosed alkaline granites (Tetlow Granite; P_-DUtl-mgt) are enclosed within strongly foliated masses of Davey Well Granite (P_-DUda-mgmu). The metagranites are always strongly deformed and contain a subtle compositional layering. Both the fabrics and layering in the metagranites are parallel to those within the enclosing Davey Well Granite which can be correlated with the regional-scale sinistral fabric present throughout the Mutherbukin Zone. The metagranites comprise plagioclase, subordinate aegerine–augite or amphibole, and lesser amounts of quartz (5–12%), epidote, titanite, and allanite. Importantly, the titanite appears to be metamorphic in origin. SHRIMP U–Pb dating of this titanite (in situ) has yielded an age of c. 1250 Ma indicating that the main tectonic fabric in the Tetlow Granite and surrounding Davey Well Granite formed during the D_{2u} event of the Mutherbukin Tectonic Event.

Dykes and plugs of metadolerite and amphibolite (P_-mod-GA) that extensively intrude the Davey Well Granite on southeastern Eudamullah and central Yinnetharra have massive, medium- to coarse-grained interiors and variably foliated, fine- to medium-grained margins. This foliation wraps the plugs, is developed to varying extents within the dykes, and is continuous with the foliation in the surrounding metagranite. The metadolerite and amphibolite have textures ranging from polygonal granoblastic to partly recrystallized, intergranular and subophitic igneous textures. The rocks are mainly composed of green hornblende, plagioclase, titanomagnetite, and quartz, with varying amounts of hypersthene (pleochroic from pale pink to pale green) and clinopyroxene forming partly recrystallized aggregates of larger igneous crystals. Where igneous textures are partly preserved, the pyroxenes have thick coronas of fine-grained, granoblastic green hornblende and ?titanomagnetite. The pyroxene interiors also show replacement by hornblende and ?titanomagnetite needles. In some samples titanomagnetite is rimmed or replaced by titanite, in conjunction with sericite and epidote development in plagioclase; the age of this retrogression is not known.

Geochronology

Mutherbukin Orogeny	*Maximum*	*Minimum*
Age (Ma)	1250	1250
Age	Mesoproterozoic	Mesoproterozoic
Source	Inferred	Inferred
References	B Rasmussen (2007, written comm.)	B Rasmussen (2007, written comm.)

Samples from four widely spaced localities in the Mutherbukin Zone have yielded SHRIMP U–Pb monazite dates between c. 1280 Ma and 1250 Ma. In the ‘Nick belt’ on Mount Sandiman, monazite within a staurolite–biotite–garnet schist (GSWA 36493) is found within staurolite porphyroblasts and within the matrix. Those grains contained within staurolite porphyroblasts yielded dates of c. 1280 Ma and are correlated with D_{1u}, whereas those in the enclosing fabric indicates dates of c. 1250 Ma (B Rasmussen, 2007, written comm.), suggesting that the main fabric in the schists is S_{2u}. Near Tommie Well on southeastern Eudamullah, similar relationships and dates were determined for a sample of garnet–staurolite–biotite schist (B Rasmussen, 2007, written comm.). The staurolite porphyroblasts contain curved and folded inclusion trails of quartz and rutile, which are oblique or perpendicular to the schistosity in the matrix and yielded dates of c. 1280 Ma. Monazite from the matrix provided a date of c. 1250 Ma.

On central Yinnetharra, where the Dairy Creek – Cobra Road crosses the Gascoyne River near Yinnetharra Homestead, porphyritic metamonzogranite of the Davey Well Granite contains a gneissic fabric. At the river crossing, the gneissic fabric is cut by a metre-wide, undeformed, leucocratic pegmatite dyke that has been dated using SHRIMP U–Pb zircon geochronology at 1030 ± 6 Ma (Wingate et al., 2010). This age indicates that the fabric developed sometime between the formation of the granite at c. 1665 Ma and the age of the pegmatite dyke at c. 1030 Ma. Preliminary SHRIMP U–Pb dating of metamorphic titanite (in situ) from within strongly deformed metamorphosed alkaline granites (Tetlow Granite) that lie within the Davey Well Granite provide an age of c. 1250 Ma (B Rasmussen, 2007, written comm.). This date confirms that the main fabric within the Tetlow Granite, the enclosing Davey Well Granite and regional-scale sinistral fabrics throughout the Mutherbukin Zone formed during D_{2u}.

Tectonic setting

See **Mutherbukin Tectonic Event**

References

Sheppard, S, Rasmussen, B, Muhling, JR, Farrell, TR, and Fletcher, IR 2007, Grenvillian-aged orogenesis in the Palaeoproterozoic Gascoyne Complex, Western Australia: 1030–950 Ma reworking of the Proterozoic Capricorn Orogen: Journal of Metamorphic Geology, v. 25, p. 477–494.

Wingate, MTD, Kirkland, CL, Sheppard, S and Johnson, SP 2010, 185946; pegmatite dyke, Yinnetharra Homestead; Geochronology Record 902, Geological Survey of Western Australia, 4p.

Thirty Three Supersuite (P_-TT-g)

Legend narrative

Leucocratic granite and metagranite, and pegmatite

Rank	Supersuite
Parent	Top of lithostratigraphic order (TOL)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MW-od (intrusive)
Underlying units	P_-LS-xmd-mk, P_-MO-g, P_-PO-md, P_-DU-g (intrusive), P_-MEP3-sk (faulted)

Summary

The Thirty Three Supersuite comprises a belt of plutons: foliated, leucocratic, muscovite(–tourmaline) metamonzogranite; leucocratic, foliated, biotite–muscovite(–tourmaline) monzogranite; and granodiorite, as well as a belt of muscovite–tourmaline and rare-element bearing pegmatite along the northern edge of the Mutherbukin Zone on Yinnetharra and Mount Phillips. The supersuite is considered to have intruded during the 1030–950 Ma Edmundian Orogeny, but only one rock (a pegmatite) from the supersuite has been successfully dated; monazite from this rare-element bearing pegmatite gave a ^{207}Pb*/^{206}Pb* date of c. 950 Ma (Sheppard et al., 2007). Some of these dykes contain abundant concentrations of rare earth elements (e.g. Bi, Be, Nb–Ta) and have been the subject of small-scale mining.

Distribution

The Thirty Three Supersuite is largely known from the Mutherbukin Zone, between the Ti Tree Shear Zone to the north and the Chalba Shear Zone to the south, in the central part of the Gascoyne Province. Elements of it may outcrop on either side of this zone, but in the absence of Mesoproterozoic to Neoproterozoic tectonism, dykes and plutons of the supersuite are not readily distinguishable from late phases of the 1680–1620 Ma Durlacher Supersuite. The supersuite comprises a belt of foliated leucocratic muscovite(–tourmaline) metamonzogranite and foliated leucocratic biotite–muscovite(–tourmaline) metamonzogranite about 5 km wide and 50 km long on northern Yinnetharra and southwestern Mount Phillips. three granite plutons south of the Ti Tree Shear Zone between Louden Well on southwestern Mount Phillips and Reid Well on the northern edge of Yinnetharra, as well as widespread pegmatite dykes and sheets throughout the Mutherbukin Zone, but particularly in a belt about 60 km long and up to 15 km wide from New Well on southeastern Eudamullah southeast to near Mount James on southeastern Yinnetharra. Two swarms of tourmaline–muscovite pegmatite dykes, each less than 15 km^2, that intrude the Minnie Creek batholith on northwestern Eudamullah are also assigned to the Thirty Three Supersuite.

Derivation of name

The Thirty Three Supersuite is named after the Thirty Three River, which flows through the main pegmatite field and across one of the granite plutons.

Lithology

The Thirty Three Supersuite comprises a range of rock types, most of which are leucocratic and carry primary muscovite and tourmaline. The most voluminous single rock type is a fine- to medium-grained, foliated, leucocratic, muscovite(–tourmaline) metamonzogranite or foliated, leucocratic, biotite–muscovite(–tourmaline) metamonzogranite. These rocks are intruded by three plutons composed of massive, leucocratic, equigranular, muscovite–tourmaline(–biotite) monzogranite and granodiorite, and porphyritic biotite(–muscovite–tourmaline) monzogranite. The porphyritic monzogranite is medium grained with 5–15% round K-feldspar phenocrysts up to 2 cm in diameter (locally these may reach 4 cm). Tourmaline may be disseminated through the granite, or form splays or clots with bleached haloes. Pegmatites range from veins through dykes up to 10 or 20 m wide to shallowly dipping sheets which may reach 200 m in thickness. The dykes and sheets are typically zoned, and contain cores of massive quartz. Many of these pegmatites contain rare elements (e.g. Bi, Be, Nb–Ta) and have been the subject of small-scale mining.

Age code	Proterozoic	P_-
Stratigraphic code	Thirty Three Supersuite	TT-
Rock type	Igneous granitic	g
Rock code		**P_-TT-g**

Contact relationships

Granites and pegmatite of the Thirty Three Supersuite intrude numerous units of the 1840–1810 Ma Leake Spring Metamorphics (P_-LS-xmd-mk), 1760–1680 Ma Pooranoo Metamorphics (P_-PO-md), 1680–1620 Ma Durlacher Supersuite (P_-DU-g), and at least one unit of the 1820–1775 Ma Moorarie Supersuite. Despite the early Neoproterozoic age of the supersuite, none of the granites and pegmatites is known to intrude Mesoproterozoic sedimentary rocks of the Edmund and Collier Groups. Components of the Thirty Three Supersuite are intruded by dykes of the c. 755 Ma Mundine Well Dolerite Suite (P_-MW-od).

