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Chapter 6: Arnhem Province

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Chapter 6: ARNHEM PROVINCE

M Ahmad and TJ Munson

INTRODUCTION

The Arnhem Province (previously known as Arnhem Inlier) forms basement to sedimentary and minor volcanic rocks of the McArthur Basin succession in northeastern Arnhem Land (**Figures 6.1**, **6.2**). The stratigraphic succession of the province is summarised in **Table 6.1**. It comprises pre-Nimbuwah Event metasedimentary and anatectic rocks of the Bradshaw and Mirarrmina complexes, and the turbidite-dominated Grindall Formation. These are possibly equivalent to the Cosmo Supergroup of the Pine Creek Orogen (P4 interval of Ahmad 2000). Intruding these units are granites and coeval felsic volcanic rocks, which were divided by Budd *et al* (2002) into the Bradshaw and Giddy suites. The ca 1865 Ma 'Bradshaw Suite' was an informal name for intrusive rocks dominated by restite-rich, garnet-bearing S-type granite and migmatite that are now included within the Mirarrmina and Bradshaw complexes. The ca 1835 Ma Giddy Suite includes the Bukudal, Giddy, Garrthalala and Dhalinybuy granites and comprises Fe-rich, relatively anhydrous fayalite-bearing granite.

PALAEOPROTEROZOIC

Grindall Formation

The Grindall Formation (originally Grindall Metamorphics; Plumb and Roberts 1992) is a deformed and locally metamorphosed succession of interbedded sandstone and mudstone (**Figure 6.3**), which is unconformably overlain by various units of the McArthur Basin. The formation is intruded by granite of the Bradshaw Complex, but may be contiguous with and a partial protolith of the metamorphic component of the complex (Pietsch *et al* 1997a, Haines *et al* 1999). The Bukudal Granite and felsic and mafic dykes also intrude the formation.

The Grindall Formation is best exposed in the south of the Arnhem Province along the eastern flank of the Coast Range and on some islands in BLUE MUD BAY[1] (**Figure 6.2c**). Widespread clasts of Grindall Formation in the basal units of the McArthur Basin succession indicate that the unit is probably extensive in the subsurface. The thickness of the unit is uncertain, as the base and top of the formation are not defined, but Haines *et al* (1999) estimated in excess of 1000 m. Island outcrops of the Grindall Formation are relatively unmetamorphosed and consist of rhythmically intercalated red-brown to grey-green sandstone and mudstone that have been tightly to openly folded (**Figure 6.3**). The fine to medium sandstone is thinly to thickly bedded and sandstone beds have sharp bases, but commonly grade upwards into finer lithologies. Planar- and cross-laminations are present in the finer tops of sandstone beds and water-escape structures are also present. Contact- and regionally metamorphosed equivalent strata from mainland localities consist of metasandstone interbedded with phyllite and quartz-sericite schist. The metasandstone is apparently coarser than that on the islands and the beds are thicker or occur in amalgamated packets (Haines *et al* 1999). The succession is also more tightly folded, has common quartz veins and exhibits a steeply dipping northwest-trending foliation in finer lithologies. Haines *et al* interpreted the Grindall Formation as representing a turbidite succession, probably deposited in a rapidly subsiding marine basin, with mainland exposures in the west probably representing more proximal facies.

[1] Names of 1:250 000 and 1:100 000 mapsheets are in large and small capital letters, respectively, eg BLUE MUD BAY, CALEDON.

