

Geology and mineral resources of the Northern Territory

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Chapter 4: Archaean

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Chapter 4: ARCHAEAN

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INTRODUCTION

Neoarchaean granite, gneiss and metasedimentary rocks occur as small inliers in the Pine Creek Orogen (PCO) and Tanami Region (**Figure 4.1**). A major unconformity separates the Archaean rocks from overlying Palaeoproterozoic strata at Rum Jungle, but at other locations, this contact is either faulted or under cover. Archaean rocks have not been identified in other geological regions of the Northern Territory; however, detrital zircons from almost all of the geological regions of the North Australian Craton (NAC) show an Archaean inheritance, indicating the presence of widespread Archaean hinterlands in the Palaeoproterozoic.

PINE CREEK OROGEN

In the PCO, Neoarchaean rocks are exposed at the westernmost margin of the Central Domain and also in the Nimbuwah Domain (**Figure 4.2**) to the east. They include the Rum Jungle Complex near Batchelor township (Rhodes 1965, Lally 2002), the Nanambu Complex near Jabiru (Needham 1984, 1988), and the Kukalak Gneiss and Arrarra Gneiss (Hollis *et al* 2009b). They also include the subsurface Woolner Granite, which has been intersected in drill core under Cretaceous cover (at about 40–120 m depth) in the Money Shoal Basin, approximately 60 km east of Darwin.

Rum Jungle Complex

The Rum Jungle Complex is located in the western part of the Central Domain of the PCO (**Figure 4.2**). It was first defined by Rhodes (1965) to include granitic rocks, metasedimentary schist, gneiss and banded ironstone exposed north of Batchelor township over an area of about 230 km². Johnson (1974) used the term Waterhouse Complex for similar rocks exposed in an oval-shaped area (130 km²) about 5 km to the south and separated by the Giants Reef Fault (**Figure 4.3**). Lally (2002) extended the term 'Rum Jungle Complex' to describe the rocks within both areas, and proposed that the terms Rum Jungle Dome and Waterhouse Dome be used to describe the geographical entities.

The oval shapes of these complexes and updoming of the surrounding sedimentary rocks have been variously explained. Rhodes (1965) suggested that the Rum Jungle Dome represent a mantled gneiss dome (*sensu* Eskola 1949), comprising a gneissic core with overlying younger strata. Stephansson and Johnson (1976) considered that, in the case of both the Rum Jungle and Waterhouse domes, the intrusion of Palaeoproterozoic granitoids caused the doming. Johnston (1984) interpreted the doming and oval shape to be the result of non-cylindrical folding, modified by fold interference and late faulting.

Originally, the Rum Jungle rocks were subdivided by Rhodes (1965) into six units. More recently, Lally (2002) informally subdivided igneous rocks in the area into fifteen different granite units based on a combination of outcrop, aeromagnetic, gravity and radiometric data. These include

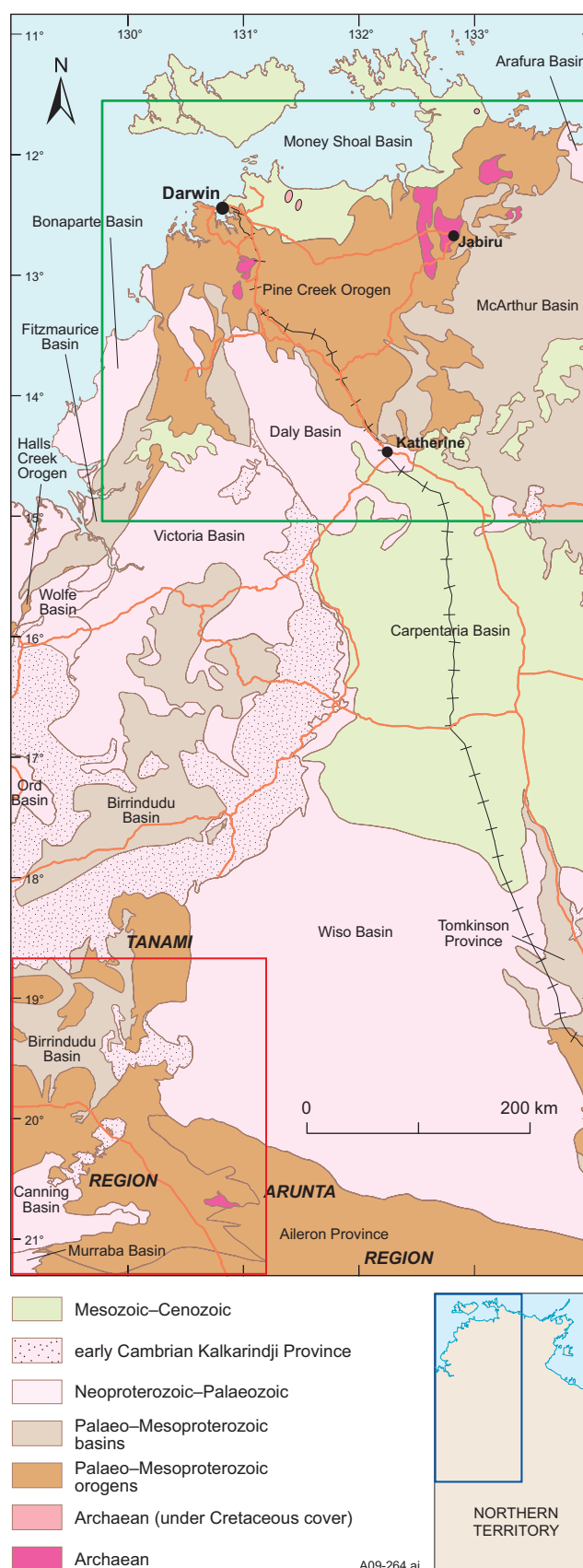


Figure 4.1. Distribution of Archaean rocks in the Northern Territory. NT geological regions from NTGS 1:2.5M geological regions GIS dataset. Green and red boxes show locations of **Figures 4.2** and **4.8**, respectively.