Geochronology

P_-TT-g	*Maximum*	*Minimum*
Age (Ma)	995 ± 6	954 ± 12
Age	Neoproterozoic	Neoproterozoic
Source	Isotopic	Isotopic
References	Sheppard et al., 2007	Sheppard et al., 2007

Only one sample for SHRIMP U–Pb geochronology from the Thirty Three Supersuite has yielded an age of igneous crystallization. The sample was taken from the blocky K-feldspar zone of a rare-element pegmatite at Bismuth Hill on northwestern MOUNT PHILLIPS (SXSYIN007191; Zone 50, MGA 405963E 7288621N; sample UWA 117154 (Trautman, 1992)). Seven analyses of a coarse monazite crystal from the pegmatite produced a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 954 ± 12 Ma (Sheppard et al., 2007). It is inferred that other pegmatites and granites of the supersuite, which have the same field relationships as the dated pegmatite (namely, they intrude across metamorphic and structural fabrics dated at 1030–990 Ma), are also early Neoproterozoic in age. Two leucocratic granites with the same field relationships as the pegmatites (GSWA samples 183287 and 183288) were dated. Analytical results from both samples are interpreted to date inherited zircons only (Kirkland et al., 2009; GSWA, unpublished data). The minimum age of the supersuite is only loosely defined as the youngest dated sample at c. 955 Ma. It is possible that younger granitic phases will be identified in future. The only robust constraint for the minimum age is provided from cross-cutting undeformed dolerite dykes of the Mundine Well Dolerite Suite dated at c. 755 Ma (Wingate and Giddings, 2000). The age range of the supersuite is tentatively given to be c. 995–955 Ma.

References

Kirkland, CL, Wingate, MTD, Bodorkos, S and Sheppard, S 2009, 183287: granite, Perseverance Well; Geochronology Record 756: Geological Survey of Western Australia, 4p.

Sheppard, S, Rasmussen, B, Muhling, JR, Farrell, TR, and Fletcher, IR 2007, Grenvillian-aged orogenesis in the Palaeoproterozoic Gascoyne Complex, Western Australia: 1030–950 Ma reworking of the Proterozoic Capricorn Orogen: Journal of Metamorphic Geology, v. 25, p. 477–494.

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Wingate, M TD and Giddings, JW 2000, Age and palaeomagnetism of the Mundine Well dyke swarm, Western Australia: implications for an Australia–Laurentia connection at 755 Ma: Precambrian Research, v. 100, p. 335–357.

Thirty Three Supersuite; subunit (P_-TT-gmlt)

Legend narrative

Leucocratic, medium-grained, muscovite–tourmaline(–biotite) monzogranite; equigranular to porphyritic

Rank	Formation
Parent	Thirty Three Supersuite (P_-TT-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-TT-gpvt, P_-MW-od (intrusive)
Underlying units	P_MO-mgsl, P_-POb-mlsm, P_-POs-mtqs, P_-DUda-mgm; P_-TT-gmpt (intrusive)

Summary

Leucocratic, medium-grained, muscovite–tourmaline(–biotite) monzogranite of the Thirty Three Supersuite forms part of two composite intrusions in the area between the Nardoo Hills and Reid Well immediately south of the Ti Tree Syncline on southwestern Mount Phillips and northwestern Yinnetharra. So far, SHRIMP U–Pb zircon geochronology has failed to yield an igneous crystallization age for the monzogranite. Nevertheless, the intrusions cut 1030–955 Ma regional metamorphic assemblages and tectonic fabrics formed during the Edmundian Orogeny (Sheppard et al., 2007), and are intruded by dykes of the c. 755 Ma Mundine Well Dolerite Suite (Wingate and Giddings, 2000). The monzogranite appears to be broadly coeval with a suite of rare element bearing pegmatites (Černý and Ercit, 2005; London, 2008), which have been the subject of sporadic, small-scale mining.

Distribution

Leucocratic, medium-grained, muscovite–tourmaline(–biotite) monzogranite forms part of two composite plutons just south of the Ti Tree Syncline on southwestern Mount Phillips and northern Yinnetharra. The eastern pluton is bisected by the Thirty Three River. Most of the smaller western pluton consists of leucocratic, medium-grained, muscovite–tourmaline(–biotite) monzogranite, with xenoliths of subordinate porphyritic metamonzogranite of the c. 1665 Ma Davey Well Granite (P_-DUda-mgm). The larger eastern pluton contains leucocratic, medium-grained, muscovite–tourmaline(–biotite) monzogranite in its core, and along part of the margin, but most of the intrusion consists of porphyritic biotite–muscovite(–tourmaline) monzogranite (P_-TT-mgpt).

Lithology

Leucocratic, medium-grained, muscovite–tourmaline(–biotite) monzogranite of the Thirty Three Supersuite is typically massive and equigranular. Parts of the unit are fine grained, and locally the monzogranite contains sparse tabular feldspar phenocrysts about 1 cm long. All of the rocks contain magmatic muscovite, and many contain tourmaline. Disseminated tourmaline crystals are commonly the same size as biotite, and some contain inclusions of groundmass; therefore, they are regarded as magmatic. Parts of the monzogranite also contain irregular-shaped patches of tourmaline typically less than about 5 mm in diameter. There are also small pegmatite patches with tourmaline locally. Garnet is a rare accessory mineral. Quartz may show undulose extinction and subgrain development, and plagioclase and microcline are partly sericitized.

Adjacent to the country rocks, the monzogranite may be closely jointed and cut by numerous randomly oriented planar veins of quartz and tourmaline–quartz. Fluorite is locally present in fractures. In the Perseverance Well area on northern Yinnetharra, leucocratic monzogranite at the margins of the pluton is marked by intensive quartz–tourmaline veins and pervasive and fracture-related tourmalinization (e.g. SXSYIN000006; Zone 50, MGA 423844E 7289404N).

Inclusions of any sort are rare, but locally the monzogranite contains rafts of coarsely porphyritic biotite monzogranite (P_-TT-gmpt).

Age code	Proterozoic	P_-
Stratigraphic code	Thirty Three Supersuite	TT-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	leuco-	l
2nd qualifier	tourmaline	t
Rock code		**P_-TT-gmlt**
Additional lithologies	granodiorite	

Contact relationships

Leucocratic, medium-grained, muscovite–tourmaline(–biotite) monzogranite is massive to weakly foliated and truncates the lithological layering and tectonic fabrics in biotite–quartz–muscovite schist (P_-POb-mlsm) and quartzite and muscovite-quartz schist (P_-POs-mtqs) of the Pooranoo Metamorphics, the Davey Well Granite (P_-DUda-mgmu), and schistose, leucocratic muscovite(–biotite) monzogranite (P_-MO-mgsl) of the Moorarie Supersuite. Metamorphic monazite aligned within these fabrics has been dated at 1030–990 Ma, indicating that regional metamorphism and deformation is related to the Edmundian Orogeny (Martin et al., 2006; Sheppard et al., 2007).

Contact relationships with porphyritic monzogranite of the Thirty Three Supersuite (P_-TT-gmpt) are more ambiguous. Locally the leucocratic monzogranite contains rafts of coarsely porphyritic biotite monzogranite (P_-TT-gmpt), but in other places it passes gradually into coarse-grained, sparsely to strongly porphyritic monzogranite that is rich in tourmaline and biotite.

Geochronology

P_-TT-gmlt	*Maximum*	*Minimum*
Age (Ma)	995	954
Age	Neoproterozoic	Neoproterozoic
Source	Inferred	Inferred
References	Sheppard et al., (2007)	Sheppard et al., (2007)

Several samples of this unit were selected for zircon dating but all samples yielded only xenocrystic zircons. The best constraints for the age of this unit are provided by cross-cutting relationships. Plutons of leucocratic, medium-grained, muscovite–tourmaline(–biotite) monzogranite cut a composite S_{1e}/S_{2e} foliation formed during low- to medium-grade regional metamorphism during the D_{1e}/D_{2e} event of the 1030–955 Ma Edmundian Orogeny (Sheppard et al., 2007). This is the best estimate for the maximum age of the monzogranites. The monzogranite has the same field relationships as a swarm of rare-element bearing pegmatite dykes (P_-TT-gpvt), one of which is dated at c. 955 Ma (Sheppard et al., 2007) thus providing a tentative minimum age for the unit.

The westernmost of the monzogranite intrusions was previously dated using SHRIMP U–Pb zircon geochronology by Culver (2001). The sample is of a massive, medium-grained, equigranular biotite–muscovite–tourmaline monzogranite. Tourmaline crystals are the same size as biotite and are therefore considered magmatic. The U–Pb zircon date for the monzogranite of 1652 ± 5 Ma was interpreted as the igneous crystallization age (see also Varvell et al., 2003), but given younger monazite ages for the regional metamorphic fabrics, it presumably only represents xenocrystic zircons. Another specimen of muscovite–tourmaline(–biotite) monzogranite was sampled on the west side of the Dairy Creek – Cobra Road about 1.8 km southwest of Perseverance Well for SHRIMP U–Pb zircon geochronology. From the sample, GSWA 183287, 28 analyses were obtained from 27 zircons (Kirkland et al., 2009). All analytical results are interpreted to date inherited zircons because this granite cross-cuts Neoproterozoic tectonic fabrics (Sheppard et al., 2007). The date of 1309 ± 13 Ma from the youngest analysis places a crude upper constraint on the maximum age of crystallization of this granite (Kirkland et al., 2009).

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Thirty Three Supersuite; subunit (P_-TT-gmpt)

Legend narrative

Medium-grained, coarsely porphyritic, biotite–tourmaline monzogranite; massive

Rank	Formation
Parent	Thirty Three Supersuite (P_-TT-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-TT-gmlt, P_-TT-gpvt, P_-MW-od (intrusive)
Underlying units	P_-MO-mgsl, P_-POs-mtqs, P_-POb-mlsm, P_-POb-mtef, P_-MEl-mlst (intrusive); P_-MEk-sf, P_-MEy-st (faulted)

Summary

Medium-grained, coarsely porphyritic, biotite–tourmaline monzogranite of the Thirty Three Supersuite is confined to a single intrusion a little over 50 km^2 straddling the boundary between YINNETHARRA and MOUNT PHILLIPS. The monzogranite contains phenocrysts of K-feldspar up to 4 cm in diameter, and locally features an exceptionally tourmaline-rich groundmass.

Distribution

Medium-grained, coarsely porphyritic, biotite–tourmaline monzogranite of the Thirty Three Supersuite has only been identified in a single intrusion, a little over 50 km^2 in area, which straddles the boundary between YINNETHARRA and MOUNT PHILLIPS.

Lithology

Medium-grained, coarsely porphyritic, biotite–tourmaline monzogranite of the Thirty Three Supersuite strongly resembles lesser deformed parts of the Davey Well Granite; nevertheless they are distinguished by different aeromagnetic patterns, contrasting relationships with Edmundian structural fabrics, and an abundance of tourmaline in monzogranite of the Thirty Three Supersuite.