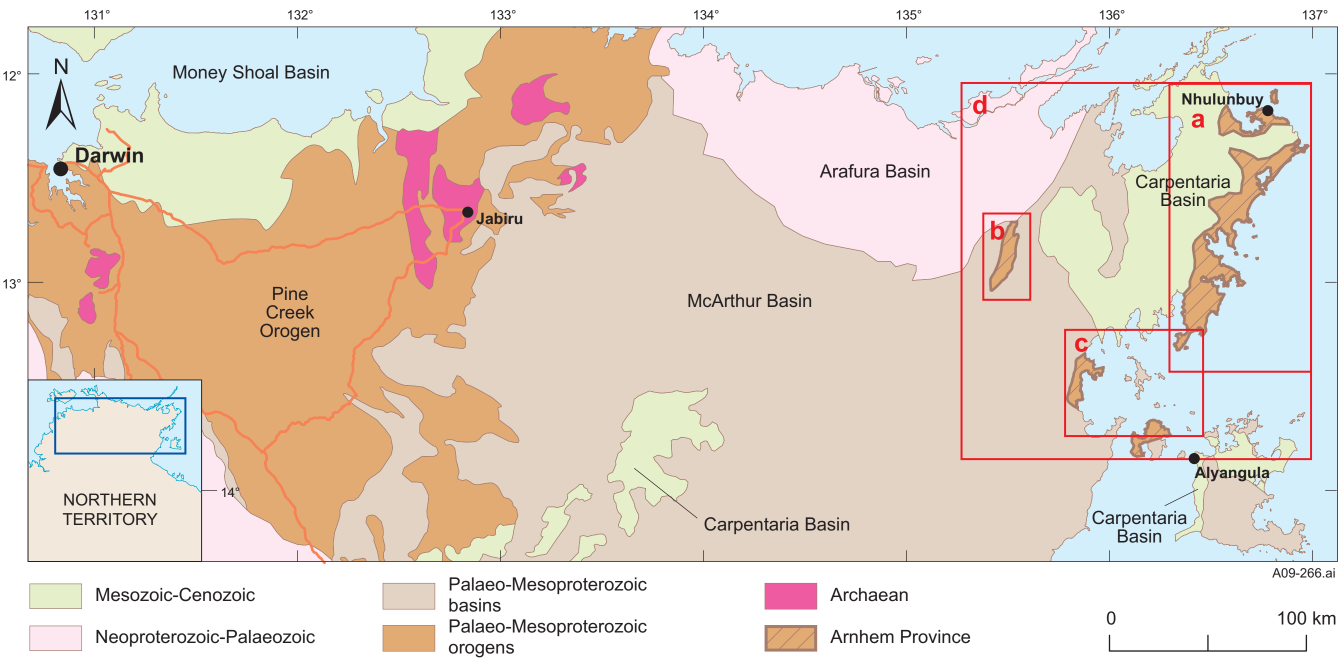

Figure 6.1. Regional geology of Arnhem Province. NT geological regions from NTGS 1:2.5M geological regions GIS dataset. Boxes show locations of maps in **Figure 6.2**.

