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NORTHERN TERRITORY GEOLOGICAL SURVEY

M AHMAD
AS WYGRALAK
PA FERENCZI

GOLD DEPOSITS OF THE NORTHERN TERRITORY

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AS Wygralak and
IR Scrimgeour

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CHIEF EXECUTIVE: Richard Galton

NORTHERN TERRITORY GEOLOGICAL SURVEY
DIRECTOR: Ian Scrimgeour

Ahmad M, Wygralak AS and Ferenczi PA[1]
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EDITORS: TJ Munson and KJ Johnston

Northern Territory Geological Survey
3rd floor Paspalis Centrepoint Building
Smith Street Mall, Darwin
GPO Box 3000
Darwin NT 0801, Australia

Arid Zone Research Institute
South Stuart Highway, Alice Springs
GPO Box 8760
Alice Springs NT 0871, Australia

For further information contact:
Minerals and Energy InfoCentre
Phone +61 8 8999 6443
Website: **http://www.minerals.nt.gov.au/ntgs**
Email: Geoscience.Info@nt.gov.au

[1] Current address: Queensland Department of Mines and Energy, Central West Region, PO Box 548, Rockhampton QLD 4700.

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SUMMARY

Since the first discovery of gold in 1870, the Northern Territory has produced nearly 464 tonnes (t) or 14.9 million ounces (Moz) of gold (Au), and there are currently over 800[1] documented gold occurrences and a resource inventory of a further 530 t (17 Moz) Au. Nearly all of these deposits occur within metamorphosed and deformed sedimentary or volcanic rocks of Palaeoproterozoic age.

There have been three significant periods of gold production. Early mining (1870–1915) was selective and concentrated on high-grade (several tens of grams per tonne Au) veins, mainly in the Pine Creek Orogen. The next significant phase commenced with the discovery of medium- to high-grade (about 15–20 g/t Au), ironstone-hosted deposits in the Tennant Region in 1936, with production peaking during 1971–1975. The current phase of gold production commenced in 1987 and concentrated on bulk open-cut mining of relatively low-grade (about 2–3 g/t Au) ores. Earlier mining was from highly selective shallow pits, shafts and narrow adits that systematically followed the auriferous lodes. The old mine workings generally stopped at the water table, because of the influx of water. Most modern mining is by large open cuts, but some deposits, eg Callie, Brocks Creek (Zapopan) and Tom's Gully, have moved into substantial underground operations.

All the significant gold occurs within the North Australian Craton (NAC) in the Pine Creek Orogen, Tennant Region, Tanami Region and Arunta Region. Other Palaeoproterozoic terranes (eg Murphy and Arnhem inliers) have fewer occurrences and deposits, but this may be due, in part, to insufficient exploration. The gold deposits are predominantly (>80%) hosted within low-grade greywacke-siltstone-shale successions, but metabasalt is also a significant host rock. There are no significant gold occurrences in arenaceous rocks and only two (Giants Reef and Bonrook) occur in granite. Most gold occurs in rocks that were metamorphosed at grades between lower greenschist facies and middle amphibolite facies.

Most of the gold deposits of the Northern Territory have a structurally controlled mesothermal setting and, on the basis of host rock and mineral association, can be divided in to seven types: (1) gold-quartz veins; (2) gold-ironstone bodies; (3) gold in iron-rich sedimentary rocks; (4) polymetallic deposits; (5) gold-PGE (platinum group element) deposits; (6) uranium-gold deposits; and (7) placer deposits. Over half of the occurrences are gold-quartz veins, as are typical of the Pine Creek Orogen. The gold-ironstone association characterises the Warramunga Province of the Tennant Region and constitutes about a third of the deposits. Gold deposits hosted by iron-rich sedimentary rocks are present in the Pine Creek Orogen and Tanami Region. Although forming only five percent of occurrences, these have contributed significantly to the gold inventory. In the other hard-rock types, gold is present as a secondary commodity and, although there are only a few examples (Coronation Hill, Jabiluka, Koongarra, Mount Bonnie, Iron Blow), these could form an important source of future gold. Future uranium exploration in Arnhem Land and the southern part of the McArthur Basin (Tawallah Group) may add significantly to the present gold inventory. Small placer deposits are present in the Pine Creek Orogen and Arunta Region.