Medium-grained, coarsely porphyritic, biotite–tourmaline monzogranite of the Thirty Three Supersuite contains about 5–15% round or tabular K-feldspar phenocrysts up to 4 cm in diameter or length. In part, the monzogranite is seriate, and may locally be fine grained. Contacts between the fine-grained phase and the more abundant medium-grained, porphyritic monzogranite are gradational. The monzogranite is typically rich in biotite, which commonly forms small clots (<10 mm in diameter) in addition to being disseminated through the groundmass. Muscovite is intergrown with biotite, indicating that the muscovite is primary. The monzogranite contains varying amounts of fine-grained tourmaline in clots up to 50 mm in diameter, with or without bleached haloes, and as disseminated crystals in the groundmass.

Age code	Proterozoic	P_-
Stratigraphic code	Thirty Three Supersuite	TT-
Rock type	Igneous granitic	g
Lithname	monzogranite	m
1st qualifier	porphyritic	p
2nd qualifier	tourmaline	t
Rock code		**P_-TT-gmpt**

Contact relationships

The pluton of medium-grained, coarsely porphyritic, biotite–tourmaline monzogranite of the Thirty Three Supersuite is elongate, but slightly oblique to the regional structural grain. The pluton cuts across low- to medium-grade fabrics that have been dated at 1030–990 Ma using SHRIMP U–Pb geochronology of monazite in situ (Sheppard et al., 2007). The monzogranite intrudes schistose, leucocratic, muscovite(–biotite) metamonzogranite of the Moorarie Supersuite (P_-MO-mgsl), and the Biddenew and Spring Camp Formations of the late Paleoproterozoic Mount James Subgroup (P_-POs-mtqs, P_-POb-mlsm, P_-POb-mtef). The monzogranite also intrudes pelitic and semipelitic staurolite–garnet–biotite–muscovite(–andalusite) schist of the Ullawarra Formation of the Edmund Group. The northern margin of the monzogranite pluton is interpreted to be in faulted contact with units of the Edmund Group (Kiangi Creek Formation and Yilgatherra Formation) in the Ti Tree Syncline.

Geochronology

P_-TT-gmpt	*Maximum*	*Minimum*
Age (Ma)	995	954
Age	Neoproterozoic	Neoproterozoic
Source	Inferred	Inferred
References	Sheppard et al., (2007)	Sheppard et al., (2007)

Porphyritic, medium-grained, biotite–muscovite–tourmaline monzogranite about 850 m west-northwest of Perseverance Well was sampled for SHRIMP U–Pb zircon geochronology (GSWA 183288). Although the pluton cuts metamorphic fabrics dated at 1030–990 Ma, the zircons provided a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 1648 ± 5 Ma (GSWA, unpublished data). This relatively old result, together with the relatively low Zr content of the rock (90 ppm), suggests that the analysed zircons are all of xenocrystic origin. The age of this unit is therefore poorly constrained and is taken to be the age of the supersuite at 995–955 Ma.

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Thirty Three Supersuite; subunit (P_-TT-gpvt)

Legend narrative

Muscovite–tourmaline pegmatite; some rare-element bearing

Rank	Formation
Parent	Thirty Three Supersuite (P_-TT-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-MW-od
Underlying units	P_-LS-xmd-mk, P_-PO-md, P_-DU-g, P_-TT-gmlt

Summary

Pegmatites have been intruded across the whole Gascoyne Province, but the vast majority of these dykes are barren, containing combinations of only muscovite, biotite, and tourmaline. Most were probably intruded during three Paleoproterozoic orogenic events. However, pegmatites in the Mutherbukin Zone in a belt south of the Ti Tree Syncline post-date structural fabrics and metamorphic assemblages formed during the 1030–955 Ma Edmundian Orogeny (Martin et al., 2006; Sheppard et al., 2007). Some of these pegmatites have been the subject of sporadic, small-scale mining for mica, beryl, tantalite–columbite, and bismuth (Williams et al., 1983; Fetherston, 2004).

Distribution

Muscovite–tourmaline pegmatite dykes and sheets of the Thirty Three Supersuite form two belts, each up to 60 km long, in the Mutherbukin Zone in the central part of the Gascoyne Province. The first extends from around New Well on southeastern EUDAMULLAH, southeastwards across YINNETHARRA, and onto the Injinu Hills on western PINK HILLS. Smaller numbers of the pegmatites are present in an east-southeast trending belt from central LOCKIER onto southeastern YINNETHARRA.

Lithology

The mineralogy of, and mineral production from, the rare element pegmatites (Černý and Ercit, 2005; London, 2008) of the Thirty Three Supersuite was summarized by Williams et al. (1983). Subsequently, the rock types and mineralogy of 13 rare element pegmatites in the Thirty Three Supersuite were documented in some detail by Trautman (1992). Carter (1984) described the characteristics of the uranium-bearing pegmatite at the Mortimer Hills prospect. The geology and exploration history of the main tantalum-bearing pegmatites in the supersuite were summarized by Fetherston (2004). Some of the pegmatites are also covered in Calderwood et al. (2007). Trautman (1992) recognized a reasonably consistent zonation in most of the rare element pegmatites: a muscovite-rich margin, passing inwards to a graphic zone, then a zone characterized by block K-feldspar, then an albitic replacement unit, and commonly a core of massive quartz. Most of the pegmatites are less than 20 m wide, and have a strike length at surface of no more than 100–150 m. The pegmatites contain a variety of accessory minerals, including bismutite (Ellis, 1940, 1941), bismuthinite (Trautman, 1992), pitchblende and euxenite (Williams et al., 1983; Carter, 1984), beryl (Wilson, 1923, 1927; Ellis, 1941; Owen, 1944; Matheson, 1945), clinobisvanite ($BiVO4$; Bridge and Pryce, 1974), xenotime (Grace, 1941; Trautman, 1992), and tantalite–columbite (Miles et al., 1945; Trautman, 1992; Fetherston, 2004). The pegmatites are typically associated with a halo of intense alteration, up to several metres wide, to muscovite–tourmaline–biotite schists.

Age code	Proterozoic	P_-
Stratigraphic code	Thirty Three Supersuite	TT-
Rock type	Igneous granitic	g
Lithname 1	pegmatite	p
1st qualifier	muscovite	v
2nd qualifier	tourmaline	t
Rock code		**P_-TT-gpvt**

Contact relationships

Muscovite–tourmaline pegmatite of the Thirty Three Supersuite intrudes a large number of stratigraphic units, including those belonging to the Leake Spring Metamorphics, Pooranoo Metamorphics and the Durlacher Supersuite. Despite the early Neoproterozoic age for the pegmatites, none of them are known to intrude Mesoproterozoic sedimentary rocks of the Edmund and Collier Groups. Dykes and veins of muscovite–tourmaline pegmatite intrude muscovite–tourmaline(–biotite) monzogranite of the Thirty Three Supersuite, which has a maximum age of 995 ± 6 Ma.

Most of the rare element pegmatites are tabular, steeply dipping structures, many of which strike east-southeast, parallel to the structural grain in the enclosing rocks. However, some rare element pegmatites on southern MOUNT PHILLIPS and northern YINNETHARRA either consist of undeformed saddle reef structures in the hinges of F_{3e} folds, or are emplaced into north- to northeast-striking brittle faults that cut D_{3e} structures. These field relationships have been interpreted to indicate that the rare-element pegmatites were emplaced during and after D_{3e} (Hardy, 1992; this work). The large pegmatite at the Mortimer Hills U prospect, consists of a shallowly dipping, sheet-like body (Carter, 1984). The pegmatites are commonly associated with an envelope of muscovite–tourmaline–biotite metasomatism. The muscovite–tourmaline–biotite schists are crenulated or tightly folded (L_{3e}/F_{3e}); tourmaline porphyroblasts commonly grow subparallel to the crenulation hinge, but splays also cut it, suggesting tourmaline growth during or after D_{3e}. Consistent with this interpretation, the New Well dyke on southeastern EUDAMULLAH appears to plunge parallel to F_{3e}/L_{3e} in the enclosing schists.

Geochronology

P_-TT-gpvt	Maximum	Minimum
Age (Ma)	954 ± 12	954 ± 12
Age	Neoproterozoic	Neoproterozoic
Source	Isotopic	Isotopic
References	Sheppard et al., 2007	Sheppard et al., 2007

Aldrich et al. (1959) determined reconnaissance Rb–Sr dates of c. 980 and c. 940 Ma for muscovite from two pegmatite dykes of the Thirty Three Supersuite. These dates were dismissed by Carter (1984) as being too young to be ages of intrusion, because pegmatites and granites do not intrude Mesoproterozoic low-grade sedimentary rocks of the Bangemall Supergroup that overlie the Gascoyne Complex. The rare-element Beryl Hill pegmatite from northwestern EUDAMULLAH (SXSYIN007191; Zone 50, MGA 405963E 7288621N; sample UWA 117154 (Trautman, 1992)) was sampled for SHRIMP U–Pb monazite geochronology. This pegmatite forms a saddle reef in the hinge zone of a regional-scale F_{3e} antiform and, in common with other pegmatites in the region, is interpreted to have intruded late during, or after, the main folding event (Hardy, 1992; Sheppard et al., 2007). The sample was taken from the kaolinized blocky K-feldspar zone of the pegmatite (site 'U' of Trautman, 1992). A coarse monazite crystal, several millimetres in diameter, and which is cut by fractures and veins containing U-oxide minerals, was separated from the pegmatite. Seven analyses from the monazite produced a weighted mean $^{207}Pb^{*}/^{206}Pb^{*}$ date of 954 ± 12 Ma (MSWD = 2.3) (Sheppard et al., 2007). It is inferred that other pegmatites of the supersuite, which have the same field relationships as the dated pegmatite, are also early Neoproterozoic in age.