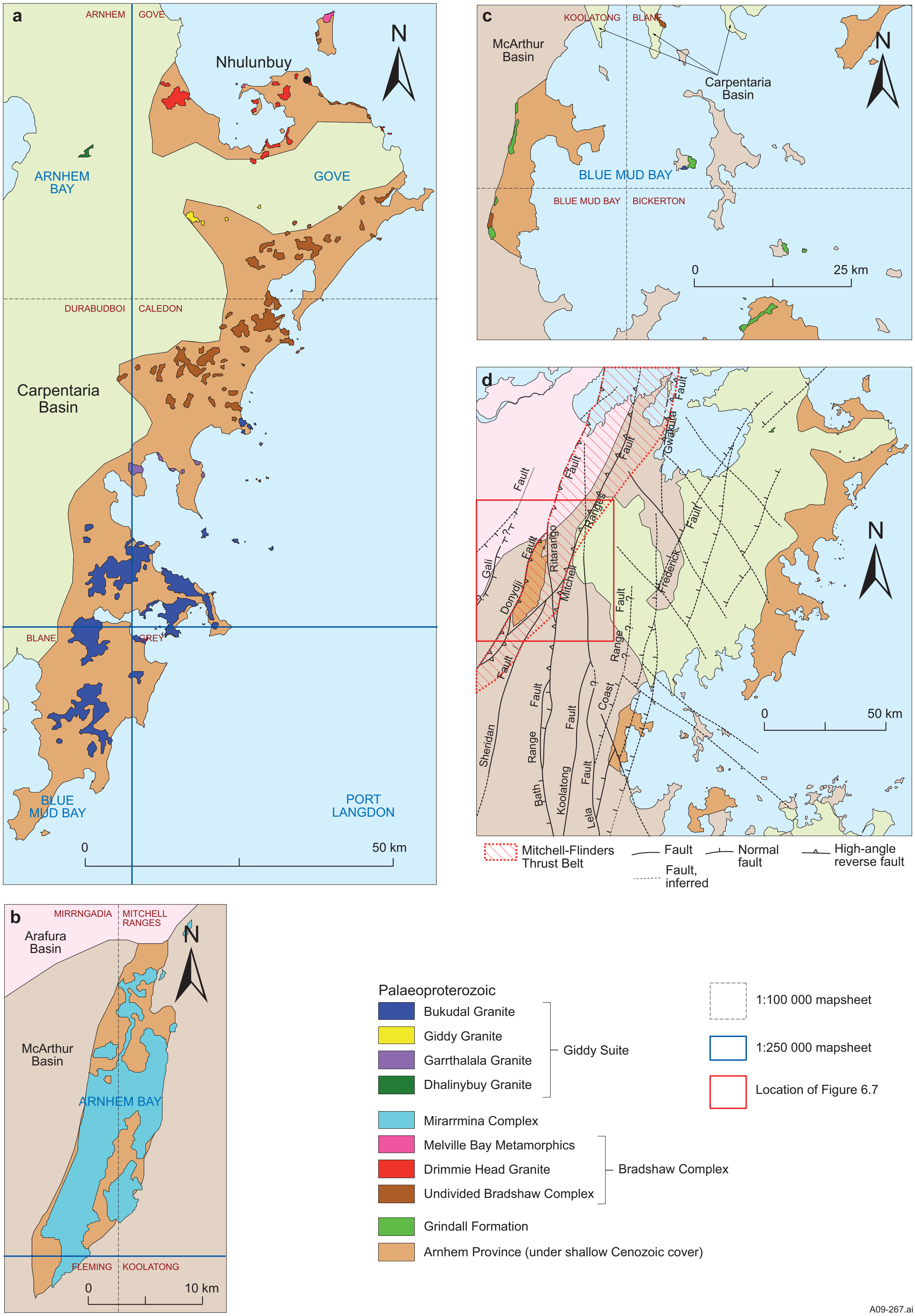

Figure 6.2. Simplified geology of Arnhem Province overlaid on NTGS 1:2.5M geological regions GIS dataset. See **Figure 6.1** for locations of maps and legend for geological regions. (**a–c**) Outcrop maps derived from GA 1:1M geology GIS dataset. (**d**) Principle faults in eastern Arnhem Land area, interpreted from mapping and geophysical data, and location of Mitchell-Flinders Thrust Belt (modified from Rawlings 2001).

A minimum age for the Grindall Formation is provided by a U-Pb SHRIMP zircon date of 1837 ± 4 Ma for the Bukudal Granite which intrudes the formation. The Grindall Formation is lithologically similar to and is tentatively correlated with the Burrell Creek Formation (Finniss River Group) of the PCO; this unit overlies the Gerowie Tuff, which which has a SHRIMP U-Pb zircon age of 1863 ± 3 Ma (Lally and Worden 2004).

Bradshaw Complex

The Bradshaw Complex comprises a continuum of deformed granite, granitic gneiss, migmatite and paragneiss, and is poorly exposed in northeastern and eastern Arnhem Land (**Figures 6.2a**, **6.4**). Several informal subdivisions of the complex were recognised by Plumb and Roberts (1992) and Madigan and Rawlings (1994), which were simplified by Rawlings *et al* (1997) into three units: the Melville Bay Metamorphics, Drimmie Head Granite and undivided Bradshaw Complex. The Melville Bay Metamorphics in the north comprises granulite-facies rocks, whereas the undivided Bradshaw Complex to the south is mainly of amphibolite-facies grade. The protolith for the Bradshaw Complex is at least partially represented by the Grindall Formation, which outcrops in BLUE MUD BAY to the south (Haines *et al* 1999).

The Bradshaw Complex is intruded by Giddy Suite granites and by dykes and sills of microgranite and dolerite. It is overlain by the Spencer Creek Group of the McArthur Basin, and by Cretaceous and Cenozoic sedimentary rocks and laterite. The complex has been given a peak metamorphic age of 1867 ± 12 Ma, on the basis of SHRIMP U-Pb zircon dating of a sample of Drimmie Head Granite (Rawlings *et al* 1997), and this corresponds to an interval of regional deformation and metamorphism (Nimbuwah Event) in the Pine Creek Orogen. A broad span of post-peak and retrograde metamorphism from 1855 to 1845 Ma is indicated by