Native gold is the main ore mineral and is commonly present as micron-sized grains; coarse gold nuggets are rare. Gold is commonly associated with pyrite, arsenopyrite and pyrrhotite, and in places, with minor base-metal sulfides. Copper and bismuth minerals are common in ironstone-hosted deposits and lead-zinc sulfides dominate the polymetallic deposits. Common gangue minerals in the quartz vein-hosted deposits are quartz, chlorite, sericite and carbonates. Ironstone-hosted gold deposits have magnetite, chlorite, muscovite, sericite and quartz. Gold deposits in iron-rich sedimentary rocks contain chlorite, sericite, cummingtonite, actinolite, chloritoid, garnet and carbonates.

All gold deposits show structural control at the regional and deposit scales. There are significant variations in the structural orientation of gold deposits, within and between tectonic units. Most deposits within the Pine Creek Orogen trend northwest; those from the Tennant Region have an easterly trend, and gold occurrences in the Arunta and Tanami regions have a northerly trend with an easterly component. In the Pine Creek Orogen, the trend of the vein-type gold deposits is significantly different from that of the tin and base metal veins, suggesting discrete mineralisation events. These regional differences represent variations in the crustal architecture of the NAC.

Most deposits show a preference for competency-contrast situations in dilatant or low-pressure zones, such as anticlinal crests, recurrent shear zones and necking zones. Gold mineralisation is invariably late, occurring after orogenic events.

Common factors for most gold deposits include: (1) most are in low-grade (sub-greenschist- to greenschist-facies) regionally metamorphosed sedimentary rocks (commonly greywacke-siltstone-shale); (2) anticlinal hinges and shear zones are generally the most favourable loci; (3) subsequent to regional metamorphism and deformation, the metasedimentary rocks were intruded by granites with I-type characteristics and many gold deposits are within the contact metamorphic aureole; (4) fluid inclusion data suggest the involvement of low to moderate salinity, $CO_2 \pm CH_4 \pm N_2$–bearing fluids ranging in temperature from 200 to 350°C; and (5) stable isotope data suggest a magmatic/metamorphic origin of these fluids.

The above features can be used to demarcate regions of high gold prospectivity in various tectonic units of the Northern Territory. The most prospective regions are: (1) the central part of the Pine Creek Orogen, specifically a northwest-trending belt between Darwin and Katherine; (2) an east-trending belt comprising the Warramunga Formation in the central Tennant Region, including extensive under-explored regions under shallow sedimentary cover; and (3) the Mount Charles and Dead Bullock formations in the Tanami Region and their stratigraphic equivalents in the Arunta Region. Other areas, which have potential are the Murphy Inlier (Murphy Metamorphics), the Arnhem Inlier (Grindall Formation) and the basement to the Victoria and

[1] In September 2008 Mineral Deposit Data Base of the Northern Territory (MODAT) includes 869 gold occurrences.

Birrindudu basins (Inverway Metamorphics). Extensive, poorly exposed low- to medium- grade metasedimentary rocks in the northern and western Arunta Region have considerable gold potential.

The regions most suitable to host U-Au (eg Jabiluka), and Au-PGE (eg Coronation Hill) deposits include the Murphy Inlier, the Tanami Region and the eastern Pine Creek Orogen in western Arnhem Land. The Arunta Region is considered to have significant potential for iron-oxide copper-gold mineralization.

In contrast to the NAC, there are relatively few known gold occurrences in the Warumpi, Irindina and Musgrave provinces. The paucity of mineral occurrences in these terranes could be due to: (1) a relative lack of exploration; (2) deeper erosion levels below the mesothermal zone; (2) dissipation of mineral constituents due to repeated periods of high-temperature tectonic activity. Limited exploration in the northern Musgrave Province suggests that the Tjauwata Group and associated structures have significant greenfields potential.

INTRODUCTION

Scope and objectives

The first significant gold discovery in the Northern Territory was made in 1870, during the construction of the Overland Telegraph line, at Yam Creek about 30 km north of Pine Creek township. Today, there are over eight hundred documented gold occurrences and the total recorded production to 31 December 2007 is 463.8 t Au (**Figure 1**)[2]**.** Information on these occurrences is contained in over five thousand company reports and in publications by Geoscience Australia [(GA); formerly Bureau of Mineral Resources (BMR) and Australian Geological Survey Organisation (AGSO)] and the Northern Territory Geological Survey (NTGS).

During 1992–1996, NTGS placed its gold occurrence information on a SYBASE database. This package was re-released in 1999 as the MODAT database in Microsoft Access, which is subject to ongoing updating and upgrading. NTGS also produced twelve documents (Mineral Deposit Data Series) on mineral deposits in various regions of the Northern Territory. The present publication relies on these previous studies, as well as on the latest information released by exploration companies, and provides a summary of the gold deposits of the Northern Territory. The interested reader is referred to the MODAT database and publications for detailed references on particular deposits or geological provinces.