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Thirty Three Supersuite; subunit (P_-TT-jmgmt-m)

Legend narrative

Foliated, leucocratic, muscovite(–tourmaline) metamonzogranite and foliated, leucocratic, biotite–muscovite(–tourmaline) metamonzogranite; locally layered; inclusions of pelitic schist, quartzite, and amphibolite

Rank	Formation
Parent	Thirty Three Supersuite (P_-TT-g)
Tectonic units	Gascoyne Province, CAPRICORN OROGEN, WESTERN AUSTRALIA
Overlying units	P_-TT-gmlt, P_-TT-gpvt (intrusive)
Underlying units	P_-LS-mwa, P_-LS-mlst, P_-MO-mgsl, P_-POb-mlsm, P_-DUda-mgmu (intrusive)

Summary

Foliated, leucocratic, metamonzogranites are the most voluminous component of the Neoproterozoic Thirty Three Supersuite. The metamonzogranites form a belt about 5 km wide along the northern edge of the Mutherbukin Zone on southwestern Mount Phillips and northern Yinnetharra. The unit comprises foliated, leucocratic, muscovite(–tourmaline) metamonzogranite and foliated, leucocratic biotite(–muscovite) metamonzogranite. Both rock types typically contain a crude layering that is at least in part magmatic, and both contain numerous schlieren, screens, and inclusions of metamorphic rock.

Distribution

Foliated, leucocratic metamonzogranite of the Thirty Three Supersuite forms a southeasterly trending belt of intrusions from southwestern Mount Phillips across northern Yinnetharra and onto Pink Hills. The unit comprises a composite sheet-like intrusion about 260 km^2 in area, which is sandwiched between the Davey Well Granite and the Ti Tree Syncline. The intrusion (or intrusions) strikes east-southeast parallel to the regional structural grain.

Lithology

Foliated, leucocratic metamonzogranite of the Thirty Three Supersuite comprises two main rock types, which are not readily separated into discrete mappable units. Contacts between the two metamonzogranites are commonly gradational. Therefore, both rock types are included in the one unit. Both metamonzogranites contain abundant inclusions of pelitic schist, quartzite, and amphibolite.

Foliated, leucocratic, muscovite(–tourmaline) metamonzogranite is mostly fine- to medium-grained and equigranular, although it is weakly porphyritic in places. The unit contains local coarser grained or pegmatitic zones, which in many instances carry tourmaline. The metamonzogranite commonly has a vague layering defined by subtle variations in grain size and the alignment of drawn out biotite wisps and biotite-rich seams or by variations in tourmaline abundance. Lithological layering is mostly parallel to the foliation. Parts of the unit contain patchy tourmaline-rich spots, which are typically 5–15 mm in diameter, and some of which have a bleached halo. In places tourmaline is distributed throughout the metamonzogranite, and it may be the only mafic phase.

Foliated, leucocratic biotite(–muscovite) metamonzogranite is typically medium grained, but may be coarse grained to very coarse grained in places. The rock typically is equigranular, but K-feldspar phenocrysts are present in parts. Biotite and muscovite are usually the only mafic minerals, but parts of the metamonzogranite contain tourmaline, either disseminated through the rock or as concentrations.

Age code	Proterozoic	P_-
Stratigraphic code	Thirty Three Supersuite	TT-
Mixed or xenolith-bearing	Xenolith/inclusion bearing	j
Rock type 1	meta-igneous felsic intrusive	mg
Lithname 1	metamonzogranite	m
1st qualifier	—	
2nd qualifier	tourmaline	t
Rock type 2	metamorphic	-m
Rock code		**P_-TT-jmgmt-m**
Additional lithologies	quartzite, amphibolite, pelitic schist	

Contact relationships

Foliated, leucocratic, muscovite(–tourmaline) metamonzogranite and foliated, leucocratic, biotite–muscovite(–tourmaline) metamonzogranite contain abundant inclusions and screens of staurolite–garnet–biotite–muscovite(–andalusite) schist (P_-LS-mlst), amphibolite (P_-LS-mwa), psammitic schist (P_-LS-mts), and calc-silicate gneiss and schist (P_-LS-mk). In the area about 3 km west-southwest of Gillie Well, foliated, leucocratic, muscovite(–tourmaline) metamonzogranite comprises rafts within massive, leucocratic, muscovite–tourmaline(–biotite) monzogranite (P_-TT-gmlt) of the Thirty Three Supersuite. Both metamonzogranites are intruded by dykes of muscovite–tourmaline pegmatite of the Thirty Three Supersuite (P_-TT-gpvt). The foliated leucocratic metamonzogranites contain a metamorphic fabric that is absent from the younger, massive granites and pegmatites (P_-TT-gmlt, P_-TT-gpvt) of the supersuite.

Geochronology

P_-TT-jmgmt-m	*Maximum*	*Minimum*
Age (Ma)	995	954
Age	Neoproterozoic	Neoproterozoic
Source	Inferred	Inferred
References	Sheppard et al., 2007	Sheppard et al., 2007

Foliated, leucocratic, muscovite(–tourmaline) metamonzogranite and foliated, leucocratic, biotite–muscovite (–tourmaline) metamonzogranite have not been dated directly. However, the metamonzogranites cannot be older than Neoproterozoic because they intrude along or across the S_{1e} and S_{2e} foliation formed during low- to medium-grade regional metamorphism during the D_{1e}/D_2e event of the Edmundian Orogeny dated at 1030–995 Ma (Sheppard et al., 2007). The metamonzogranites contain an S_3 foliation, which is cut by a c. 955 Ma pegmatite dyke (Sheppard et al., 2007). Therefore, the metamonzogranites were emplaced between c. 995 Ma and c. 955 Ma.

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Edmundian Orogeny

Event type	deformation: undivided, metamorphism: regional, tectonics:intracontinental;
Parent event	Top of Event list (TOL)
Child event	D_{1e}, D_{2e}, D_{3e}
Tectonic units affected	Gascoyne Province, Bangemall Basin
Tectonic setting	orogen: intracratonic orogen
Metamorphic facies from	prehnite–pumpellyite facies: undivided
Metamorphic facies to	amphibolite facies: staurolite zone

Summary

The Edmundian Orogeny (Halligan and Daniels, 1964) is an intracratonic event that resulted in widespread deformation of the Bangemall Supergroup (Martin and Thorne, 2004). The orogeny largely resulted in north–south shortening that formed easterly to southeasterly trending, open to tight, upright folds and normal, reverse, and strike-slip faults. The area affected by this regional deformation is referred to as the Edmund Fold Belt (Martin et al., 2005). It is more extensive than the structural unit of the same name originally defined by Muhling and Brakel (1985), and includes the area covered by their Edmund Fold Belt, Pingandy Shelf, and Bullen Platform. In Bangemall Supergroup rocks, the Edmundian Orogeny consists of a localized D_{1e} event, widespread easterly to southeasterly trending folds and associated faults (D_{2e}), and open, northeasterly trending open folds (D_{3e}).

The affect of the orogeny in the underlying basement was thought to be limited to formation or reactivation of discrete structures. However SHRIMP U–Pb geochronology of monazite and xenotime in situ in pelitic schists from the central Gascoyne Province, shows that greenschist to amphibolite facies metamorphism occurred between c. 1030 and c. 955 Ma. These data show that the Paleoproterozoic Gascoyne Province underwent an episode of intracontinental reworking concentrated in a NW–SE striking corridor during the Edmundian Orogeny. Therefore, the Edmundian Orogeny involved not only deformation and very low- to low-grade metamorphism of the Bangemall Supergroup cover rocks, but also regional amphibolite facies metamorphism and deformation, granitic magmatism, and pegmatite intrusion in the Gascoyne Complex between c. 1030 and c. 950 Ma. In the Gascoyne Province rocks, two main pervasive deformation events (D_{2e} and D_{3e}) are recognized, as well as an earlier fabric (D_{1e}) preserved only in porphyroblasts.

Distribution

The major structures that affect the Bangemall Supergroup were formed during the Edmundian Orogeny, between 1070 and 750 Ma (Martin and Thorne, 2004). In the northwestern part of the Capricorn Orogen, three deformation events are attributed to the Edmundian Orogeny. Of these events, D_{1e} is a localized feature, whereas D_{2e} and D_{3e} affected the entire outcrop area of the supergroup. Bangemall Supergroup rocks in the Edmund Fold Belt are divided into three structural zones referred to informally as the northeastern, central, and southwestern zones (Martin et al., 2005). The northeastern zone lies northeast of the Talga Fault and corresponds broadly to the Pingandy Shelf of Muhling and Brakel (1985). The central zone equates to the Wanna Syncline, an asymmetric southeasterly plunging synclinorium between the Talga Fault and the main Gascoyne Province outcrop to the southwest; whereas the southwestern zone is represented by the more highly deformed rocks of the Mangaroon and Cobra Synclines. The combined central and southwestern zones are approximately equivalent to the Edmund Fold Belt of Muhling and Brakel (1985).

The Edmundian Orogeny is also responsible for pervasive reworking along the northern margin of the Mutherbukin Zone in the central Gascoyne Province. This event was responsible for reworking in the Nardoo Hills area in the northern part of the zone, but similar fabrics farther south probably formed during the older Mutherbukin Tectonic Event. Three deformation events are recognized in the Nardoo Hills area, but it is not clear how they relate to the events identified in the overlying Bangemall Supergroup. Regional metamorphism associated with the Edmundian Orogeny in the Mutherbukin Zone ranges from greenschist to upper amphibolite facies (Sheppard et al., 2007).

Description

The earliest deformation attributed to the Edmundian Orogeny in the Bangemall Supergroup rocks, D_{1e}, consists of northwest verging thrust faulting along the margin of a thick dolerite sill that intrudes the lower Edmund Group in the northwestern part of the Capricorn Orogen (Martin and Thorne, 2000). The main period of Edmundian deformation, D_{2e}, produced east–west to southeast–northwest trending, generally upright open folds throughout the Bangemall Supergroup. However, D_{2e} folds may be tightened and inclined locally, particularly where associated with the major basement structures such as the Talga and Lyons River Faults, and in the Mangaroon and Ti Tree Synclines. Tight folding and steep dips along the southern limb of the Wanna Syncline are also related to D_{2e}. The youngest of the Edmundian events, D_{3e}, resulted in open northeast-trending upright folds. On a regional scale, these are responsible for plunge reversals in the F_{2e} folds. The metamorphic grade in Bangemall Supergroup rocks is typically very low.