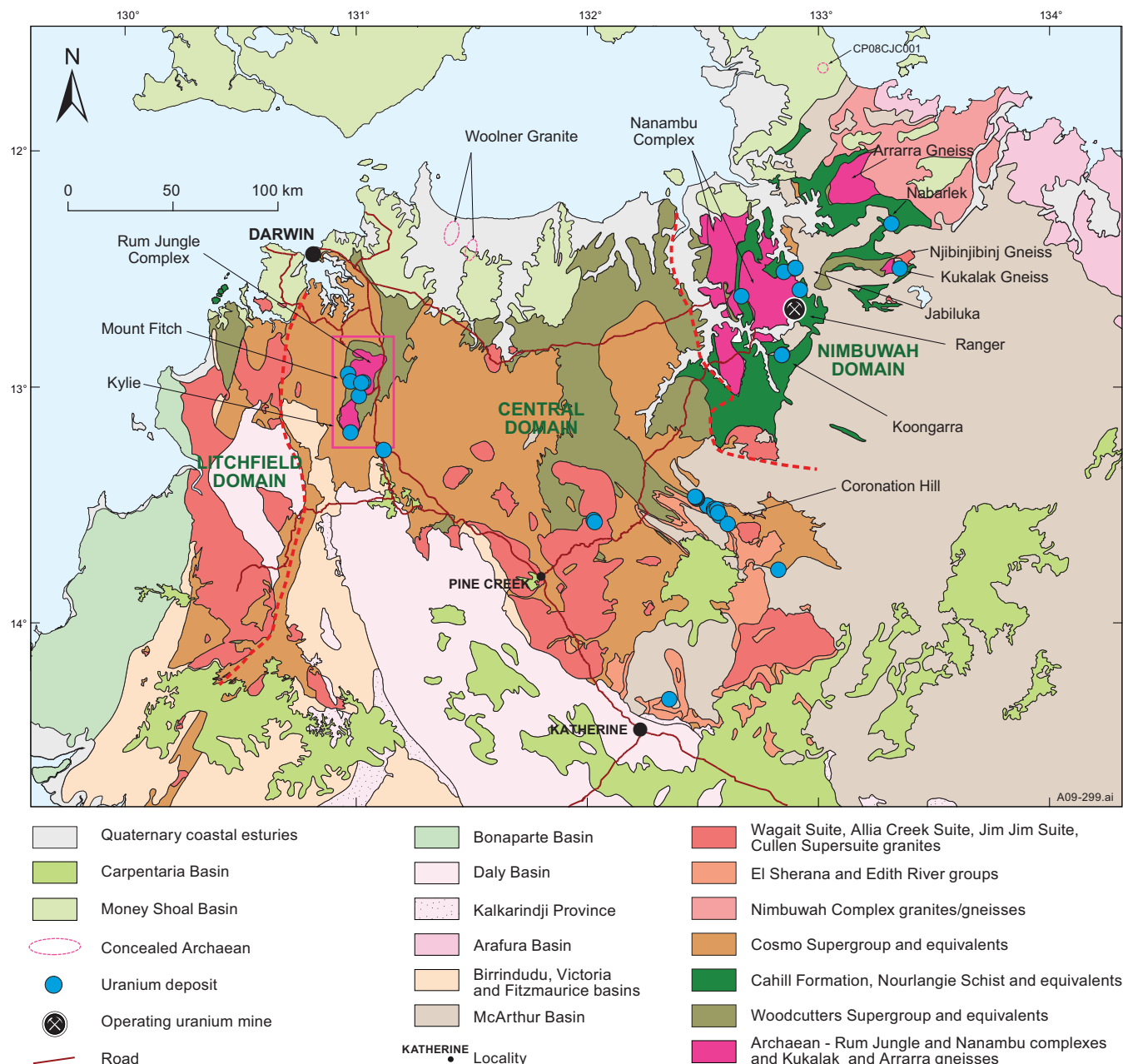


Figure 4.2. Interpreted distribution of Archaean rocks in the Pine Creek Orogen and adjacent areas. Outcrop in western Arnhem Land is largely under shallow cover. Mesoproterozoic to Mesozoic cover successions are indicated. Approximate locations of major uranium deposits within PCO are shown. Red box shows location of Rum Jungle Mineral Field (**Figure 4.3**).

granite gneiss, metadiorite, and a wide variety of granite types intruded by pegmatites, dolerite and quartz tourmaline veins. The latter are more extensive along the margins of the domes. Granite gneiss is medium grained, non-porphyritic and ranges from foliated to homogeneous in composition. It comprises microcline, quartz, oligoclase, biotite, muscovite, and accessory apatite, fluorite and zircon. Rhodes (1965) considered it to be older than the other granitic phases. The metadiorite has a small areal extent and is intruded by younger leucocratic granite. It is dark grey, fine to medium grained and massive, and is composed of biotite with minor epidote, titanite and magnetite. The leucocratic granite is a fine to medium grained, equigranular, pink-grey quartz monzonite, which is pegmatitic and aplitic in places. It consists of microcline, quartz, albite, biotite and minor muscovite. Accessory minerals include apatite, magnetite, fluorite, zircon and rare epidote. A coarser-grained granite,

which is pink, leucocratic, massive and evenly grained, is older than the leucocratic granite as is shown by veins of the latter occurring within it. It has a gradational relationship (Rhodes 1965) with a coarse-grained feldspar granite, which comprises microcline, quartz, plagioclase, biotite and common accessory fluorite. Pale blue opalescent quartz is characteristic. High-K granitoids in the Rum Jungle Complex, as described by Drüppel *et al* (2009), are subdivided into two groups: (1) felsic granites; and (2) intermediate to felsic granites, quartz monzonite and diorite. Compared to average upper crust, these high-K granitoids have anomalously high Th (up to 123 ppm) and high U (up to 40 ppm; Drüppel *et al* 2009).

A wide variety of rock types are represented in these granites, ranging from quartz syenite and quartz monzonite to more acidic alkali granite and syenogranite. The normative corundum content of the samples varies from 0 to