Almost all occurrences are located in four Palaeoproterozoic provinces. In order of abundance of gold occurrences, these are the Pine Creek Orogen, the Tennant

[2] Production and resource figures, especially for the earlier period, are often incomplete. In this report, such figures were compiled from several sources, including Northern Territory Government records, company data, Stock Exchange announcements and anectodal information. Some figures are estimates only.

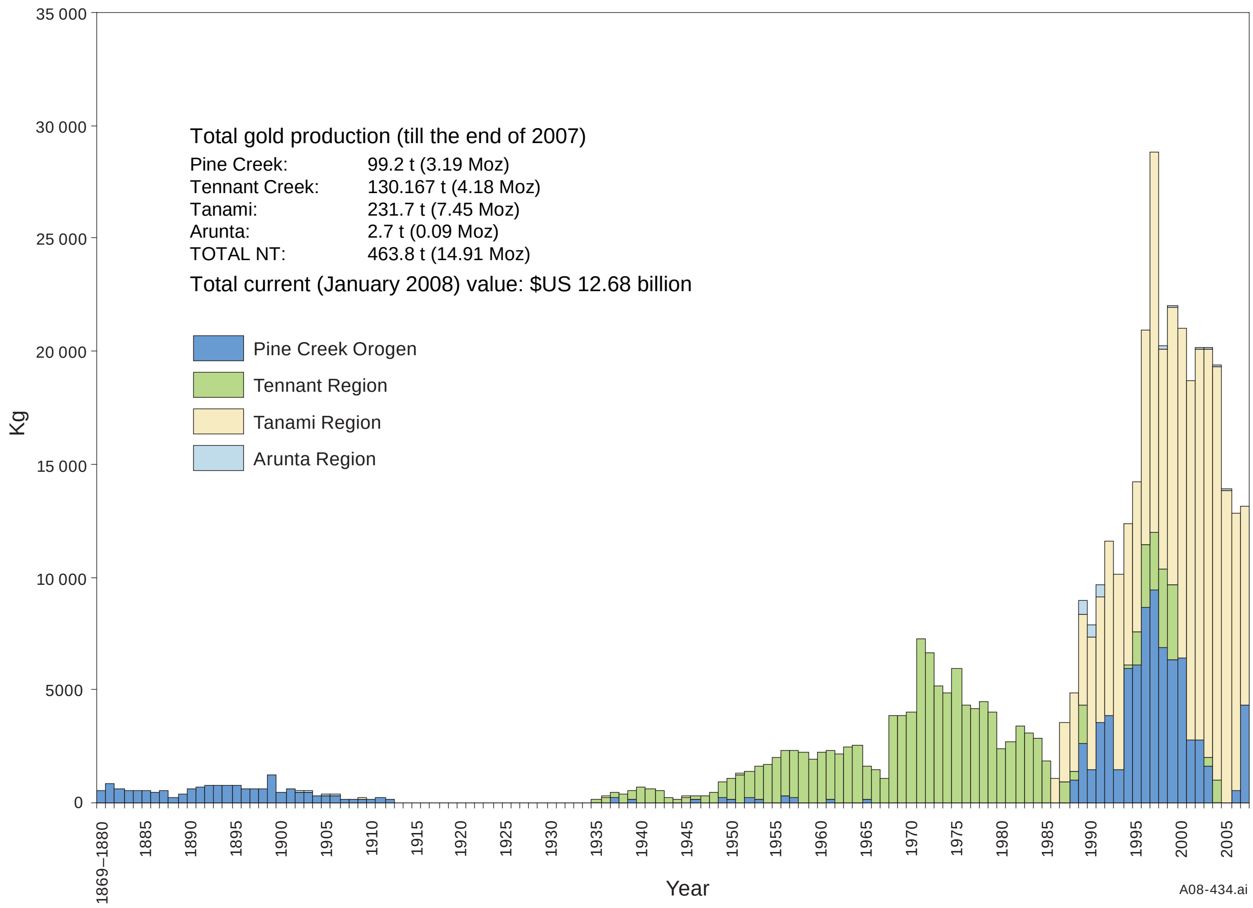

Figure 1. Estimated annual gold production from various Northern Territory tectonic units (data sources: Minerals and Energy, Northern Territory records, Kalix *et al* (1966), Gamble (1962), Mackie (1986) and personal communications with mining companies (September 2008).