In the Gascoyne Province, penetrative deformation and regional metamorphism up to amphibolite facies was concentrated in the Mutherbukin Zone. Two main pervasive deformation events (D_{2e} and D_{3e}) are recognized, as well as an earlier fabric (D_{1e}) preserved only in porphyroblasts. The first of the pervasive events, D_{2e}, produced a strong foliation that was associated with greenschist to amphibolite facies metamorphism (M_2:M_1 of Williams et al., 1983; Culver, 2001; Varvell, 2001). Within the Mutherbukin Zone, the grade of metamorphism ranges from greenschist facies in the south around Mount James, and gradually increases to the amphibolite facies in the northern part around the Nardoo Hills area, rapidly declining back to the greenschist facies adjacent to the Ti Tree Syncline. The D_{3e} event (D_2 of Culver, 2001) is associated with retrogression of M_{2e} assemblages at greenschist facies conditions (M_{3e}). Structures produced during D_{3e} consist of microscopic to megascopic, east-southeasterly trending upright folds (F_{3e}) characterized by a crenulation schistosity parallel to the axial surfaces. These F_{3e} folds plunge shallowly or moderately to the east-southeast and west-northwest, and define the major map-scale patterns.

Geochronology

Edmundian Orogeny	*Maximum*	*Minimum*
Age (Ma)	1026 ± 12	954 ± 12
Age	Mesoproterozoic	Neoproterozoic
Source	Isotopic	Isotopic
References	Sheppard et al., 2007	Sheppard et al., 2007

Five samples of schist were collected from the Pooranoo and Leake Spring Metamorphics in the Nardoo Well area of the central Gascoyne Province (GSWA numbers 180911, 180918, 191970, 191975 and 191977) for SHRIMP U–Pb monazite and xenotime dating. Three of the samples contain amphibolite facies assemblages, whereas the two most northerly samples (GSWA 191970 and 191975) contain greenschist facies assemblages. The oldest date obtained was 1026 ± 12 Ma (GSWA 180911; SHRIMP U–Pb monazite) thus providing a maximum age for D_{1e}/D_{2e} (Sheppard et al., 2007). Additional dates were: 1005 ± 10 Ma (GSWA 180918: monazite), 1004 ± 8 Ma (GSWA 191977: monazite), 998 ± 8 Ma (GSWA 191970: xenotime), and 995 ± 6 Ma (GSWA 180918: xenotime) (Sheppard et al., 2007). The minimum age constraint for deformation (D_{3e}) is provided by an undeformed dyke from the Thirty Three Supersuite that cross-cuts all of the Edmundian-age fabrics. This dyke has been dated at 954 ± 12 Ma (Sheppard et al., 2007).

Farther south, where the Gascoyne River crosses the Cobra – Dairy Creek road on YINNETHARRA, 10–100 cm long, discontinuous, melt-filled pockets are developed within strongly foliated metamonzogranite of the Durlacher Supersuite. These shears cut the main L–S fabric in the metamonzogranites which have been correlated with the c. 1250 Ma D_{2u} event of the Mutherbukin Tectonic Event. A sample of these melt-filled shear zones (GSWA 185945) yielded abundant, concentrically zoned, igneous zircon cores that are overgrown by structureless, high-U rims interpreted to be of metamorphic origin. The cores yielded a date of c. 1650 Ma, whereas the metamorphic rims yielded a concordia age of 1000 ± 8 Ma (Wingate et al., 2010), indicating that the rims formed during the Edmundian Orogeny under middle to upper amphibolite facies conditions.

Tectonic setting

Previous studies have attributed the Edmundian Orogeny to far-field reactivation of the Capricorn Orogen during the break up of Rodinia (Powell et al., 1994) and the assembly of Gondwana (Fitzsimons, 2003). In contrast, Myers et al. (1996) suggested that the Edmundian Orogeny resulted from the collision of the North and West Australian Cratons between 1300 and 1100 Ma. However, dolerite sills dated at c. 1070 Ma (Wingate, 2002) that intrude the Bangemall Supergroup are also deformed into easterly trending folds. More recent advances in understanding the amalgamation history of the Rodinia supercontinent indicates that the collision of Australia (along its eastern margin) with Laurentia occurred at c. 1000 Ma (Li et al., 2008 and references therein), a time coincident with the Edmundian Orogeny recorded here in the West Australian Craton. In most Rodinia reconstructions (i.e. Pisarevsky et al., 2003; Li et al,. 2008) the western margin of the West Australian Craton faces an open ocean, so if these configurations are correct, the Edmundian Orogeny must be a response to far-field plate stresses related to Rodinia assembly along the eastern margin of Australia. However, it is possible that the Edmundian Orogeny formed in response to plate collision/accretion along the western margin of the West Australian Craton and that current models of Rodinia are incomplete. Uplift of the southern Capricorn Orogen between c. 950 and c. 850 Ma (Occhipinti, 2004, 2007) has been linked to collision of the Kalahari Craton with the western margin of Australia along the Pinjarra Orogen (Occhipinti, 2004). The Northampton and Mullingarra Complexes in the Pinjarra Orogen are interpreted to be allochthonous terranes, derived from the Albany Fraser Belt (Ksienzyk et al., 2007) that were metamorphosed at granulite and amphibolite facies, respectively at c. 1080 Ma and intruded by granites at c. 1070 Ma. The complexes were emplaced in their present position relative to the Yilgarn Craton in the Neoproterozoic (Fitzsimons, 2003), although because they contain undeformed dolerites of the Mundine Well Dolerite Suite, emplacement must have occurred prior to their intrusion at c. 755 Ma. The metamorphism in the central Gascoyne Province is a minimum of 40 Ma younger than that in the Northampton Complex, but a pegmatite from the Northampton Complex has been dated at 989 ± 2 Ma (Bruguier et al., 1999), suggesting that there could be other tectonothermal events in the Pinjarra Orogen coeval with the metamorphism and magmatism dated here (see also Ksienzyk et al., 2007). A comparison of the age of detrital zircons from metasedimentary rocks of the Northampton Complex with similar, possibly correlative packages from the Maud Belt of Antarctica reveal little similarity suggesting that the Kalahari Craton – West Australian Craton association may not be valid.

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Edmundian Orogeny D_{1e}/M_{1e}

Event type	deformation: undivided
Parent event	Edmundian Orogeny
Tectonic units affected	Gascoyne Province, Bangemall Basin
Metamorphic texture/ tectonic feature	schistose

Summary

The first event attributed to the Edmundian Orogeny in the basement, D_{1e}/M_{1e}, is represented by inclusion trails in porphyroblasts from pelites in the Nardoo Hills area in the northern part of the Mutherbukin Zone. U–Pb monazite geochronology from a pelite sample yielded a weighted mean $^{207}Pb^*/^{206}Pb^*$ date of 1026 ± 12 Ma, which may approximate the age of D_{1e}/M_{1e}. The metamorphic grade of this event is currently unknown.

Distribution

Evidence for D_{1e} is confined to the Nardoo Hills area, in the northern part of the Mutherbukin Zone.

Description

Evidence for D_{1e} is restricted to inclusion trails within porphyroblasts in the Nardoo Hills area, in the northern part of the Mutherbukin Zone.

Geochronology

Edmundian Orogeny	Maximum	Minimum
Age (Ma)	1026 ± ??	995 ± ??
Age	Mesoproterozoic	Neoproterozoic
Source	Inferred	Inferred
References	Sheppard et al., 2007	

There are no direct age constraints for the timing of D_{1e}. Five samples of schist were collected from the Pooranoo and Leake Spring Metamorphics in the Nardoo Well area of the central Gascoyne Province (GSWA numbers 180911, 180918, 191970, 191975, and 191977). All of the schists contained a composite S_{1e}/S_{2e} fabric. Dating of monazite and xenotime revealed a wide range of dates between 1026 and 954 Ma (Sheppard et al., 2007). However, the oldest date, at 1026 ± 12 Ma, is decidedly older than the rest and may relate directly to the D_{1e} event.

In light of the poor constraints, the maximum and minimum ages for D_{1e} are taken to be the oldest and youngest dates of 1026 and 954 Ma.

Tectonic setting

See **Edmundian Orogeny**

References

Sheppard, S, Rasmussen, B, Muhling, JR, Farrell, TR, and Fletcher, IR 2007, Grenvillian-aged orogenesis in the Palaeoproterozoic Gascoyne Complex, Western Australia: 1030–950 Ma reworking of the Proterozoic Capricorn Orogen: Journal of Metamorphic Geology, v. 25, p. 477–494.

Edmundian Orogeny
D_{2e}/M_{2e}

Event type	deformation: undivided
Parent event	Edmundian Orogeny
Tectonic units affected	Gascoyne province, Bangemall Basin
Tectonic setting	orogen: intracratonic orogen
Metamorphic texture/ tectonic feature	schistose
Metamorphic facies from	greenschist facies: chlorite zone
Metamorphic facies to	amphibolite facies: sillimanite zone

Summary

The first pervasive deformation event attributed to the Edmundian Orogeny in the basement (D_{2e}) reflects structural and metamorphic reworking within the Mutherbukin Zone between the Ti Tree and Chalba Shear Zones. Deformation and metamorphism resulted in the formation of a pervasive foliation and, locally the growth of both garnet and staurolite porphyroblasts. These tectonic fabrics and metamorphic assemblages were previously interpreted to be related to the Paleoproterozoic Capricorn Orogeny (Williams et al., 1983; Williams, 1986; Culver, 2001; Varvell, 2001; Fitzsimons et al., 2004) or to the Paleoproterozoic Mangaroon Orogeny (Sheppard et al., 2006). However, SHRIMP U–Pb dating of monazite and xenotime aligned within the D_{2e} fabric indicates that regional metamorphism and deformation occurred between 1030 Ma and 990 Ma (Sheppard et al., 2007).

Distribution

Prograde metamorphic assemblages and tectonic fabrics related to the Edmundian basement D_{2e} are developed in metasedimentary and meta-igneous rocks in the Nardoo Hills region on southern Mount Phillips and adjacent northern Yinnetharra.