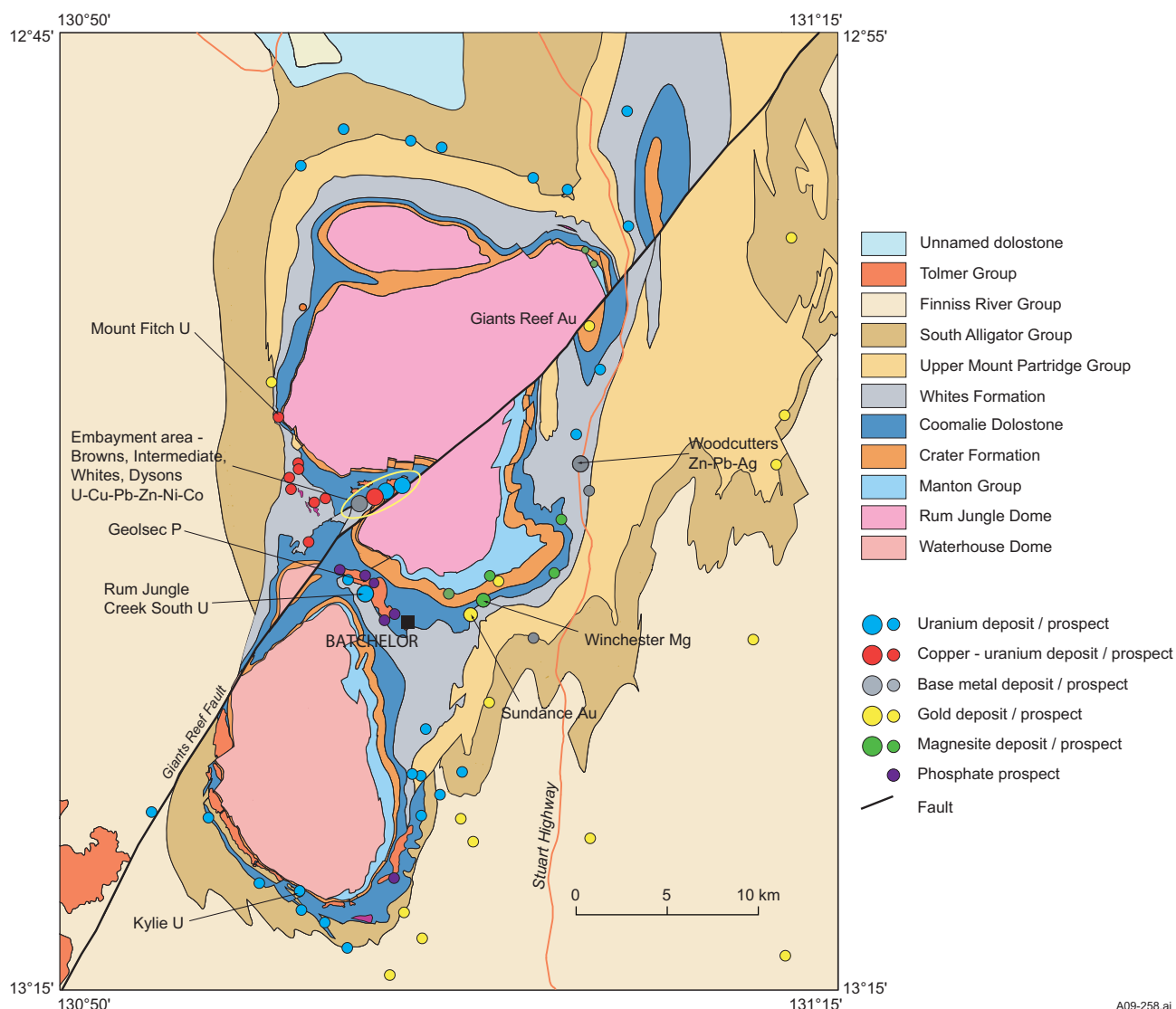


Figure 4.3. Geological map showing distribution of Archaeon Rum Jungle Complex (Rum Jungle and Waterhouse domes) in western Pine Creek Orogen. Commodity locations in overlying Pine Creek Orogen succession are shown for reference (modified from Lally 2002). Location shown in **Figure 4.2**.

3.15%. Where corundum is absent, diopside occurs. Both I- and S-type granites are present. I-type granites have a pristine mineral assemblage that includes quartz, two feldspars, biotite $\pm$ hornblende $\pm$ titanite $\pm$ allanite $\pm$ zircon. S-type granites do not contain hornblende or allanite, but may include any or all of the following minerals: garnet, muscovite, cordierite and sillimanite. Several samples of granites have been analysed for major, trace and rare earth elements. Discussions of geochemical data have been provided in previous studies (Ferguson *et al* 1980, McCready *et al* 2003). These particular granitic rocks also have higher than average uranium contents (average 11 ppm), compared with an average crustal abundance of 4.8 ppm in granitoids. S-type phases have relatively higher uranium concentrations than I-type. McCready *et al* (2003) noted the presence of U/Th-rich bitumen in Archaeon granitic phases and overlying Palaeoproterozoic black shale. In granite, this bitumen is present as small (up to 400 μ m diameter), discrete individual nodules. In the black shale, it occurs as veins and elongated seams. Both bitumen varieties are likely to postdate metamorphism (ie, postdate central Pine Creek Orogen greenschist-facies metamorphism at ≤ 1855 Ma, see **Pine Creek Orogen**).

The contact between the Rum Jungle Complex and overlying Palaeoproterozoic sedimentary rocks is clearly unconformable. It is best exposed about 5 km northwest of Batchelor township along the road to the Rum Jungle mine. There, granitic rocks are unconformably overlain by the basal conglomerate of the Beestons Formation, which incorporates mineral grains derived from the basement and sub-angular pebbles of milky quartz pebbles (**Figure 4.4**).

Lally (2002) discussed the structural history of the Rum Jungle Complex prior to deposition of the PCO succession. The Rum Jungle Complex has an east-west to northwest-southeast trend, which is reflected by the strike of foliation (Rhodes 1965). At least two deformational events are documented in the Rum Jungle Complex before Palaeoproterozoic sedimentation commenced. This is evidenced by two foliations preserved in quartz-biotite and quartz-amphibole schist enclaves near Mount Fitch: an early east-west-striking schistosity and an overprinting crenulation cleavage striking 060° . Within BIF outcrops in the northeast of the Rum Jungle Dome, a bedding-parallel foliation, axial planar to rare isoclinal folds, is present. Several shear zones mapped within the basement complexes also do not appear to correspond to faults or folds in the

overlying succession. They are considered to be pre-Manton Group deformation structures and some mark the boundaries between geophysical subdivisions of the complexes. Further evidence of an earlier deformation is provided by tightly refolded folds that are preserved in clasts in metasedimentary rocks of the Beestons and Crater formations (Johnston 1984).

Cross *et al* (2005) determined SHRIMP U-Pb zircon ages for three granites and one diorite from the Rum Jungle Dome, and for two granites from the Waterhouse Dome. All samples from the Rum Jungle Dome yielded magmatic crystallisation ages in the range 2534–2521 Ma, whereas the Waterhouse Dome samples yielded similar ages of 2545 and 2535 Ma. This is reasonably consistent with the conventional U-Pb results of Richards *et al* (1966) for three samples of granites from the Rum Jungle Complex. These included leucocratic granite, coarse-grained feldspar granite and granite gneiss that gave an extrapolated age of 2550 Ma. Richards *et al* (1977) determined a whole rock Rb-Sr age on the leucocratic granite of 2400 Ma. This may reflect the effects of a younger, but poorly-constrained disturbance of the U-Pb isotopic system in the Palaeoproterozoic, as is indicated in several samples by the occurrence of young, in some cases, high-U zircon grains or their rims, of inferred metamorphic origin (Cross *et al* 2005). At the exposed unconformable contact of the Rum Jungle Complex and the Beestons Formation (see above), the granite yielded a SHRIMP U-Pb crystallisation age of 2525 ± 5 Ma, which is very similar to the dominant detrital zircon age peak of ca 2535 Ma from unconformably overlying arkose of the Beestons Formation (Cross *et al* 2005). This is consistent with the derivation of the lowermost Palaeoproterozoic stratigraphic succession in that area from immediately underlying Neoarchaeon source rocks. Inherited zircons in a Neoarchaeon granitic sample, as documented by Drüppel *et al* (2009), yielded ages of ca 3535 Ma. They suggested that these older zircons imply crustal recycling of an older component to the North Australian Craton.

Stanley Metamorphics

Granitic rocks of the Rum Jungle Complex intrude older Archaeon metasedimentary rocks of the Stanley



Figure 4.4. Unconformable contact of Beestons Formation angular quartz pebble conglomerate (above white dashed line) on Rum Jungle Complex granite (below white dashed line; BATCHELOR¹: 52L 718270mE, 8559490mN).

¹ Names of 1:250 000 and 1:100 000 mapsheets are in large and small capital letters, respectively, eg GORDON DOWNS, BATCHELOR.