Unit /Age	Lithology	Relationships	Diagnostic Features
ARNHEM INLIER			
Garrthalala Granite (P5) 1833 ± 3 Ma	Granite, medium- to fine-grained, porphyritic, massive, distinctive reddish brown weathered surface, composed of quartz, K-feldspar, plagioclase, fayalite and biotite; fine- to medium-grained white granite xenoliths.	Intrudes Bradshaw Complex, coeval with Bukudal Granite. Intruded by 1710 Ma rhyolite dykes.	K-feldspar megacrysts; fayalite-bearing. White xenoliths of thermally metamorphosed Bradshaw Complex.
Bukudal Granite (P5) 1837 ± 4 Ma	Granite, massive, white to pink, equigranular, medium- to coarse-grained, composed of quartz, K-feldspar, plagioclase, biotite and fayalite; locally sheared.	Intrudes Bradshaw Complex, coeval with Garrthalala Granite. Intruded by ca 1710 Ma rhyolite dykes.	Reddened spherical inclusions; fayalite-bearing.
Dhalinybuy Granite (P5)	Granite, pink to green, medium- to coarse-grained, equigranular to porphyritic, composed of quartz, K-feldspar and biotite; locally sheared and foliated, local mylonite.	Inferred to intrude the Bradshaw Complex; overlain unconformably by Spencer Creek Group. Intruded by dykes of Yanungbi Volcanics.	K-feldspar megacrysts; localised foliation and mylonite.
Giddy Granite (P5) 1836 ± 4 Ma	Granite, pink to grey, medium- to coarse- grained, massive, equigranular to porphyritic, composed of quartz, K-feldspar, plagioclase, biotite and fayalite; locally sheared.	Inferred to intrude the Bradshaw Complex. Inferred to be intruded by Latram Granite (1712 ± 10 Ma).	K-feldspar megacrysts; fayalite-bearing.
undivided Bradshaw Complex	A continuum of amphibolite-facies gneiss, migmatite, granitic gneiss and granite; fine- to coarse-grained, foliated to massive.	Intruded by Bukudal and Garrthalala granites.	Amphibolite-facies mineral assemblages.
Drimmie Head Granite (P4) 1867 ± 12 Ma	Leucogranite and granitic gneiss, medium- to coarse-grained, massive to foliated, composed of quartz, garnet, plagioclase, cordierite and K-feldspar; abundant enclaves including psammitic and pelitic gneiss, calc-silicate hornfels and mafic granulite.	Derived from and intruded into the Melville Bay Metamorphics.	Leucogranite; mafic granulite enclaves.
Melville Bay Metamorphics (P4)	Banded granulite, alternate dark pelitic layers and white felsic layers, medium- to coarse-grained with localised veins and pods of coarse-grained, garnetiferous leucogranite.	Intruded by Drimmie Head Granite.	Relict sedimentary layering; granulite facies assemblages.
Grindall Formation (P4)	Sandstone, red-brown to grey-green, fine to medium grained, thin to thick bedded, graded, interbedded with red-brown to grey-green mudstone.	Oldest known component of the Arnhem Inlier. Intruded by the granites of the Bradshaw Complex and Bukudal Granite.	Deformed and locally metamorphosed turbidite sequence.
MIRARRMINA INLIER			
Mirarrmina Complex (P4)	'Older' component: metasedimentary gneiss, migmatite, granite, minor cataclasite; mineral assemblage - garnet, quartz, orthoclase, biotite, plagioclase, cordierite and retrograde muscovite and sericite; commonly foliated. 'Younger' component: porphyritic microgranite, rhyolite, dolerite, minor hybrid rock.	'Older' high-grade metamorphic and anatectic rocks intruded by 'younger' felsic and mafic dykes. Probably unconformably overlain by Dhunganda Formation (Donydji Group).	Amphibolite facies assemblages; retrogressed along shear-zones to greenschist facies. Garnet-dominated.

Table 6.1. Summary of stratigraphic succession of Arnhem Province (after Rawlings *et al* 1997, Haines *et al* 1999). P4–P5 terminology after Ahmad (2000).

ages determined from lower-grade parts of the complex (Rawlings *et al* 1997).

Melville Bay Metamorphics

The Melville Bay Metamorphics occur in the northeast of the Arnhem Province on Bremer Island and Wargarpunda Point near Nhulunbuy (**Figure 6.2a**). They are intruded by irregular pods and veins of leucogranite of the Drimmie Head Granite (Rawlings *et al* 1997), and are overlain by Quaternary sediments and alluvium. The metamorphics consist mostly of banded garnetiferous granulite with alternate dark pelitic layers, and white felsic layers (**Figure 6.5**). The pelitic layers are medium- to coarse-grained and contain cordierite, garnet, sillimanite, K-feldspar, biotite and accessory spinel, magnetite, ilmenite, zircon, plagioclase and monazite. Felsic bands comprise either garnet, quartz, plagioclase, orthopyroxene, sillimanite, cordierite and K-feldspar, with accessory magnetite, biotite, ilmenite, zircon and spinel, or calcite, scapolite, quartz, clinopyroxene, wollastonite, plagioclase, sphene with accessory zircon, magnetite and monazite. These layers were referred to as 'quartzite' by Plumb and Roberts (1992), but are probably better described as metapsammite and calcsilicate rock (Rawlings *et al* 1997).

Pressure and temperature estimates for the Melville Bay Metamorphics have been determined to be in the ranges 700–750ºC and 4–5 kbar, respectively (IR Scrimgeour, NTGS, pers comm in Rawlings *et al* 1997).

Drimmie Head Granite

The Drimmie Head Granite is exposed as sheets and plutons around the Melville Bay area in the northeast of the Arnhem Province to the west of Nhulunbuy (**Figure 6.2a**). The granite intrudes the Melville Bay Metamorphics and is overlain by Cretaceous and Cenozoic sediments, and by Quaternary alluvium. It comprises garnetiferous leucogranite and granitic gneiss with abundant enclaves of granulite-facies metasedimentary and mafic rocks. The main rock type is a medium to coarse leucogranite, which consists of quartz, garnet, plagioclase, cordierite, K-feldspar and accessory magnetite, biotite and zircon. It is peraluminous, has a relatively narrow range in silica (68.19–73.92%) and is generally low in Fe_2O_3 (0.57–4.88%). The granite is massive for the most part, but local alignment of K-feldspar crystals does occur. Minor shear zones and extensive pegmatite zones are also present. The granitic gneiss is medium to coarse and can be distinguished from the granite by the presence of orthopyroxene and blocky sillimanite. It contains abundant schlieren, as well as metasedimentary and mafic enclaves (Rawlings *et al* 1997).