Description

In the Nardoo Hills area along the northern edge of the Mutherbukin Zone, the first of the pervasive events attributed to the Edmundian Orogeny, D_{2e}, produced a strong foliation associated with greenschist to amphibolite facies metamorphism (M_{2e}:M_1 of Williams et al., 1983; Culver, 2001; Varvell, 2001). This area preserves an M_{2e} metamorphic gradient ranging from amphibolite facies in the south to lower greenschist facies in the north adjacent to the Ti Tree Syncline. Pelitic schist of the Leake Spring Metamorphics in the southern part of the Nardoo Hills area contains black staurolite and scattered dark red–brown garnet porphyroblasts, which are enclosed by a strong composite fabric (S_{1e}/S_{2e}) and locally have remnants of S_{1e} in pressure shadows and inclusion tails. A prominent mineral lineation (L_{2e}) is defined mainly by the alignment of 1–2 mm-sized staurolite crystals. Interlayered amphibolite is fine grained and compositionally homogeneous with a strong foliation and a weak mineral lineation.

The southern margin is marked in the Nardoo Well area, by a distinctive, foliated marine quartzite (Spring Camp Formation). The quartzite has a strong planar foliation (S_{1e}/S_{2e}) dipping to the south-southwest at 30–40°, and a prominent lineation (L_{2e}). The lineation is similar in orientation to the mineral lineation in the pelitic schists to the north, but the foliation dips more shallowly to the south approaching the southern margin of the Pooranoo Metamorphics, which is interpreted to be in sheared contact with leucocratic granites of the Moorarie Supersuite. Much of the Pooranoo Metamorphics in the Nardoo Hills area comprises biotite–quartz–muscovite schist and quartz–muscovite–biotite schist (Biddenew Formation), in which the S_{1e}/S_{2e} schistosity is crumpled by a moderately to steeply north-dipping crenulation cleavage. In low-grade areas of the Nardoo belt, near the Ti Tree Syncline, the Pooranoo Metamorphics are typically fine-grained rocks comprising mainly slate and phyllite. The rocks have a pervasive cleavage (S_{3e}), which is axial planar to kilometre-scale folds in the Pooranoo and Morrissey Metamorphics, and broadly parallel to structures in low-grade Edmund Group rocks within the Ti Tree Syncline.

Sheared leucogranite of the Moorarie Supersuite (Zone 50, MGA 408838E 7293140N) contains sparse porphyroclasts of K-feldspar up to 4 mm, and in some areas, boudinaged and isoclinally folded (F_{2e}) pegmatite veins. The foliation in the monzogranite dips moderately or steeply to the south, parallel to the S_{1e}/S_{2e} fabric in the Pooranoo Metamorphics to the north, and is folded about an isoclinal F_{3e} fold. In the sheet-like monzogranite there is a trend, of increasing grain size and decreasing strain to the south and west, away from the contact with the Pooranoo Metamorphics. Combined with the southward increase in metamorphic grade in the Pooranoo Metamorphics, the dominance of D_{2e} structures in this zone and the south to south-southwest dip of the foliation, suggests that the contact between the monzogranite and the Pooranoo Metamorphics was a zone of uplift during D_{2e}.

On central, southern Pink Hills, metasedimentary rocks of the Edmund Group and mafic intrusives of the Narimbunna Dolerite have been metamorphosed and deformed in the lower to middle amphibolite facies, with the widespread production of andalusite and garnet porphyroblasts within pelitic lithologies. These rocks form part of a regional-scale tight to isoclinal syncline presumably formed during either the D_{2e} or D_{3e} event. The presence of andalusite rather than staurolite, as is prominent within similar rocks in the Nardoo Hills area, suggests that M_{2e} metamorphism peaked at slightly lower pressures and temperatures than those in the Nardoo Hills area.

In the east in gneissic and foliated granites of the Moorarie Supersuite (P_-MO-mgn, P_-MO-mgnl), the D_{2e} event has produced metre-scale close to tight upright folds. These folds are not present in the surrounding foliated granites of the younger Durlacher Supersuite.

Middle amphibolite facies rocks are abundant in the northern part of the Mutherbukin Zone and contain the assemblage staurolite–biotite–muscovite–quartz (e.g. GSWA 180911 and 191977), or staurolite–plagioclase–biotite–muscovite–quartz (e.g GSWA 180918). The schists also contain lesser amounts of apatite, tourmaline, Fe–Ti oxide minerals, chlorite, zircon, xenotime, monazite, and barite. The schists have a strong composite S_{1e}/S_{2e} fabric, which is defined by the alignment of quartz, muscovite, biotite, and Fe–Ti oxide minerals, and quartz-rich and mica-rich domains. The pelites all contain coarse porphyroblasts of biotite and staurolite that overprint S_{1e} and are enclosed by S_{2e}. The biotite contains abundant pleochroic haloes, produced by inclusions of zircon, monazite, and xenotime. One of the most distinctive assemblages in the Nardoo Hills area is a staurolite–garnet–biotite–muscovite(–andalusite) schist. Staurolite porphyroblasts 4–6 cm long are not uncommon in the area to the north and northwest of Morrissey Hill on southern MOUNT PHILLIPS and northern YINNETHARRA, but towards Reid Well on northeastern YINNETHARRA, the rocks become finer grained with fewer large staurolite and garnet porphyroblasts. Some of the staurolite–garnet–biotite–muscovite(–andalusite) schists contain two generations of staurolite: large porphyroblasts and smaller crystals that define a lineation. Staurolite porphyroblasts commonly overprint an S_{1e}/S_{2e} schistosity. Inclusion trails show that porphyroblast growth post-dated an early S_{1e} foliation and some rotation of that foliation near porphyroblast margins, suggesting that growth may be late synkinematic with S_{2e}. Mafic rocks interleaved with the metasedimentary rocks comprise amphibolites.

Lower amphibolite facies rocks are prevalent on central southern PINK HILLS immediately adjacent to the Ti Tree Shear Zone. The dominant pelitic rocks contain abundant 1–10 mm long andalusite and 1–5 mm diameter garnet porphyroblasts set within a matrix of muscovite and quartz. The andalusite porphyroblasts commonly grow in random orientations within the main S_{2e} foliation, but the relation of garnet porphyroblasts to this fabric is more equivocal as they commonly overgrow this fabric, but are also locally wrapped by it. Associated dolerite sills contain an amphibolite facies assemblage of hornblende–plagioclase–epidote. Peak metamorphic conditions constrained by the andalusite–garnet bearing pelites is <550°C and <3 kbar.

Greenschist facies pelites contain the assemblages biotite–plagioclase–chlorite–muscovite–quartz (GSWA 191970) or muscovite–quartz–chlorite (GSWA 191975). The dominant foliation (S_{2e}) is defined by parallel muscovite, chlorite, and Fe–Ti oxide minerals, and mica-rich and quartz-rich bands. The S_2 fabric has undergone folding and the development of a weak crenulation cleavage (S_{3e}). Samples also contain minor amounts of Fe–Ti oxide minerals, Fe oxide minerals, zircon, xenotime and apatite. Monazite is absent from greenschist facies samples, which is consistent with previous studies that have found that monazite appears at the staurolite isograd in prograde pelites (e.g. Smith and Barreiro, 1990; Kingsbury et al., 1993; Spear and Pyle, 2002; Wing et al., 2003).

The presence of andalusite and cordierite in amphibolite facies pelites in the Leake Spring Metamorphics and Pooranoo Metamorphics was used originally to infer high-temperature and low-pressure conditions within the belt (Williams et al., 1983; Williams, 1986). However, the subsequent identification of kyanite in amphibolite facies assemblages (kyanite–staurolite–biotite–quartz–muscovite [CV063] and kyanite–chlorite–plagioclase–biotite–quartz–muscovite [CV064] schists) from two localities in the Nardoo Hills belt was used to infer a Barrovian thermal regime (600–700°C and 8–9 kbar; Varvell, 2001; Varvell et al., 2003; Fitzsimons et al., 2004). Based on these estimates, it was argued that metamorphism involved burial to depths of 30 km and intense north-northwest – south-southeast shortening, during continent–continent collision (Fitzsimons et al., 2004).

We have re-examined thin sections from the two samples containing what was interpreted to be kyanite (CV063 and CV064; Fig. 12; Varvell, 2001). The comparatively low relief and low birefringence of the mineral in question, combined with its length-fast optical orientation, are indicative of andalusite (Deer et al., 1983). X-ray diffraction analysis of the same mineral in samples of the Morrissey Metamorphics (GSWA 46981) and Pooranoo Metamorphics (Y65; Trautman, 1992) 5 km along strike from, and 2.5 km north of, respectively, the reported kyanite-bearing samples (CV063 and CV064) confirms that the stable Al_2SiO_5 polymorph is andalusite (R Clarke, pers. comm., 2006, 2007). The widespread presence of andalusite and the absence of kyanite in these samples is consistent with earlier observations (e.g. Williams et al., 1983; Williams, 1986), and indicates that peak regional metamorphism reached temperatures of 500–550° C and pressures of 3–4 kbar.

Geochronology

Edmundian Orogeny	*Maximum*	*Minimum*
Age (Ma)	1026 ± 12	995 ± 6
Age	Mesoproterozoic	Neoproterozoic
Source	Isotopic	Isotopic
References	Sheppard et al., 2007	Sheppard et al., 2007

Five samples of schist were collected from the Pooranoo and Morrissey Metamorphics in the Nardoo Well area of the central Gascoyne Complex (GSWA numbers 180911, 180918, 191970, 191975, and 191977) for SHRIMP U–Pb dating of monazite and xenotime in situ (Sheppard et al., 2007). Monazite is widespread in all three samples of the staurolite-bearing schists (GSWA 180918, 180911, and 191977) where it typically occurs in the matrix as idioblastic crystals oriented parallel to the main fabric, S_{1e}/S_{2e}. Monazite crystals are also present as inclusions aligned with S_{1e} in staurolite and biotite porphyroblasts that overprint the matrix. In places, monazite crystals contain inclusions of Fe–Ti oxide minerals, quartz, and muscovite that are aligned parallel to S_{1e}/S_{2e}, suggesting that monazite grew with these minerals during deformation. Xenotime crystals are found in all of the metapelitic schists (GSWA samples 180918, 180911, and 191977) but are less abundant and smaller than monazite. Xenotime is typically subidioblastic and equant, although elongate crystals are aligned with S_{1e}/S_{2e}. Xenotime occurs in the matrix and as inclusions within large overprinting staurolite and biotite porphyroblasts.