Metamorphics (Lally 2002, Ahmad *et al* 2006). They represent the oldest known sedimentary rocks within the North Australian Craton, as they predate granitoids of the Rum Jungle Complex and are unconformably overlain by the Beestons Formation. They form scattered outcrops mostly in the central eastern side of the Rum Jungle Dome; however, large inclusions of schistose material are found in younger granites of the Rum Jungle Complex. In the Rum Jungle and Waterhouse domes, common metamorphic rock types are biotite gneiss, biotite-muscovite gneiss, biotite granofels, feldspathic gneiss, quartz-muscovite schist, chlorite schist, actinolite schist and banded ironstone. Quartz, microcline, plagioclase, biotite and muscovite are common minerals. Based on the presence of oligoclase, Rhodes (1965) suggested a metamorphic grade of almandine-amphibolite facies. Lally (2002) suggested that the schist and gneiss were probably derived from sedimentary precursors. The Stanley Metamorphics are thought to correlate with the Dirty Water Metamorphics which overlie ca 2674 Ma Woolner Granite (Williams and Compston 1983, Glass *et al* 2010).

Woolner Granite

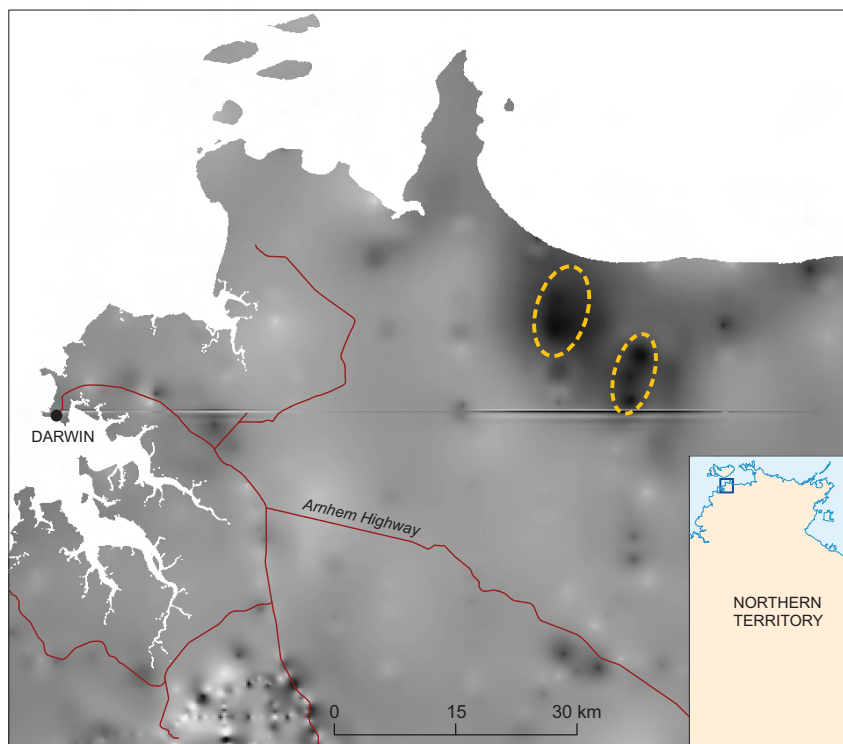
The Woolner Granite comprises two dome-shaped granitic bodies concealed beneath a 40–120 m-thick cover of Cenozoic and Cretaceous strata (Pietsch 1985, **Figures 4.1, 4.2**). The granites have been intersected in drill core and are coincident with pronounced gravity lows (Perring and Farrar 1980, **Figure 4.5**). The total areal extent of the granite is probably about 170 km² (Pietsch 1985). Three granite varieties have been identified: (1) foliated and gneissic, red-brown and grey, albitised biotite granite; (2) grey muscovite biotite granite; and (3) pink muscovite-biotite-orthoclase granite. Pegmatite intrusions are more common in the gneissic variety. The Woolner Granite is overlain unconformably by the Dirty Water Metamorphics and Koolpinyah Dolostone.

The Woolner Granite was originally dated by SHRIMP U-Pb in the 1980s, prior to the availability of cathodoluminescence imaging techniques. The age data was based on four samples of granite, derived from drill core. Zircons from two of these samples yielded ages of 2660 ± 20 Ma and 2690 ± 20 Ma. The best estimate of the age for these samples is 2675 ± 14 Ma. Zircons from the other two samples contained high proportions of non-radiogenic lead and were not suitable for precise age determinations (Williams and Compston 1983). More recently, Glass *et al* (2010) reported a much more precise SHRIMP U-Pb zircon age of 2674 ± 3 Ma validating the earlier data and confirming this as the oldest known rock in the Northern Territory.

Dirty Water Metamorphics

The Dirty Water Metamorphics overlie the Woolner Granite with an apparent unconformity (Pietsch and Stuart-Smith 1987) as ascertained from drillhole data. They are not exposed at the surface and are under 40–120 m of Cretaceous and Cenozoic cover. The metamorphic rocks have been informally divided into upper and lower members: the lower member comprises quartz-feldspar-biotite gneiss, quartz-feldspar-mica gneiss with subordinate meta-arkose

Figure 4.5. Gravity high-pass image highlighting gravity lows that define Archaean Woolner Granite under Cenozoic and Cretaceous cover. Gold dotted ellipsoids show interpreted distribution of concealed granite.



and quartzite, minor hornblende schist and quartz-biotite gneiss; the upper member includes chlorite-quartz-calcite schist, graphite-mica-quartz-calcite schist, magnetite-chlorite-quartz-calcite schist, hornblende-biotite schist, quartz-chlorite schist, banded magnetite-calcite-pyrite metaquartzite and dolomitic marble. The boundary between the two members is gradational and Pietsch and Stuart-Smith (1987) suggested it may represent a transgression from shallow- to deeper-water sediment deposition. Both members are unconformably overlain by the Mount Partridge Group.

The age of the Dirty Water Metamorphics is uncertain. Pietsch and Stuart-Smith (1987) considered these rocks to be younger than the Woolner Granite and therefore younger than 2674 Ma. They are older than the Mount Partridge Group, the stratigraphic age of which is constrained by recent SHRIMP zircon U-Pb data from tuffaceous rocks of the Wildman Siltstone to be 2019 ± 4 Ma (Worden *et al* 2008a, b). It is likely that the Dirty Water Metamorphics are correlatives of the Stanley Metamorphics, which were intruded by the ca 2535–2520 Ma Rum Jungle Complex; they were therefore likely to have been deposited between 2674 Ma and 2520 Ma.

Nanambu Complex

The Nanambu Complex occurs as three elongated to oval-shaped domes to the west of Jabiru in the Nimbuwah Domain and is exposed over a total area of about 1800 km² (Figure 4.2). These domes are referred to as the Magela, Jim Jim and Munmarlary masses (Needham 1988). Another subcropping area, confirmed by drilling, occurs to the west of Jabiluka. The rocks of the Nanambu Complex are predominantly granite or granitic gneiss (Figure 4.6), with minor amphibolite. A steeply dipping north-northwest-trending foliation is preserved in rocks in the centre of



Figure 4.6. Foliated biotite feldspar augen gneiss of Nanambu Complex (CAHILL: 53L 233221mE 8602546mN).

the complex (Johnston 1984), in contrast to a more gently dipping foliation at the margins.