Region, the Tanami Region and the Arunta Region. This report provides a brief summary of the geology of each of the four provinces, with an emphasis on features related to gold mineralisation.

Note that many of the resource estimates quoted in this report may not comply with statutory stock exchange reporting requirements (eg JORC or NI 43-101). If citing resource figures, please refer to the original source documents rather than to this report.

History of exploration and mining

In the Pine Creek Orogen, FH Litchfield made the first discovery of gold in 1865 in the Finniss River area (Jones 1987). Shortly after, in 1868, specks of gold were found at Tumbling Waters. These early finds did not have immediate economic benefits. It was the discovery in 1870 of coarse gold near Yam Creek that resulted in the first gold rush and discoveries at Pine Creek, Union Reefs, Cosmo Howley, Mount Todd, Fountain Head, Zapopan, Spring Hill, Brocks Creek and Woolwonga. Production from these deposits commenced soon afterwards and continued until 1915, when most mines ceased. A total production of nearly 17 t Au was recorded during this period (**Table 1**).

Minor production (177 kg) took place in the Pine Creek Orogen between 1916 and 1930. A significant increase in exploration during the early 1980s, resulting from an increase in gold prices and improvements in gold mining and extraction techniques, led in October 1985 to the opening of the first modern mining venture, the Enterprise mine at Pine Creek. Several other mining operations, including Brocks Creek, Cosmo Howley, Golden Dyke, Goodall, Moline, Mount Todd, Rustlers Roost, Toms Gully, Union Reefs, and Woolwonga, commenced shortly afterward.

In 2005, Canadian-listed GBS Gold Australia Pty Ltd (hereafter referred to as GBS) commenced an extensive exploration program in the Pine Creek Orogen. The company consolidated exploration tenements and announced a total resource of 3.5 Moz Au. This exploration culminated in the re-opening of three mines [Rising Tide, Fountain Head and Brocks Creek (previously known as Zapopan)], and the definition of redefined resources at Cosmo Deeps, Princes Louise, Chinese Howley and Maud Creek.

Between 1987 and 2007, the total recorded production from the Pine Creek Orogen was 79.3 t Au.

In the Arunta Region, gold was discovered at Arltunga in 1887 and White Range in 1897. Early last century gold was also discovered in the Winnecke goldfield. Production commenced in 1890 and practically ceased by 1917, except for intermittent small-scale operations that continued until 1934. Recorded production for this period amounted

Year	Pine Creek Orogen	Tennant Region	Tanami Region	Arunta Region
1869–80	579			
1881–85	3 063			
1886–90	2 161			
1891–95	3 870			
1896–00	3 511			62
1901–95	2 195			220
1996–10	914		33	145
1911–15	567		45	48
1916–20	114		6	1
1921–25	49		3	
1926–30	14		1	
1931–35	116	89	40	
1936–40	451	1 881	53	
1941–45	117	1 627	85	
1946–50	567	2 486	84	
1951–55	454	7 523	63	
1956–60	737	10 325		
1961–65	485	10 670		
1966–70		14 179		
1971–75		29 897		
1976–80		19 458		
1981–85	1	13 847		
1986–90	5 257	2 940	16 995	1 151
1991–95	20 914	1 641	34 821	575
1996–00	37 662	12 230	62 958	228.4
2001–05	12 445	1 374	92 805	369
2006	505		12 342	
2007	2 500		11 400	
Total	**99 248**	**130 167**	**231 734**	**2 799.4**

Table 1. Historical gold production (kg) from NT goldfields.

to 476 kg Au (**Table 1**). More recently, during 1989–1991, the reefs at White Range were mined by open-cut methods, producing 1.73 t Au. Intermittent treatment of tailings during 1998–2005 produced a further 597 kg Au. The total recorded production from the Arunta Province remains at 2.8 t Au (as of September 2008). In September 2006, Tanami Gold NL announced a significant gold discovery at the Tekapo prospect in the Lake Mackay area of the western Arunta Region, with a best drilling intersection of 16 m at 3.4 g/t Au.

Gold in the Tanami Region was discovered around 1900, with small-scale mining continuing intermittently until 1955. A total production of 413 kg was recorded for this period. In 1975, North Flinders Mines Ltd were introduced to The Granites field by prospector S Griffith and, following negotiations with Aboriginal landowners, four exploration licences were granted in 1983. By June 1985, a total of 57 diamond drillholes and 75 reverse circulation holes had been completed at the Bullakitchie and Shoe deposits, delineating ore reserves totalling 1.9 Mt at an average grade of 8.0 g/t Au (Mayer 1990). Production commenced at these deposits in July 1986. A total of 6.4 Mt @ 5.5 g/t Au was produced till the closure of mining operations at The Granites in 2001 (Wygralak *et al* 2005).