Pelitic enclaves comprise garnet, K-feldspar, cordierite, sillimanite, quartz, and accessory minerals. Calcsilicate and psammitic enclaves are equigranular, fine-grained and massive, and are petrologically similar to enclaves from the undivided Bradshaw Complex. Mafic enclaves are fine-to medium-grained and consist of orthopyroxene, clinopyroxene, plagioclase (bytownite), titanite and biotite (Rawlings *et al* 1997).

The Drimmie Head Granite is a syn-metamorphic leucogranite that was probably derived from the inhomogeneous melting of a metasedimentary protolith that included the Melville Bay Metamorphics (Rawlings *et al* 1997).

Figure 6.4. Migmatite gneiss of Bradshaw Complex showing anastomosing leucosome development (GOVE, CALEDON: (53L 687100mE, 8590300mN, small island southeast of Mount Alexander). Sledge hammer is 1 m long. Photo courtesy of DJ Rawlings (formerly NTGS).

Figure 6.3. Steeply dipping sandstone and mudstone beds at the Grindall Formation type section on eastern Morgan Island (BLUE MUD BAY, BLANE: (53L 619500mE, 8510300mN). Width of section is about 20 m. Photo courtesy of DJ Rawlings (formerly NTGS).

Figure 6.5. Layered granulite of Melville Bay Metamorphics exposed on beach at Gove near NABALCO processing plant (GOVE, GOVE: 53L 683600mE, 8652400mN). Lens cap is 5 cm in diameter. Photo courtesy of DJ Rawlings (formerly NTGS).

Undivided Bradshaw Complex

Undivided Bradshaw Complex forms an elongate northeast-trending belt in the east of the Arnhem Province in CALEDON and GOVE (**Figure 6.2a**) and consists of amphibolite-facies paragneiss, migmatitic gneiss, migmatite, granitic gneiss and granite (Rawlings *et al* 1997). It is intruded by the Bukudal and Garrthalala granites of the Giddy Suite (Budd *et al* 2002), and by dykes and sills of microgranite and dolerite. Undivided Bradshaw Complex is overlain by Cretaceous sedimentary rocks and by Cenozoic laterite.

Paragneiss occurs mostly as enclaves within migmatitic gneiss, granitic gneiss and granite. There is an apparent continuum between deformed paragneiss and migmatitic gneiss, defined by different degrees of partial melting. Migmatitic gneiss is characterised by an anastomosing compositional partitioning into leucosomes and melanosomes, and migmatite is mainly stromatic, although some may be nebulitic. Granitic gneiss is commonly deformed and contains abundant enclaves and schlieren. Enclaves are also common within migmatitic gneiss and granite, and include pelitic schist and gneiss, and calcsilicate (**Figure 6.6**), psammitic and mafic rocks. Granite is abundant in the complex and is mostly light to dark grey, medium to coarse grained, massive, and equigranular to porphyritic. Overall, the undivided Bradshaw Complex exhibits a mineralogy characterised by the presence of andalusite, sillimanite and cordierite, suggesting that it formed under Buchan-style metamorphic conditions (see Hietanan 1967) of low to moderate pressure and high temperature. Paragneiss, migmatite and granite are intimately associated, suggesting that the complex formed by heterogeneous melting of a sedimentary protolith (Rawlings *et al* 1997).

Mirarrmina Complex

The poorly exposed Mirarrmina Complex is distributed over a small area (<450 km^2) along the western margin of the Mitchell Ranges, centred on the Aboriginal community of Donydji in southwestern ARNHEM BAY and northwestern BLUE MUD BAY (**Figures 6.2b**, **6.7**). Rawlings *et al* (1997) and Haines *et al* (1999) described the complex as a composite unit comprising metamorphic and anatectic granitoid basement; intrusive equivalents of the Donydji Group; structurally intercalated strips of the Donydji and probably Parsons Range groups; and relatively young dolerite dykes. This structural complex thus incorporates elements of the McArthur Basin as well as basement rocks that are equivalent to those of the Arnhem Province. Rawlings *et al* (1997) further described the complex as occupying the sole thrust zone of the Mitchell-Flinders Thrust Belt (**Figure 6.2d**), a “north-northeast-trending region of thrust duplexes and imbricate stacks, separated by steep oblique ramps”, extending from northwestern BLUE MUD BAY to the Melville Bay area. This thrust belt is part of the Walker Fault Zone (see **McArthur Basin**) and was formed during D_2 (Plumb 1994), which is equivalent to the ‘Post-Nathan Shortening’ event of Haines *et al* (1999). The age of this deformation is poorly constrained between ca 1600 and ca 1430 Ma (Rawlings *et al* 1997). All components of the Mirarrmina Complex, except the younger dykes, have been overprinted by deformation related to this event. Deformational products range from weak to intense cataclasite or mylonite, in which almost all primary fabric has been destroyed. Basement rocks of the complex are presumed to be overlain unconformably by the Donydji Group, although the contact is not exposed.