On the basis of lithology and metamorphism, Needham (1988) divided the rocks of the Nanambu Complex into metamorphosed and unmetamorphosed granites. The metamorphosed granites (almandine amphibolite facies) represent strongly foliated granite and augen orthogneiss. Essential minerals include either quartz or K-feldspar, or both, and biotite. Muscovite may be present, but is subordinate to biotite, and almandine is a rare accessory. The unmetamorphosed granite is massive, foliated, white to light grey and medium- to coarse-grained. It comprises quartz, microcline, plagioclase and biotite, with accessory muscovite. Conventional (TIMS) U-Pb zircon and whole-rock Rb-Sr dating of a granitic gneiss from ca 3 km south of Jabiluka, gave an upper intercept age of $2470 \pm 47/-40$ Ma (Page *et al* 1980). However, high zircon U contents and indications of more than one episode of Pb loss add

complexity to the interpretation of the data. It is possible that the 2470 Ma zircon age is the product of partial resetting of the U-Pb isotopic system during ca 1865 Ma metamorphism, which is constrained by the U-Pb age of a monazite from the same rock. Other samples of the Nanambu Complex have yielded much younger whole rock and mica Rb-Sr ages of between 1980 and 1880 Ma, attributed to incomplete isotopic resetting during metamorphism (Page *et al* 1980). However, recent U-Pb SHRIMP zircon dating of a porphyritic granitic gneiss of the Nanambu Complex yielded a magmatic crystallisation age of 2520 ± 3 Ma (Hollis *et al* 2009b).

Njibinjibinj, Arrarra and Kukalak gneisses

Widespread Neoarchean basement in western Arnhem Land, (**Figures 4.1, 4.2**), has been identified on the basis of field mapping criteria and SHRIMP U-Pb zircon age data (Hollis *et al* 2008, 2009a, b). Metamorphosed basement to the Kombolgie Subgroup at the base of the McArthur Basin is well exposed in the Myra Falls and Caramal inliers, and is sporadically exposed further north in OENPELLI. This metamorphosed basement is comprised of amphibolite-facies psammitic and pelitic rocks of the Palaeoproterozoic Kakadu Group and Cahill Formation, and intrusive Nimbuwah Complex granites and felsic gneiss. However, located in the eastern part of the Myra Falls Inlier and structurally underlying the Kakadu Group, are multiply deformed, layered, biotite quartzofeldspathic gneisses (**Figure 4.7a**) with subordinate discontinuous amphibolite and muscovite-bearing pelitic layers and pods (Needham 1984, Hollis *et al* 2008, 2009b). Similar layered quartzofeldspathic gneiss with lesser amphibolite is also exposed further east in the Caramel Inlier (Hollis *et al* 2008, 2009b). Historically, these quartzofeldspathic gneisses were mapped as the Myra Falls Metamorphics (Needham 1984). However, textures in low-strain zones indicate they have a magmatic origin (**Figure 4.7b**) and, based on their tectonostratigraphic position beneath the Kakadu Group, the gneisses are interpreted to be basement to the Palaeoproterozoic strata. This interpretation is further reinforced by SHRIMP U-Pb zircon geochronology on quartzofeldspathic gneisses in western Arnhem Land, which yielded magmatic crystallisation ages of 2510 ± 4 Ma from the Caramal Inlier and 2527 ± 3 Ma from the Myra Falls Inlier (Hollis *et al* 2008, 2009a, b). A third sample of layered quartzofeldspathic gneiss, from drill core below

Cretaceous cover northwest of WELLINGTON RANGE on the Cobourg Peninsula, yielded a magmatic crystallisation age of 2513 ± 14 Ma (Hollis *et al* 2008, 2009a, b) confirming that Neoarchean basement extends far to the north beneath the Proterozoic McArthur Basin and Cretaceous Money Shoal Basin. Collectively, these ca 2500 Ma Neoarchean rock units within the Nimbuwah Domain have been called the *Kukalak Gneiss* (Hollis *et al* 2009b). Additional U-Pb SHRIMP zircon dating (Hollis *et al* 2009a, b) for quartzofeldspathic gneiss from the northeastern Myra Falls Inlier, yielded a magmatic crystallisation age of 2671 ± 3 Ma. This is the oldest known *exposed* basement in the Northern Territory and is named the *Njibinjibinj Gneiss* (Hollis and Glass 2012). Further to the north, U-Pb SHRIMP zircon results for a felsic gneiss beneath incised, shallow Cenozoic cover, ca 14 km northeast of Oenpelli township, yielded a magmatic crystallisation age of 2640 ± 4 Ma, with metamorphic zircon rim growth/recrystallisation at 2498 ± 14 Ma (Hollis *et al* 2009a, b). This latter age is consistent with the results of Worden *et al* (2006), who reported a magmatic crystallisation age of 2634 ± 3 Ma with metamorphic zircon growth at 2473 ± 12 Ma for a leucocratic gneiss from drill core in the same vicinity. These have been formally named as the *Arrarra Gneiss* (Hollis *et al* 2009a, b).

The magmatic crystallisation ages (ca 2670–2635 Ma and 2530–2510 Ma) that have been obtained for quartzofeldspathic gneisses from Arnhem Land are consistent with those of the Woolner Granite and Rum Jungle Complex, respectively, and imply a continuity of Neoarchean crystalline basement beneath the Palaeoproterozoic metasedimentary successions over at least 260 km across the Pine Creek Orogen (Hollis *et al* 2009a, b). However, Neoarchean basement to the east of Jabiru is typically gneissic rather than granitic and contains fabrics that preserve evidence of multiple ductile deformation events, features that are not recognised in the Woolner Granite and the Rum Jungle Complex.

It is also noteworthy that Neoarchean zircon is a significant component in the detrital zircon spectra of the metasedimentary rocks of the overlying Palaeoproterozoic strata, indicating that these rocks were probably derived from the erosion of underlying Neoarchean basement (Cross *et al* 2005, Worden *et al* 2004, 2006, 2008a, Hollis *et al* 2008, 2009a, Carson *et al* 2009). Zircons of Neoarchean age are also a common detrital component in metasedimentary Palaeoproterozoic units across much of the North Australian Craton, implying that the extent of unexposed Neoarchean