In June 1989, North Flinders Mines Ltd announced the discovery of the Callie deposit, containing 0.6 Mt at an average grade of 3.3 g/t Au and located about 40 km west of The Granites mine, in the Dead Bullock Soak (DBS) area. By June 1992, the resource had increased to 6.6 Mt @ 5.4 g/t Au (Lovett *et al* 1993). As of June 1998, the total resource of the Dead Bullock Soak deposits, including Callie, was 21.1 Mt, averaging 5.5 g/t (Normandy NFM 1998). Open-cut mining commenced at Dead Bullock Soak in 1991 and at Callie in 1992. Ore was trucked 40 km east to the processing plant at The Granites. Wygralak *et al* (2005) quoted total production from the DBS goldfield as 13 Mt at 4.6 g/t Au, and the remaining resource (essentially at Callie) as 18.2 Mt at 5.2 g/t Au.

In the Tanami Mine area, Harlock Pty Ltd commenced exploration in 1985, drilling 11 diamond holes and 468 percussion holes. Mining at the Tanami mine commenced in 1987 (Nicholson 1990). Exploration by the Central Desert Joint Venture (Acacia Resources Ltd and Otter Gold Mines Ltd) in an area southwest of the Tanami mine commenced in 1990. By 1994, a resource of 3.45 Mt at 3.2 g/t Au had been identified in this area, which includes Jims Find, Dogbolter and Redback Rise. Total initial resources were 9.3 Mt averaging 3.2 g/t Au and production to the end of 1998 was 379 360 oz from 3.87 Mt of ore. By June 2001, the Tanami goldfield had produced 0.9 Moz Au with the remaining resource of 0.7 Moz Au (*ibid*)[3].

In the Tennant Region, the first discovery was made in 1874 in the Last Hope area, 48 km northwest of the Old Telegraph Station, near Tennant Creek (Northern Territory Times and Gazette, October 1881). Gold was also discovered in the Kurundi area in 1898 (Davidson 1905). In 1925, about 0.5 kg of alluvial gold was produced from the Kurinelli goldfield (Roarty 1977). Significant mining and prospecting did not take place until 1932, when two small batteries were constructed near Tennant Creek township.

By 1936, some 50 small mines were in operation, the most notable being Nobles Nob, Eldorado, Peko, Golden Forty, Lone Star, Rising Sun, Blue Moon, Northern Star and Hammer Jack. During the Second World War, all mines were closed, except for Eldorado. Mining activity resumed soon after the war, and by 1947, some 25 mines were operating, although by 1952, the number had dropped to eight.

Production dramatically increased during the 1960s and 1970s, due to the discovery of several subsurface deposits (Orlando, Ivanhoe, Juno, Gecko and Warrego), using airborne magnetic methods followed up by ground magnetic surveys and diamond drilling. That period also saw the expansion of mining operations at Peko and Nobles Nob. During the 1980s and 1990s, exploration methods were still targeting ironstone-hosted deposits with some success (Argo and TC8), as well as non-magnetic mineralisation (Orlando East). Higher gold prices and improvements in gold extraction techniques led to several old mines being reworked by open-cut (Northern Star, Black Angel, White Devil and Kurinelli) and underground methods (Rising Sun, New Hope and White Devil). Some old tailings were also re-treated (Eldorado and Warrego).

During the late 1990s, gold exploration in the Tennant Region was undertaken by Giants Reef Mining Ltd. It culminated in the discovery of the Chariot deposit, which during 2003–2004, produced 33 770 oz Au from 56 400 t ore @ 12.3 g/t Au (Giants Reef Mining Ltd, Quarterly Report to the ASX, June 2004).

A resurgence in gold exploration in the Tennant Creek Mineral Field commenced in 2007. This resurgence concentrated on the historical Tennant Creek field, where the main explorers included Emmerson Resources Ltd, Excalibur Resources Ltd, Truscott Mining Corporation Ltd and Prosperity Resources Ltd, and the Rover field, under Palaeozoic cover 70 km southwest of Tennant Creek, where exploration was undertaken by Westgold Resources NL and Adelaide Resources Ltd. A number of these companies developed new exploration models, which advocate structurally controlled mineralisation and mineralisation associated with non-magnetic (haematitic) ironstones. Such types of mineralisation were subjected to little exploration activity in the past. This new phase of exploration has resulted in the discovery of significant high-grade gold mineralisation at the Rover 1 prospect in 2008, as well as bonanza intersections at a number of prospects in the Tennant Creek field.