Figure 6.6. Calcsilicate enclave within granitic gneiss of undivided Bradshaw Complex, cut by late stage pegmatite veins (GOVE, CALEDON: 53L 683300mE, 8586300mN; one of the Three Hummocks, a group of small islands southeast of Mount Alexander). Photo: DJ Rawlings (formerly NTGS).

Mirarrmina Complex basement rocks that are equivalent to the Bradshaw Complex comprise foliated metasedimentary rocks and granite gneiss. The metasedimentary rocks include an amphibolite-grade granofels that has been locally retrogressed to lower greenschist-grade quartz-sericite schist and phyllonite along shear zones. The granofels contains mineral assemblages that are consistent with those of the Bradshaw Complex to the east. Foliated gneiss and granite comprise porphyroblastic garnetiferous gneissic granite and granite gneiss, augen gneiss, banded gneiss and migmatite, and minor quartz monzonite and granodiorite. However, relationships between these rock types are obscured by poor exposure. The garnetiferous gneissic granite is distinctly S-type and resembles that of the coeval Bradshaw Complex. Compositionally, the gneiss and granite are quite uniform, consisting of microperthitic K-feldspar, quartz, biotite and garnet. Grainsize varies from medium to coarse, and fabrics range from massive to foliated, and equigranular to porphyroblastic. Rawlings *et al* (1997) interpreted the mineralogy of these basement rock types as representing an aluminous sedimentary protolith, which probably included equivalents of the Grindall Formation to the southeast and the PCO succession to the west. Metamorphism of these basement rocks is presumed to be equivalent to the peak metamorphic event effecting the Bradshaw Complex to the east (Rawlings *et al* 1997), which corresponds in age to the Nimbuwah Event in the Pine Creek Orogen.

The younger intrusive units of the Mirarrmina Complex include porphyritic rhyolite, megacrystic microgranite and dolerite/gabbro. Rhyolite and microgranite form the more resistant outcrop and occur as vertical dykes intruding the older gneiss and metasedimentary rocks. They are probably stratigraphically equivalent to the nearby Fagan Volcanics (Donydji Group).

SHRIMP U-Pb geochronology of zircons of anatectic basement rocks from the complex have yielded an interpreted metamorphic age of 1870 ± 8 Ma, similar to the age of the Bradshaw Complex, whereas the younger felsic intrusive rocks are dated at 1705 ± 10 Ma, similar to the age of the Fagan Volcanics (Rawlings *et al* 1997).

Giddy Suite

The Giddy Suite granites were emplaced after the main deformation and metamorphic event to effect the Arnhem Province and are essentially undeformed. They are correlated with the Cullen Supersuite in the PCO, but have little associated mineralisation. The granites have undergone fractionation to a high level of Rb content that reaches about 500 ppm at a SiO_2 concentration of 75%. Two granites (Giddy Granite and 'Caledon Granite') were originally differentiated by Dunnet (1965) and Plumb and Roberts (1992), but Rawlings *et al* (1997) revised this into four new units (Giddy, Garrthalala, Bukudal and Dhalinybuy granites). The first three are essentially coeval, with indistinguishable SHRIMP U-Pb zircon ages in the range 1833–1837 Ma (Rawlings *et al* 1997). The Dhalinybuy Granite is undated, but was regarded by Rawlings *et al* as being probably comagmatic (if not connected at depth) with the Giddy Granite. A minimum age for this granite of about 1710 Ma is given by an unconformable or nonconformable relationship with the overlying Yanungbi Volcanics of the Spencer Creek Group (basal McArthur Basin). These granites were all included in the Giddy Suite by Budd *et al* (2002).

Bukudal Granite

The Bukudal Granite intrudes the Bradshaw Complex and is a white to pink, fine to coarse, equigranular and massive granite. It is exposed over a wide area in the east of the Arnhem Province from BLANE to CALEDON, including a number of offshore islands (**Figure 6.2a**). The granite contains quartz (35-45%), K-feldspar (microcline and orthoclase) (35%), plagioclase (10%), biotite (5%) and garnet (10%), with minor fayalite, orthopyroxene, clinopyroxene and hornblende and accessory fluorite, spinel, magnetite, zircon and rutile. Secondary minerals include sericite, muscovite, chlorite and epidote. The Bukudal Granite has an SiO_2 range of 68.15–75.39% and is more felsic when compared to the Garrthalala Granite. It is low in Fe_2O_3 and CaO and high in K_2O, when compared to the Giddy and Garrthalala granites, and to average I-type granites with similar silica contents. In comparison to I-type granites, it is also high in Rb, Ba, La, Ce, Zr and Ga. A significant feature is the higher than normal Ga concentration, varying from 20 to 28 ppm (average 25 ppm).

Miarolitic cavities and granophyric intergrowths are common in the Bukudal Granite and are indicative of high-level emplacement. Petrological and geochemical data show that the granite has A-type affinities (Rawlings *et al* 1997).