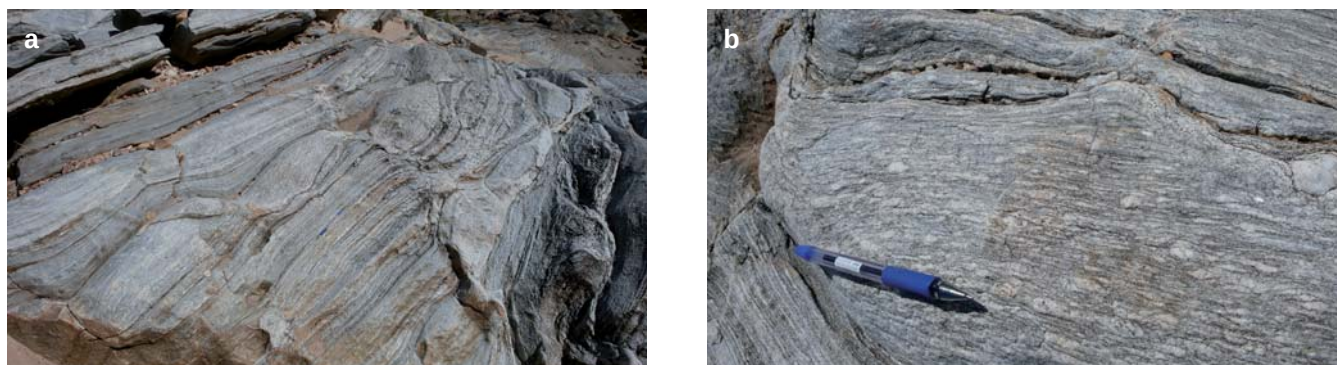


Figure 4.7. Biotite granodioritic gneiss from Myra Falls Inlier, west Arnhem Land (OENPELLI: 53L 318354mE, 8622428mN). (a) Strong S_2 gneissosity and heterogeneous ductile deformation, including boudinage. Individual boudins are ca 50 cm long. Field of view ca 3 m. (b) Low-strain domain within D_2 boudin showing relict feldspar phenocrysts consistent with a magmatic precursor.

crystalline basement may be much greater than the presently recognised areas.

TANAMI REGION

In the Tanami Region, an area of rocks interpreted to comprise Archaean material occurs approximately 70 km southeast of Rabbit Flat at the Billabong Complex (Page *et al* 1995, Crispe *et al* 2005, Crispe *et al* 2007, **Figure 4.8**). Surface exposure is very limited, but interpretation of geophysical data indicates the Billabong Complex extends undercover across a relatively large area of approximately 200 km².

Granite, gneiss and metamorphic rocks of the Browns Range Metamorphics form a crescent-shaped belt along the southern edge of the Browns Range Inlier (previously referred to as Browns Range Dome, **Figure 4.8**) in GORDON DOWNS (Western Australia) and TANAMI (Blake *et al* 1979). These rocks were considered by early workers to be Archaean in age, based in part on geochronological data that included an Archaean component (2510 ± 22 Ma; Page *et al* 1995). Subsequent reinvestigation of the southern margin of the inlier suggests that these rocks are more likely

to be Palaeoproterozoic in age and the Archaean ages are now interpreted to represent an inherited zircon population (Cross and Crispe 2007, Vandenberg *et al* in prep a).

Billabong Complex

The name Billabong Complex was given by Page *et al* (1995) to an area of Neoarchaean felsic gneiss immediately southwest of De Bavay Hills in the Tanami Region. Outcrop is limited to a few small tors and pavements of banded quartz-feldspar-biotite-tourmaline gneissic granite, phenocrystic feldspar-quartz-biotite gneissic granite, thin quartz-feldspar-rich leucocratic bands and associated mica-rich melanosomes (**Figure 4.9**). U-Pb SHRIMP dating of zircons has yielded a crystallisation age of 2514 ± 3 Ma, but there are also two populations of older inherited zircons aged ca 2550 and 2530 Ma (Page *et al* 1995). The ages of inherited zircon in Palaeoproterozoic granites and metasediments in the region suggests that Archaean gneiss is a major component of the underlying basement. The metamorphic grade (amphibolite facies) of the gneissic granite contrasts with that of the nearby greenschist-facies Tanami Group (Vandenberg *et al* in prep b).

GEOCHEMISTRY

Neoarchaean granitoids and gneisses from the Nimbuwah Domain in the PCO (Arrarra Gneiss, Nanambu Complex and Kukalak Gneiss) have a distinctive chemistry that allows them in general to be distinguished from the younger Palaeoproterozoic Nimbuwah Complex (Glass *et al* 2009). They are strongly fractionated (**Figure 4.10**); ie, they have steeply sloping, chondrite-normalised Rare Earth Elements (REE) patterns, showing enrichment in the Light Rare Earth Elements (LREE) and strong depletion in the Heavy Rare Earth Elements (HREE). Silica values are in general consistently higher than Palaeoproterozoic suites and range from ca 65 to 78 wt% SiO₂. They are dominantly monzogranite to granodiorite in composition. Based on the ASI index of Peacock (1931), the Archaean granites and gneisses are calc-alkalic to alkalic-calcic. Nd isotope data (Glass *et al* 2009) show that the ca 2500 Ma Neoarchaean suites are consistently close to Bulk Earth, with ϵ_{Nd} ranging from -0.1 to -0.7.

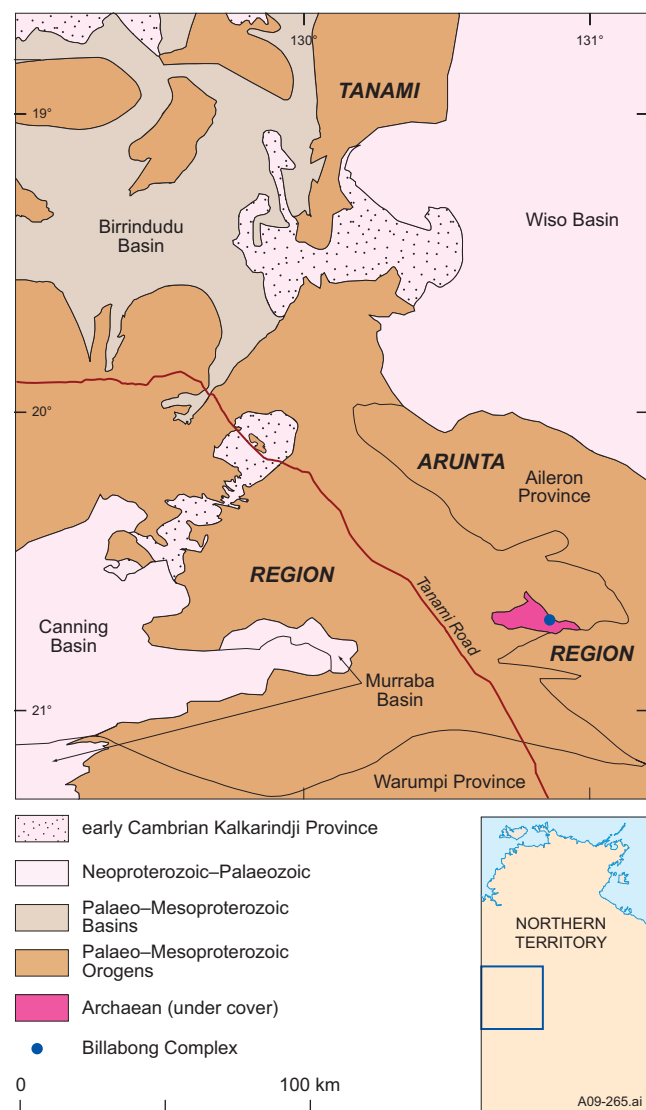


Figure 4.8. Distribution of Archaean rocks in Tanami Region. NT geological regions from NTGS 1:2.5M geological regions GIS dataset.