Since 1934, a total of 130.2 t Au was produced from the Tennant Region.

Gold exploration in the Northern Territory was negatively affected by the gradual fall of the gold price to just over $US250 in 1999 (**Figure 2**). To reverse this trend, the Northern Territory Government has undertaken three major exploration attraction initiatives aimed to revitalise and facilitate mineral exploration. The initiatives, along with gradually increasing gold prices, which in 2007

[3] Combined production from The Granites, DBS and Tanami goldfields between 1986–2007 amounts to 231 734 kg (7.45 Moz) Au (Mines and Energy, Northern Territory, production records).

reached $1000, have resulted in a reinvigoration of gold exploration.

In spite of an extensive exploration history, gold provinces of the Northern Territory remain largely underexplored. For example, it is estimated that only 20% of the Tanami Region has been subjected to modern gold exploration. In most provinces, gold exploration is still largely concentrated on 'brownfields' areas, close to existing or historical mines. It is crucial for the long-term sustainability of the gold industry in the Northern Territory to extend exploration into under-explored 'greenfields' areas.

A list of all gold occurrences in the Northern Territory is given in **Appendix 1** at the end of this report.

CLASSIFICATION OF GOLD DEPOSITS OF THE NORTHERN TERRITORY

For the purpose of this publication, the gold deposits of the Northern Territory are divided into seven types. These are, in order of abundance:

- Gold-quartz veins, lodes, sheeted veins, stockworks and saddle reefs; eg many deposits in the Pine Creek Orogen, the Tanami Region, Arunta Region, and Davenport Province of the Tennant Region.
- Gold-ironstone bodies; eg in the Tennant Region.
- Gold in iron-rich sedimentary rocks; eg many deposits in the Pine Creek Orogen and Tanami Region.
- Gold in association with platinum group elements; eg the South Alligator Valley in the Pine Creek Orogen.
- Gold in association with uranium; eg the Pine Creek Orogen and Murphy Inlier.
- Polymetallic gold deposits; eg the Iron Blow and Mount Bonnie mines in the Pine Creek Orogen.
- Placer deposits.

Most of the bedrock deposits involve veins, formed under mesothermal pressure-temperature regimes and hosted within regionally metamorphosed, greenschist-facies greywacke-siltstone-shale (flysch) successions. Most deposits are within the contact aureole of late- to post-orogenic I-type granites. A brief description of each class of deposit follows.

Gold-quartz veins, lodes, sheeted veins, stockworks and saddle reefs

This type includes 60% of the known occurrences, which have been a major source of gold in the Northern Territory. Tonnages and grades of some important deposits are given in **Figure 3**. These deposits are found in all the Palaeoproterozoic terranes and are usually contained within folded, faulted and regionally metamorphosed (usually lower greenschist-facies) flysch successions. A few are hosted by intermediate to basic intrusive and volcanic rocks. Late- to post-orogenic granites intrude these successions, causing superimposed contact metamorphism. Most deposits are within the contact metamorphic aureole. Vein quartz is the principal gangue mineral and is accompanied by white mica, chlorite and minor K-feldspar. The width of gold-bearing quartz veins ranges from millimetres to a few metres. Pyrite and arsenopyrite are the main sulfide minerals, together with minor pyrrhotite, chalcopyrite, sphalerite and galena. Base-metal sulfides are paragenetically late. Late-stage carbonate veining occurs in many deposits. Wall-rock alteration effects are negligible and are confined to a few tens of millimetres along vein edges. Silicification and sericitisation are the main alteration processes. Gold is fine-grained to microscopic in size and is rarely visible. Free gold is common, but in most deposits, it is contained as inclusions in arsenopyrite, pyrite and pyrrhotite.