Dhalinybuy Granite

The Dhalinybuy Granite is exposed as rounded tors and boulders of pink to green, medium to coarse, equigranular to porphyritic granite in a small area in eastern ARNHEM BAY (**Figure 6.2a**). It is inferred to intrude the Bradshaw Complex and is overlain by the Yanungbi Volcanics or Gove Sandstone of the Spencer Creek Group (McArthur Basin) and by Cenozoic sediments. There are also numerous

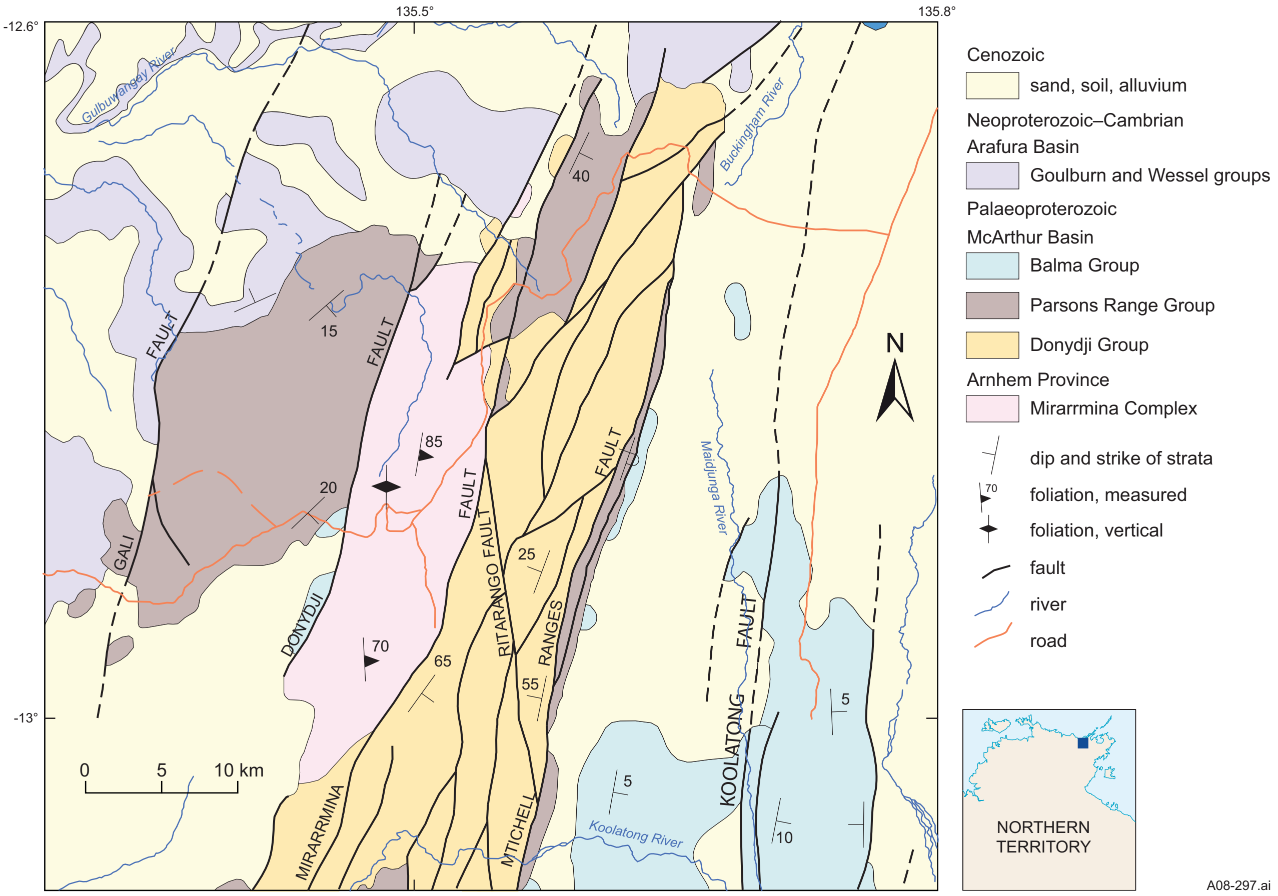

Figure 6.7. Geological map of the Mirarrmina Complex and surrounds (simplified from Pietsch *et al* 1997b). Location shown in **Figure 6.2d**.

shallow intrusions of fine-grained rhyolite of the Yanungbi Volcanics within the granite (Rawlings *et al* 1997).

The Dhalinybuy Granite is composed of K-feldspar (45%), quartz (40%) and intergranular pale to dark brown biotite (10%), with minor (<5%) plagioclase (albite-oligoclase). K-feldspar megacrysts up to 8 cm across occur locally. It is variably deformed, with textures ranging from massive (undeformed) to foliated (moderately deformed) to proto-mylonite (strongly deformed).