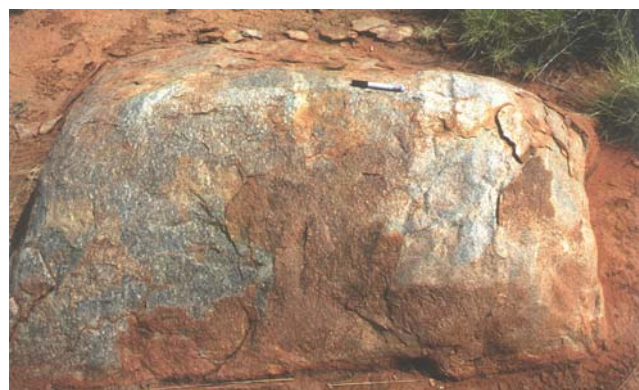


Figure 4.9. Billabong Complex. Dark grey, fine- to medium-grained, non-porphyritic feldspar-quartz-biotite ± amphibole (± chlorite) gneissic granite is crosscut by coarser-grained, light-coloured and less-deformed, porphyritic to non-porphyritic feldspar-quartz-biotite gneissic granite (GIBBESMURRAY: 52K 694750mE 7712612mN, photo Leon Vandenberg NTGS).

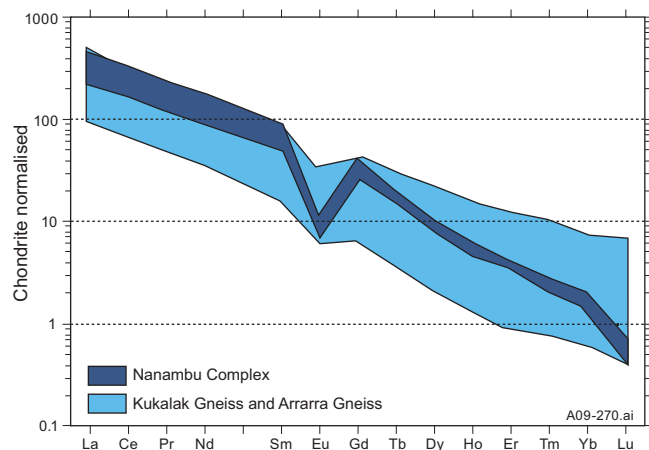


Figure 4.10. Chondrite-normalised Rare Earth Element (REE) plot for Archaean rocks in the Nimbawah Domain, Pine Creek Orogen (modified from Glass *et al* 2009). Shaded areas represent spread of data for multiple analyses of each rock suite. Normalising values from McDonough and Sun (1995).

MINERAL RESOURCES

There are no significant mineral occurrences in the Archaean rocks of the Pine Creek Orogen. The only known mineralisation is at the Giants Reef prospect (**Figure 4.3**), where rock chip samples provided gold values of up to 48.2 g/t in vein quartz within the Rum Jungle Complex. The mineralised vein is parallel to the Giants Reef Fault. Five percussion holes were completed on this prospect. The highest grades of 1.72 g/t Au over a 2 m interval were recorded in MRR-1 (Carter 1992a, b). The vein quartz-hosted mineralisation is similar to that of other Palaeoproterozoic gold deposits in the Pine Creek Orogen.

Archaean rocks of the Pine Creek Orogen have a strong spatial association with known uranium deposits in the Rum Jungle and East Alligator River regions (see **Figures 4.1, 4.2**). The Archaean granite and gneiss are highly radioactive (averaging about 10 ppm U). Mineralogical and geochemical studies of the Nanambu Complex by McAndrew and Finlay (1980) showed that uranium is present in zircon, monazite, xenotime, uranotorite, uraninite and apatite. Zircon is highly uraniferous and contains 0.18–0.36% U. It is likely that this uranium-rich granite and gneiss may be the ultimate source for the uranium orebodies of the PCO (Ahmad *et al* 2006, McAndrew and Finlay 1980).

There are no known mineral occurrences within the Archaean rocks of the Tanami Region, but by analogy with the Pine Creek Orogen, the vicinity of the Archaean strata may be prospective for unconformity-style uranium deposits.

REFERENCES

- Ahmad M, Wygralak AS and Ferenczi PA, 2009. Gold deposits of the Northern Territory (Second Edition). *Northern Territory Geological Survey, Report 11* (Second Edition update by Wygralak AS and Scrimgeour IR).
- Ahmad M, Lally JH and McCready AJ, 2006. Economic geology of the Rum Jungle Mineral Field. *Northern Territory Geological Survey, Report 19*.
- Blake DH, Hodgson IM and Muhling PC, 1979. Geology of The Granites-Tanami region. *Bureau of Mineral Resources, Australia, Bulletin 197*.
- Carson CJ, Claoué-Long JC, Stern RA, Close DF and Glass LM, 2009. Summary of results. Joint NTGS-GA geochronology project: Arunta and Pine Creek regions July 2006–May 2007. *Northern Territory Geological Survey, Record 2009-001*.
- Carter DN, 1992a. Annual report EL 7142. Burmine Ltd. *Northern Territory Geological Survey, Company Report, CR1992-0247*.
- Carter DN, 1992b. EL 7142, Daly Range, Final report. Burmine Ltd. *Northern Territory Geological Survey, Company Report, CR1992-0508*.
- Crispe AJ, Vandenberg LC and Green M, 2005. *Mount Solitaire, Northern Territory (Second Edition). 1:250 000 geological map series, SF 52-04*. Northern Territory Geological Survey, Darwin.
- Crispe AJ, Vandenberg LC and Scrimgeour I, 2007. Geological framework of the Archaean and Palaeoproterozoic Tanami Region, Northern Territory: *Mineralium Deposita* 42, 1–26.
- Cross AJ, Claoué-Long JC, Scrimgeour IR, Ahmad M and Kruse PD, 2005. Summary of results. Joint NTGS-GA geochronology project: Rum Jungle, basement to southern Georgina Basin and eastern Arunta Region 2001–2003. *Northern Territory Geological Survey, Record 2005-006*.
- Cross AJ and Crispe AJ, 2007. SHRIMP U-Pb analyses of detrital zircon: a window to understanding the early Palaeoproterozoic development of the Tanami Region, Northern Territory. *Mineralium Deposita* 42, 27–50.
- Drüppel K, McCready AJ and Stumpf EF, 2009. High-K granites of the Rum Jungle Complex, N-Australia: Insights into the Late Archaean crustal evolution of the North Australian Craton. *Lithos* 111, 203–219.
- Eskola PE, 1949. The problem of mantled gneiss domes. *Geological Society of London, Quarterly Journal* 104, 461–476.
- Ferguson J, 1980. Metamorphism in the Pine Creek Geosyncline and its bearing on stratigraphic correlations: in Ferguson J and Goleby AB (editors) 'Uranium in the Pine Creek Geosyncline. *Proceedings of the International Uranium Symposium on the Pine Creek Geosyncline*.' International Atomic Energy Agency, Vienna, 39–68.
- Glass LM, Hollis JA and Carson CJ, 2009. Geochemical and Isotopic discrimination methods for Neoarchaean and Palaeoproterozoic rocks in western Arnhem Land, Pine Creek Orogen: Applications for Uranium Exploration: in 'Annual Geoscience Exploration Seminar (AGES) 2009. *Record of Abstracts*.' Northern Territory Geological Survey, Record 2009-002.
- Glass LM, Hollis JA, Carson CJ, Yaxley G and Armstrong R, 2010. Archaean and Palaeoproterozoic crustal evolution processes in the Pine Creek Orogen: U-Pb, Hf, O, Nd isotopic data and geochemistry: in 'Annual Geoscience Exploration Seminar (AGES) 2010. *Record of abstracts*.' Northern Territory Geological Survey, Record 2010-002.
- Hollis JA, Carson CJ and Glass LM, 2008. The discovery of an Archaean Inlier in Arnhem Land: in 'Annual Geoscience Exploration Seminar (AGES) 2008. *Record of Abstracts*.' Northern Territory Geological Survey, Record 2008-002.