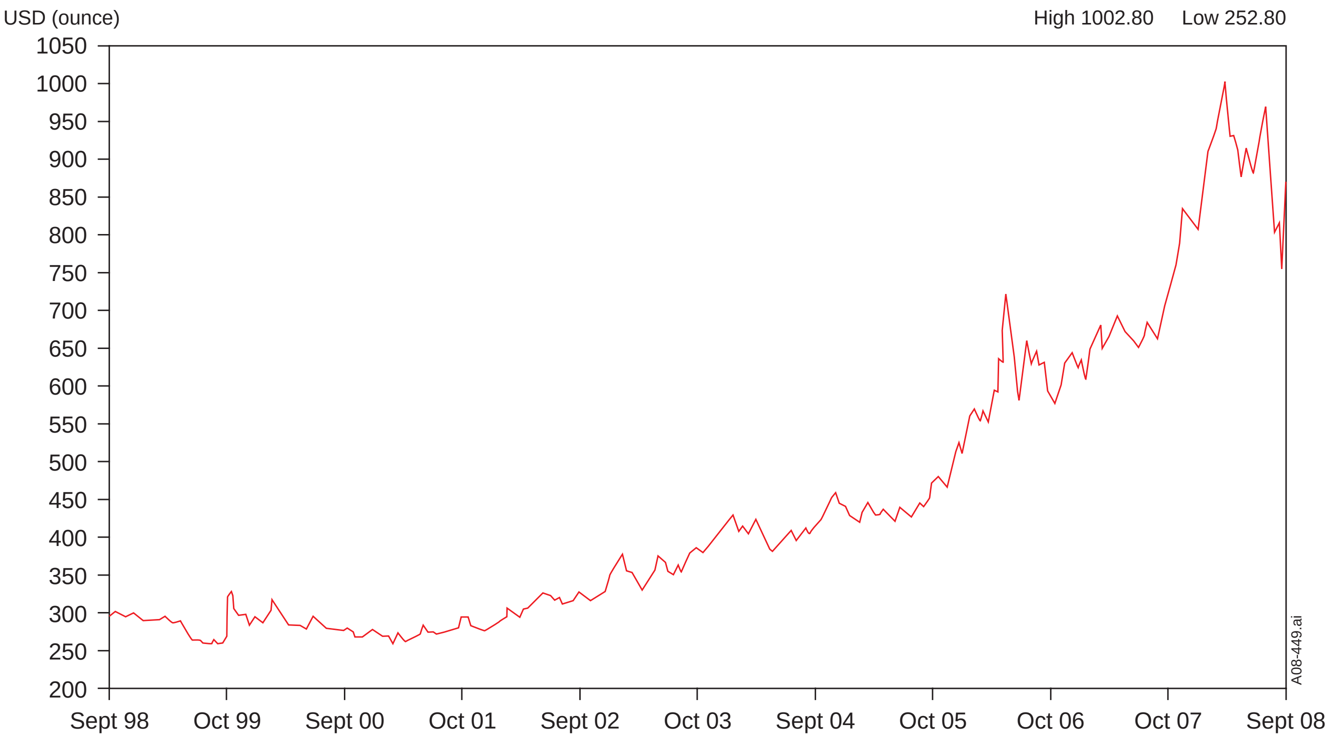

Figure 2. Changes in the gold price between 1998 and 2008.

In the oxidised zone, which extends to a depth of about 60 m, the majority of gold is free milling. Most mining activity carried out at the turn of the nineteenth century was confined to the oxidised zone. The grade is generally low (usually less than 3 g/t Au) and individual deposits have 0.5–100 t Au.

Gold in ironstone bodies

These deposits are present in the Warramunga Province of the Tennant Region and are contained in ellipsoidal to pipe-shaped, discordant, iron oxide-rich (mostly magnetite) bodies. The host rocks are folded, faulted and regionally metamorphosed flysch successions, which also contain felsic volcanic rocks and porphyry intrusive rocks, and have been intruded by syn- to post-orogenic granites. The orebodies have a complex mineralogy comprising native gold, chalcopyrite, pyrite, bismuth minerals, galena, sphalerite, cobaltite, uraninite and molybdenite. Apart from magnetite and haematite, other gangue minerals include chlorite, muscovite, talc, dolomite and sericite. The grade is generally high, about 20 g/t Au, but tonnages are low by world standards.

Gold in iron-rich sedimentary rocks

These deposits are associated with iron-rich sedimentary rocks (variously named as banded iron formation, banded ironstone, or silicate iron facies) and are generally capped by carbonaceous shale in the hangingwall. The ore horizon is often bedding concordant and gangue minerals include quartz, siderite, ankerite, calcite, chlorite, cummingtonite-grunerite, ferroactinolite, almandine and tourmaline. Gold-bearing quartz veins are present in some deposits and have probably provided most of the gold (eg Cosmo Howley).

Sulfides include pyrite, arsenopyrite, marcasite and traces of galena and sphalerite. Gold is sub-microscopic in size and a large part occurs as native gold, generally in association with arsenopyrite. In the oxidised zone, gold is mostly free milling and can be extracted by conventional metallurgical methods.