Giddy Granite

This is a coarse, porphyritic calc-alkaline granite with strong A-type affinities that outcrops in a small area in the northeastern Arnhem Province in GOVE (**Figure 6.2a**). It is overlain by Cretaceous sedimentary rocks, Cenozoic laterite and Quaternary alluvium, and is inferred to be intruded by the ca 1710 Ma Latram Granite (Rawlings *et al* 1997). The mineral assemblage includes quartz (40%), K-feldspar (30%), and plagioclase (10%), lesser (15%) biotite, amphibole, pyroxene and olivine (fayalite), and accessory (5%) garnet (almandine), magnetite, zircon and fluorite. Secondary minerals include chlorite, muscovite, rutile and biotite. K-feldspar megacrysts up to 20 cm across are commonly present and ferromagnesian minerals are scattered randomly throughout the rock.

The SiO_2 content of the Giddy Granite varies from 66.01 to 74.83% (average 71.9%), which is noticeably higher than that of the Garrthalala Granite. The Al_2O_3 content varies from 11.48 to 14.25% (average 12.7%), which is the lowest value recorded from granites in the Arnhem Province. The concentration of Fe_2O_3 is moderate, ranging from 2.39 to 5.11%. CaO and Na_2O are low and are related to the low abundances of calcite and plagioclase. K_2O is high (5.19–7.16%, average 6.41%), which may be an affect of K-metasomatism. Aluminum Saturation Index (ASI) values straddle the metaluminous–peraluminous boundary (Rawlings *et al* 1997).

The Giddy Granite is intruded by a series of pink to red microgranite dykes that are correlated with dykes intruding the Garrthalala and Bukudal granites. It is mainly massive, though zones of localised shearing have produced a very weak alignment of minerals. The granite lacks xenoliths or pegmatite. It has been dated at 1836 ± 4 Ma by SHRIMP U-Pb zircon geochronology (Rawlings *et al* 1997).

Garrthalala Granite

The Garrthalala Granite is a medium to fine, porphyritic, fayalite-bearing and massive granite that forms an east–west-trending pluton in western CALEDON. It is exposed as smooth boulders, pavements and irregular bare sheets, small knolls and islands, and has a distinctive red-brown weathered surface. The granite contains abundant xenoliths of fine to medium white granite that are interpreted to be thermally metamorphosed Bradshaw Complex. It also contains common metasedimentary enclaves, including biotite schist and calcsilicate.

Fresh Garrthalala Granite is composed of quartz (30%), K-feldspar (30–40%), plagioclase (5–20%), olivine, clinopyroxene, orthopyroxene and biotite (5–30%), with accessory magnetite, ilmenite, rutile, allanite, zircon, apatite and fluorite. Secondary minerals include muscovite, epidote, chlorite, iddingsite and calcite. Olivine (fayalite) phenocrysts exhibit characteristic fractures and are partially replaced by iddingsite (Rawlings *et al* 1997).

The granite is characterised by a narrow SiO_2 range (66.11–68.38%). Fe_2O_3 is consistently higher (4.39–7.97%, average 6.57%) and Al_2O_3 and ASI values are lower than in other plutons in the area, resulting in a metaluminous character. Another significant geochemical feature is a high concentration of CaO (average 2.31%). The granite is high in Ba, Sr, La, Ce, Y and Zr and is low in Rb and U, relative to average I-type granites with similar silica contents. It also has a higher than 'normal' concentration of Ga (21 – 28 ppm).

The Garrthalala Granite intrudes the Bradshaw Complex and has a sharp (?intrusive) contact with the broadly contemporaneous Bukudal Granite. It is intruded by red-coloured microgranite, aplite and rhyolite sills and dykes, which are probably contemporaneous with those that intrude the Bukudal and Giddy granites. The Garrthalala Granite has been dated at 1833 ± 3 Ma by SHRIMP U-Pb zircon geochronology (Rawlings *et al* 1997).

MINERAL RESOURCES

There are no known mineral occurrences in the Arnhem Province. Some regional reconnaissance exploration for base metals and uranium, conducted in the late 1960s included parts of the Arnhem Province, but was mainly focused on the McArthur Basin and younger successions. Major exploration in the area has been for manganese and bauxite in the overlying Phanerozoic strata and two world-class deposits (Gove and Groote Eylandt) are currently in production (see **Carpentaria Basin**).

The Giddy Suite is considered to have some potential for Sn, W, Mo and Ta deposits (Budd *et al* 2002). Mineralisation might be hosted by S-type granites and their aureoles, as is indicated by the presence of cassiterite in heavy-mineral sand assemblages, including 0.25 and 0.27% cassiterite in heavy mineral concentrates from Cato River and Wonga Creek (Chestnut *et al* 1966).

Budd *et al* (2002) considered their 'Bradshaw Suite' to be too restite-rich to have any metallogenic implications and there is little evidence of fractionation.

Most of the Arnhem Province is currently under application by BHP Billiton Ltd or Rio Tinto Ltd and their subsidiaries.

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