The oldest and youngest dates obtained were 1026 ± 12 Ma (GSWA 180911; monazite) and 995 ± 6 Ma (GSWA 180918: xenotime) thus providing the maximum and minimum age constraints for D_{2e} (Sheppard et al., 2007), respectively. Additional dates were: 1005 ± 10 Ma

(GSWA 180918: monazite), 1004 ± 8 Ma (GSWA 191977: monazite), 998 ± 8 Ma (GSWA 191970: xenotime) (Sheppard et al., 2007).

In the central part of the Mutherbukin Zone on YINNETHARRA, small leucocratic melt pockets are widely developed in granitic rocks of the Durlacher and Moorarie Supersuites. Small leucocratic melt pockets that cut the gneissic fabric in the Davey Well Granite were sampled for SHRIMP U–Pb zircon geochronology. Concentrically zoned zircon cores yield a concordia age of 1648 ± 6 Ma, interpreted as the age of magmatic crystallization of the monzogranite. High-U rims with low Th/U ratios (≤0.05) yield a concordia age of 1000 ± 8 Ma, interpreted as the age of magmatic crystallization of the pegmatite. This date also provides a minimum age for the gneissic fabric in the Davey Well Granite. This date is within uncertainty of most of the monazite and xenotime in situ U–Pb dates from the metasedimentary rocks.

Tectonic setting

See **Edmundian Orogeny**

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Edmundian Orogeny
D_{3e}/M_{3e}

Event type	deformation: undivided
Parent event	Edmundian Orogeny
Tectonic units affected	Gascoyne province, Bangemall Basin
Tectonic setting	orogen: intracratonic orogen
Metamorphic facies from	greenschist facies
Metamorphic facies to	greenschist facies

Summary

The D_{3e} event in the Gascoyne Province produced east-southeasterly trending upright folds that dominate the map patterns in the northern part of the Mutherbukin Zone. Folding was associated with low-grade metamorphism and retrogression of M_{2e} assemblages.

Distribution

Structures and mineral assemblages related to the D_{3e} event may have been developed across the width of the Mutherbukin Zone. Along the northern edge of the zone, adjacent to the Ti Tree Syncline, the S_{3e} cleavage in the basement rocks is broadly parallel to structures in the Edmund Group within the syncline.

Description

The D_{3e} event (D_2 of Culver, 2001) is associated with retrogression of M_{2e} assemblages at greenschist facies conditions (M_{3e}). Structures produced during D$_3$e consist of microscopic to megascopic, east–southeasterly trending upright folds (F_{3e}) characterized by a crenulation schistosity parallel to the axial surfaces. These F_{3e} folds plunge shallowly or moderately to the east–southeast and west–northwest, and define the major map-scale patterns. The metasedimentary rocks of the metamorphosed Edmund Group and Pooranoo Metamorphics show a systematic decrease in metamorphic grade north towards the Ti Tree Syncline. In low-grade areas of the Nardoo belt, near the Ti Tree Syncline, the Pooranoo Metamorphics are typically fine-grained rocks comprising mainly slate and phyllite. The rocks have a pervasive cleavage (S_{3e}), which is axial planar to kilometre-scale folds in the Pooranoo Metamorphics and metamorphosed Edmund Group, and broadly parallel to structures in unmetamorphosed Edmund Group rocks within the Ti Tree Syncline. The D_{3e} event may also have been responsible for the broad dome structure defined by the S_{2e} fabric in the Davey Well Granite on YINNETHARRA.

The D_{3e} event is associated with retrogression of M_{2e} assemblages at greenschist facies conditions (M_{3e}). In the Nardoo Hills area Culver (2001) and Varvell (2001) documented growth of chlorite and biotite porphyroblasts during M_{3e} (M_2 of Culver, 2001). They noted the presence of isograds marking the appearance of chlorite and biotite, and suggested that the grade of M_{3e} increases towards the 'Guran Gutta granite', as does the intensity of deformation. However, our mapping suggests that the Gurun Gutta granite cuts S_{3e}. Along the northern edge of the Mutherbukin Zone, adjacent to the Ti Tree Syncline, the typical assemblage in the slaty rocks of the Pooranoo Metamorphics is chlorite–muscovite–quartz(–albite–magnetite). The magnetite commonly forms small black porphyroblasts up to 2 mm. The rocks have a pervasive, planar, continuous cleavage (S_{3e}). There is probably only a small contrast in metamorphic grade between the Pooranoo Metamorphics at this locality and Edmund Group rocks in the Ti Tree Syncline.

Geochronology

Edmundian Orogeny	*Maximum*	*Minimum*
Age (Ma)	995	954
Age	Neoproterozoic	Neoproterozoic
Source	Inferred	Inferred
References	Sheppard et al. (2007)	Sheppard et al. (2007)

There are no direct ages for the D_{3e}/M_{3e} event, although some constraints are provided by ages of the D_{2e}/M_{2e} event and by the intrusion of rare-element pegmatites that cut D_{3e} structures. A maximum age for D_{3e} is provided by the youngest SHRIMP U–Pb monazite or xenotime age for the D_{2e}/M_{2e} event of 995 ± 6 Ma (Sheppard et al., 2007). Metasedimentary rocks in the Nardoo Hills area are cut by a suite of rare-element pegmatites, which were intruded during or after D_{3e} (Hardy, 1992; Sheppard et al., 2007). A rare-element pegmatite (UWA 117154; site 'U' of Trautman, 1992) was sampled for SHRIMP U–Pb geochronology by Sheppard et al. (2007). This pegmatite forms a saddle 'reef' in the hinge zone of a regional-scale F_{3e} antiform. The pegmatite plunges parallel to the plunge of the antiform, and on the exposed southern limb of the antiform the pegmatite is undeformed; these features indicate that the pegmatite probably intruded during D_{3e} (Hardy, 1992; this work). A coarse monazite crystal several millimetres in size was separated and analysed. The monazite contains inclusions of quartz, a Th-silicate mineral surrounded by radial fractures, and clusters of xenotime. Seven analyses of the monazite produced a weighted mean $^{207}Pb^*/^{206}Pb^*$ date of 954 ± 12 Ma Sheppard et al., (2007). This date provides a minimum age for D_{3e}/M_{3e}.

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Mundine Well Dolerite Suite

(P_-MW-od)

Legend narrative

Dolerite dykes, sills, and small intrusions with locally abundant xenoliths and potassic alteration of wallrocks; includes minor quartz diorite, syenite, tonalite, and biotite monzogranite

Rank	Suite
Parent	Top of lithostratigraphic order (TOL)

Summary

The Mundine Well Dolerite Suite intrudes numerous tectonic units along the western edge of the continent. Most of the dykes strike between north and north-northeast and are up to 150 m wide, although most are less than 25 m wide. Thicker dykes may be traced along strike for tens of kilometres. The dykes overwhelmingly comprise dolerite, but in places granitic rocks are present. The suite has been dated using SHRIMP U–Pb zircon and baddeleyite geochronology at 755 ± 3 Ma.

Distribution

Dykes of the Mundine Well Dolerite Suite strike north to north-northeast throughout the western part of the Capricorn Orogen, in the Pinjarra Orogen, and in the western parts of the Pilbara and Yilgarn Cratons. In the Gascoyne Province, the suite forms dense swarms on Mangaroon and Maroonah, and on the central part of Yinnetharra.

The dolerite dykes are commonly about 5–25 m wide but some reach nearly 150 m wide. They are commonly marked by sparse vegetation and typically outcrop as fresh boulders and tors amongst weathered rubble. Some of the dykes can be traced for 30 km or more. In the southwestern corner of Mangaroon, the dolerites outcrop as boulders and tors in narrow linear valleys bounded by low ridges of contact-metamorphosed granite.

Derivation of name

Hickman and Lipple (1978) referred to a suite of east-northeast trending dolerite dykes in the Pilbara region as the Mundine Well Suite. This suite was subsequently referred to as the Mundine Well dyke swarm by Wingate and Giddings (2000). The name has now been formalized as the Mundine Well Dolerite Suite.

Lithology

Almost all of the dykes are composed of dolerite. The dykes are fine-grained, or fine- to medium-grained, and aphyric to weakly porphyritic (<5% plagioclase phenocrysts up to 10 mm long). The cores of thicker dykes are typically medium grained. The dykes are massive, but locally a spaced cleavage parallel to the dyke walls is present. The dolerites have a subophitic to intergranular texture, and comprise pale-brown augite and plagioclase, and lesser olivine (<10%) and titanomagnetite. Accessory minerals include interstitial quartz, biotite, and apatite, and brown hornblende rims on titanaugite. Low-grade metamorphic recrystallization includes minor epidote and sericite replacement of plagioclase, and iddingsite replacement of olivine along fractures.

On Mangaroon and Maroonah, there are rare dykes that contain quartz diorite, syenite, tonalite, and biotite monzogranite. One of these dykes, located about 1.3 km west of Alma Well on Mangaroon, consists of heterogeneous quartz diorite to granodiorite with variable amounts of xenocrystic quartz and feldspar. The rocks have partly resorbed K-feldspar xenocrysts and 15% round quartz xenocrysts with biotite rich rims, and contain rounded to subangular inclusions of dolerite. The granitic rocks have a patchy granophyric texture developed. The granitic rocks in places grade into a dolerite with xenocrysts of quartz over a distance of several metres. Some of the dolerite inclusions contain acicular apatite crystals, a morphology that is commonly developed in quenched mafic magma (Vernon, 1983). Collectively, these features suggest mingling, and limited hybridization between mafic and felsic magma. The felsic magma, with its granophyric textures, may have been derived from melting of wall rock during intrusion of the dolerite.

A dyke located about 1.8 km south of the Joy Helen prospect on central Maroonah (MGA Zone 50, 374380E 7426070N), which intruded the lower part of the Edmund Group, was dated by Wingate and Giddings (2000). The pegmatitic leucogabbro that they sampled for geochronology forms the core of the dyke, but it has thin margins of fine-grained, equigranular biotite–muscovite monzogranite. About 750 m to the north-northeast, the dyke comprises fine-grained, weakly porphyritic biotite monzogranite. The relative age of the monzogranite and dolerite could not be established, but neither rock types contains inclusions of the other.