- Hollis JA, Carson CJ and Glass LM, 2009a. Regionally extensive Neoarchean basement in Arnhem Land: in 'Annual Geoscience Exploration Seminar (AGES) 2009. Record of Abstracts.' Northern Territory Geological Survey, Record 2009-002.
- Hollis JA, Carson CJ and Glass LM, 2009b. SHRIMP U-Pb zircon geochronological evidence for Neoarchean basement in western Arnhem Land, northern Australia. *Precambrian Research* 174(3–4), 364–380.
- Hollis JA and Glass LM, 2012. *Howship and Oenpelli, Northern Territory. 1:100 000 geological map series explanatory notes*, 5572, 5573. Northern Territory Geological Survey, Darwin.
- Johnson K, 1974. Progress report: geological review and revision of the Rum Jungle area, Northern Territory 1973. *Bureau of Mineral Resources, Australia, Record* 1974/41.
- Johnston JD, 1984. *Structural evolution of the Pine Creek Inlier and mineralisation therein, Northern Territory, Australia*. PhD thesis, Department of Earth Sciences, Monash University, Melbourne.
- Lally JH, 2002. Stratigraphy, structure and mineralisation, Rum Jungle Mineral Field, Northern Territory. *Northern Territory Geological Survey, Record* 2002-005.
- McAndrew J and Finlay CJ, 1980. The nature and significance of the occurrence of uranium in the Nanambu Complex of the Pine Creek Geosyncline: in Ferguson J and Goleby AB (editors) 'Uranium in the Pine Creek Geosyncline. *Proceedings of the International Uranium Symposium on the Pine Creek Geosyncline*.' International Atomic Energy Agency, Vienna, 357–262.
- McCready AJ, Stumpfl EF and Melcher F, 2003. U/Th rich bitumen in Archean granites and Palaeoproterozoic metasediments, Rum Jungle Mineral Field, Australia: Implications for mineralizing fluids. *Geofluids* 3, 147–159.
- Needham RS, 1984. *Alligator River, Northern Territory. (Second Edition). 1:250 000 geological map series explanatory notes*, SD 53-01. Bureau of Mineral Resources, Australia, Canberra.
- Needham RS, 1988. Geology of the Alligator River Uranium Field, Northern Territory. *Bureau of Mineral Resources, Australia, Bulletin* 224.
- Page RW, Sun Shensu and Blake DH, 1995. Geochronology of an exposed late Archaean basement terrane in The Granite-Tanami region. *AGSO Research Newsletter* 22, 19–20.
- Page RW, Compston W and Needham RS, 1980. Geochronology and evolution of the late Archaean basement and Proterozoic rocks in the Alligator River Uranium Field, Northern Territory, Australia: in Ferguson J and Goleby AB (editors) 'Uranium in the Pine Creek Geosyncline. *Proceedings of the International Uranium Symposium on the Pine Creek Geosyncline*.' International Atomic Energy Agency, Vienna, 39–68.
- Peacock MA, 1931. Classification of igneous rock series. *Journal of Geology*. 39, 54–67.
- Perring RJ and Farrar LJ, 1980. EL1642-Woolner, Second Annual Report, Geopeko Limited. *Northern Territory Geological Survey, Open File Company Report*, CR1981-0030.
- Pietsch BA, 1985. *Koolpinyah, Northern Territory (First Edition). 1:100 000 geological map series explanatory notes*, 5173. Northern Territory Geological Survey, Darwin.
- Pietsch BA and Stuart-Smith PG, 1987. *Darwin, Northern Territory (Second Edition). 1:250 000 geological map series explanatory notes*, SE 52-4. Northern Territory Geological Survey, Darwin.
- Richards JR, Berry H and Rhodes JM, 1966. Isotopic and lead-alpha ages of some Australian zircons. *Journal of the Geological Society of Australia* 13, 69-96.
- Richards JR, Ruxton BP and Rhodes JM, 1977. Isotopic dating of the leucocratic granite, Rum Jungle, Australia. *Australasian Institute of Mining and Metallurgy, Proceedings* 264, 33–43.
- Rhodes JM, 1965. The Geological relationships of the Rum Jungle Complex, Northern Territory. *Bureau of Mineral Resources, Australia, Report* 89.
- Stephannson O and Johnson K, 1976. Granite diapirism in the Rum Jungle area, Northern Territory. *Precambrian Research* 3, 159–185.
- Vandenberg LC and Crispe AJ, in prep a. Geology of the Tanami Region, Northern Territory. *Northern Territory Geological Survey, Report*.
- Vandenberg LC, Crispe AJ, Green M and Edgoose CJ, in prep b. Highland Rocks-Mount Solitaire-Mount Theo, Northern Territory (Second Edition). *1:250 000 geological map series explanatory notes*, SF 52-07, SF 52-04, SF 52-08. Northern Territory Geological Survey, Darwin.
- Williams IS and Compston W, 1983. Ion microprobe U-Pb dating of zircons from granitoids recovered in core from drill holes P4/1D, P11/1, P12/11 and P14/1, Woolner, Northern Territory: in Manning ER, Richardson BR and Starkey LJ. Annual Report for EL 3478 "Woolner", Appendix 3. Mobil Energy Minerals Australia Inc. *Northern Territory Geological Survey, Open File Company Report* CR1983-0231.
- Worden KE, Carson CJ, Close DF, Donnellan N and Scrimgeour IR, 2008a. Summary of results. Joint NTGS-GA geochronology project: Tanami Region, Arunta Region, Pine Creek Orogen and Halls Creek Orogen correlatives, January 2005–March 2007. *Northern Territory Geological Survey, Record* 2008-003.
- Worden KE, Carson CJ, Scrimgeour IR, Lally J, and Doyle N, 2008b. A revised Palaeoproterozoic chronostratigraphy for the Pine Creek Orogen, northern Australia: Evidence from SHRIMP U-Pb zircon geochronology. *Precambrian Research* 166, 122–144.
- Worden KE, Clauoué-Long JC, Scrimgeour IR and Doyle N, 2006. Summary of results. Joint NTGS-GA geochronology project: Pine Creek Orogen and Arunta Region, January–June 2004. *Northern Territory Geological Survey, Record* 2006-005.
- Worden KE, Clauoué-Long JC, Scrimgeour IR and Lally JH, 2004. Summary of results. Joint NTGS-GA geochronology project: August 2003–December 2003. *Northern Territory Geological Survey, Record* 2004-004.