Age code	Proterozoic	P_-
Stratigraphic code	Mundine Well Dolerite Suite	MW-
Rock type	Igneous mafic intrusive	o
Lithname	dolerite	d
Rock code		**P_-MW-od**

Contact relationships

Dykes of the Mundine Well Dolerite Suite intrude all the stratigraphic units in the Gascoyne Province, and rocks of the Wyloo Group, Capricorn Group, and the Bangemall Supergroup. The dykes also cut across dolerite sills of the Narimbunna Dolerite (P_-_nr-od) intruded into the Edmund Group, and dolerite sills of the Kulkatharra Dolerite (P_-WKku-od) intruded into the Edmund and Collier Groups.

The dykes are commonly associated with contact metamorphism. At several localities, thick dolerites have caused partial melting of adjacent wall rocks. East of Mullara Well on Maroonah (MGA 357100E 7408000N), intrusion of a dolerite dyke is associated with anatexis of leucocratic granite. Anatectic melt is present in a zone up to 30 cm wide along the contact. The melted granite is grey, and consists of rounded and embayed crystals of quartz and plagioclase (pseudomorphed by very fine grained albite, sericite, and epidote) in a fine-grained groundmass of quartz, orthoclase, and plagioclase, with minor chlorite and opaques. Micrographic and granophyric textures are common. Northwest of Minga Well on Mangaroon a thick dyke is associated with remelting of medium- to coarse-grained, cream-coloured tonalite. The anatectic rocks are pale pink and fine to medium grained.

In the southwestern corner of Mangaroon, the dolerite dykes are spatially associated with fine-grained pervasive and fracture-related epidote alteration in granites of the Moorarie Supersuite. Fine-grained pervasive and fracture-related epidote alteration, possibly related to the dolerite dykes, has also been identified at several localities on Maroonah. In the northwestern part of the sheet area, about 1.9 km south-southwest of the Monte Carlo workings, epidote alteration is developed in leucocratic monzogranite of the Durlacher Supersuite. About 1.6 km southeast of Dirnelleurby Bore in the southwestern corner of Maroonah, pervasive epidote alteration is intensively developed in cobble- and pebble-metaconglomerate of the Pooranoo Metamorphics.

Geochronology

P_-MW-od	*Maximum*	*Minimum*
Age (Ma)	755 ± 3	755 ± 3
Age	Neoproterozoic	Neoproterozoic
Source	Isotopic	Isotopic
References	Wingate and Giddings (2000)	Wingate and Giddings (2000)

The Mundine Well Dolerite Suite has been dated at 755 ± 3 Ma by Wingate and Giddings (2000) using SHRIMP U–Pb zircon and baddeleyite geochronology. Rasmussen and Fletcher (2004) also dated one of the dykes previously dated by Wingate and Giddings (2000) at 754 ± 5 Ma using SHRIMP U–Pb zirconolite geochronology.

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Mulka Tectonic Event

Event type	deformation: strike-slip
Parent event	Top of Event list (TOL)
Tectonic units affected	Gascoyne province, Bangemall Basin
Tectonic setting	orogen: reactivated orogen
Metamorphic texture/ tectonic feature	C–S fabric, mylonitic

Summary

The Mulka Tectonic Event is responsible for a series of anastomosing shear zones or faults that cut rocks of the Gascoyne Province and Edmund and Collier Groups across the southwestern part of the Capricorn Orogen. This tectonic event is characterized by fault reactivation, rather than reworking. The largest of the fault systems is the Chalba Shear Zone – Clere Fault. The shear zones and faults display consistent dextral strike-slip kinematics. Structures attributed to the Mulka Tectonic Event cut c. 755 Ma dykes of the Mundine Well Dolerite Suite. White mica in the S-planes of an S–C fabric in the Chalba Shear Zone has been dated in situ using the $^{40}Ar/^{39}Ar$ method, yielding a single age of 570 ± 10 Ma. The Mulka Tectonic Event represents is coeval with the Petermann, Paterson, and King Leopold Orogenies, and reflects an episode of 'pan-Gondwana' intracontinental reactivation.

Distribution

The Mulka Tectonic Event comprises narrow shear zones that transect the Gascoyne Province and Edmund and Collier Basins over a wide area. Shear zones attributed to this event have been identified as far north as the Mangaroon Syncline on MANGAROON, and south to the Chalba Shear Zone on YINNETHARRA. Where faults and shear zones reactivated during this event do not cut the 755 Ma Mundine Well Dolerite Suite, they may be incorrectly attributed to one of the numerous Paleoproterozoic or Mesoproterozoic tectonic events that affect the western Capricorn Orogen.

Description

Rocks of the Gascoyne Province and Bangemall Supergroup are cut by a network of anastomosing shear zones with dextral strike-slip kinematics, which are attributed to the Mulka Tectonic Event. This event is marked by fault and shear zone reactivation, rather than pervasive reworking. Faults and shear zones active during this event range from a few centimetres to several tens of metres wide, and strike predominantly between east and southeast (a few trend northeast). In many (?most) instances this Neoproterozoic fault movement marks a reactivation of Paleoproterozoic or Mesoproterozoic structures.

Probably the most spectacular expression of the Mulka Tectonic Event is the Chalba Shear Zone – Clere Fault, a major structure in the western part of the Capricorn Orogen. On YINNETHARRA and LOCKIER, the Chalba Shear Zone comprises numerous, anastomosing narrow mylonites in a zone up to 5 km wide. The shear zone truncates a swarm of north- to north-northeast-trending dykes belonging to the Mundine Well Dolerite Suite. Dextral offset of dolerite dykes is indicated across many individual mylonites, consistent with widespread lineations and sense-of-shear indicators. At one set of creek pavements adjacent to the Dairy Creek – Cobra Road on YINNETHARRA (SXSYIN6272; Zone 50, MGA 399994E 7257799N) strongly sheared porphyritic biotite monzogranite contains a subhorizontal mineral lineation in conjunction with climbing pegmatite veins, asymmetric folds, S–C fabrics, sigma porphyroclast tails and extensional shear bands all indicating dextral sense of shear.

Elsewhere in the Gascoyne Province, several southeast-trending faults within the Mangaroon Syncline on MANGAROON offset dykes of the 755 Ma Mundine Well Dolerite Suite, as do numerous east-southeast- and southeast-trending mylonites that cut the Minnie Creek batholith on EUDAMULLAH and MOUNT PHILLIPS. These mylonites consistently have a mineral lineation plunging shallowly to the southeast which is associated with S–C fabrics and sigma porphyroclasts indicating dextral shear. The mylonites are associated with growth of fine-grained chlorite and sericite or muscovite.

Geochronology

Mulka Tectonic Event	*Maximum*	*Minimum*
Age (Ma)	570 ± 10	570 ± 10
Age	Neoproterozoic	Neoproterozoic
Source	Isotopic	Isotopic
References	Bodorkos and Wingate, 2007	Bodorkos and Wingate, 2007

Only one date has been determined for the Mulka Tectonic Event; the following description and interpretation is taken from Bodorkos and Wingate (2007). White micas were sampled from the Chalba Shear Zone on YINNETHARRA. The sample locality shows well-developed S–C fabrics and other shear sense criteria indicating dextral strike-slip movement. White micas in different textural associations were dated in situ with an infrared laser using the $^{40}Ar/^{39}Ar$ method. Five analyses of coarse-grained crystals from C-planes yielded widely variable dates of 2790–630 Ma, and probably reflect a combination of heterogeneously distributed excess Ar and partial resetting of the Ar–Ar systematics. However, the fine-grained S-plane material indicated a single date of 570 ± 10 Ma. This reactivation may be associated with the development of dextral shear zones that offset dykes of the 755 Ma Mundine Well Dolerite Suite.

Tectonic setting

The Mulka Tectonic Event represents an episode of intracontinental reactivation coeval with other 'pan-African' or 'pan-Gondwana' events between 650 Ma and 500 Ma that reflect amalgamation of Gondwana (e.g. Veevers, 2003). Events of similar age in Australia include the Petermann Orogeny in central Australia, and the Paterson and King Leopold Orogenies in northern Western Australia.

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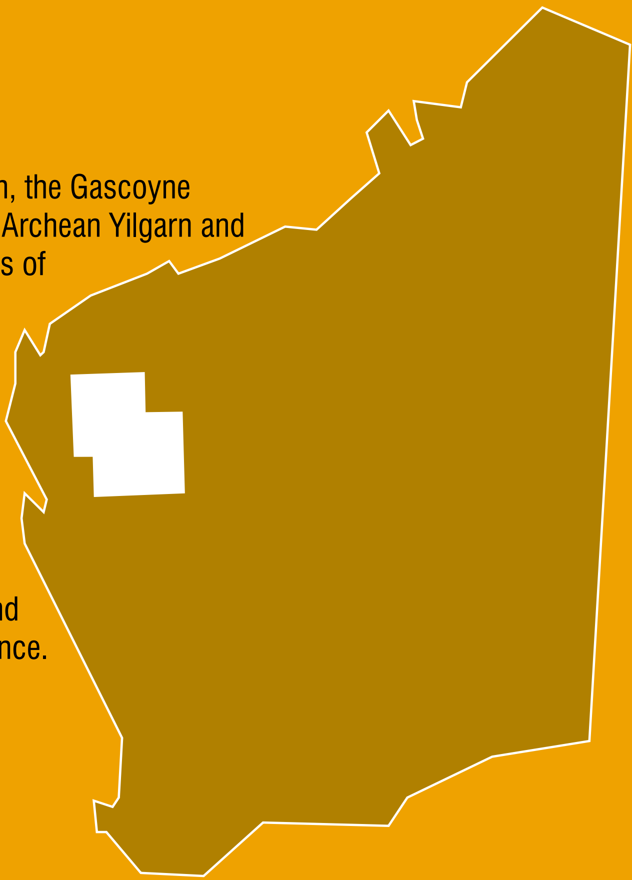
Explanatory notes for the Gascoyne Province

Located at the western end of the Capricorn Orogen, the Gascoyne Province is a major zone of tectonism between the Archean Yilgarn and Pilbara Cratons, comprising six fault-bounded zones of granitic and medium- to high-grade metamorphic rocks. Although the province has been commonly regarded as a Paleoproterozoic entity, it has an extended history of reworking and reactivation until the late Neoproterozoic. This Explanatory Notes volume provides a synthesis of the geological history of the province, along with a summary of the gaps in our knowledge, as well as detailed descriptions of all the stratigraphic units and the tectonic events recorded in the Gascoyne Province.



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