Gold in association with platinum group elements

Coronation Hill in the South Alligator River Valley region of the Pine Creek Orogen is the only example of this type. There is potential for additional discoveries in the same area and also in the Murphy Inlier. Mineralisation is in microfractures, veinlets and disseminations in quartz-feldspar porphyry, volcaniclastic siltstone, debris-flow conglomerate, sedimentary breccia and dolostone. Gold is microscopic and is associated with selenides ± replacive pyrite. The sulfide content of ore is generally low, with minor pyrite and trace amounts of marcasite, pyrrhotite, sphalerite, chalcopyrite and galena. Platinum and palladium minerals are closely associated with gold and selenides.

Gold in association with uranium

Significant gold, often in economic concentrations, is associated with uranium deposits in the Pine Creek Orogen and Murphy Inlier. Mineralisation is hosted within a variety of rock types, including carbonaceous shale, sandstone, dolerite and acid volcanic rocks. It occurs as fracture fill and breccia fill, and within the matrix of sandstones. Gold is microscopic to fine and is closely associated with uranium

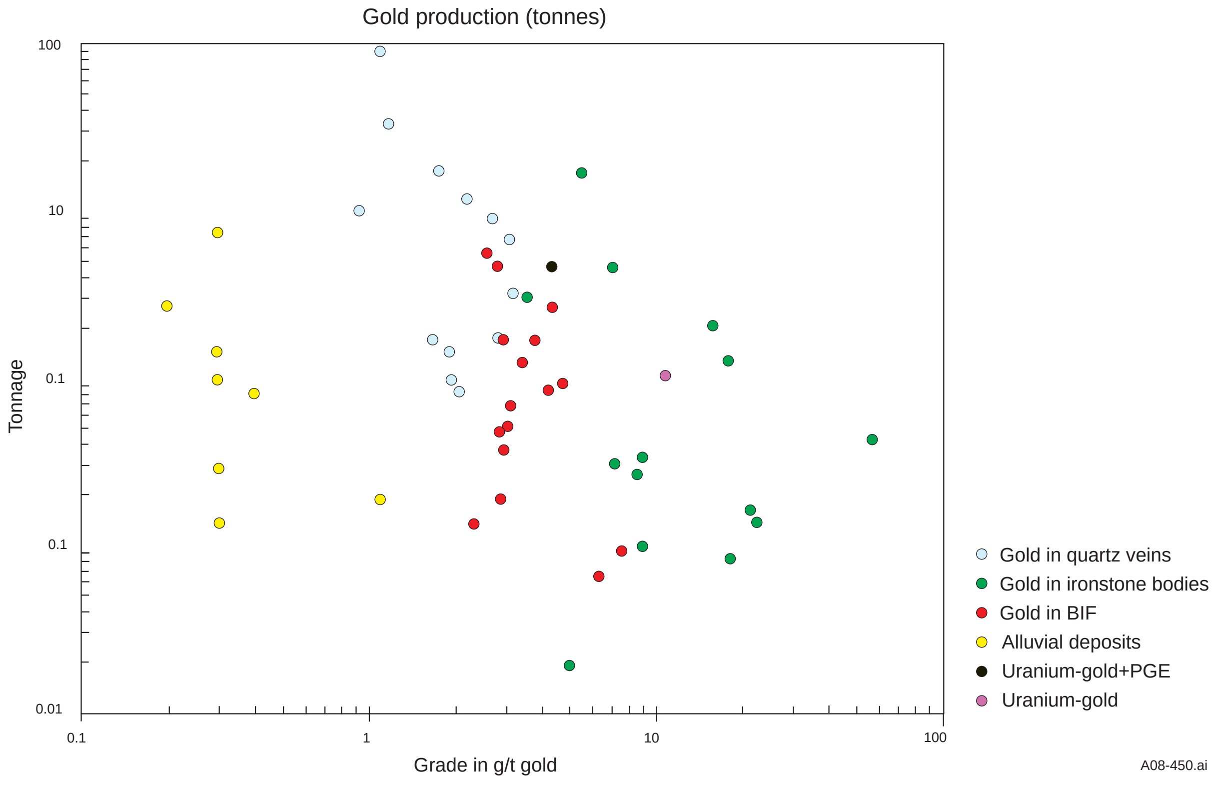

Figure 3. Tonnage (resource plus production in millions of tonnes) versus grade of various deposit types in the Northern Territory.

minerals. Other minor minerals include pyrite, tellurides and traces of galena and sphalerite. Vein quartz is rare and chlorite is the main alteration mineral.

Polymetallic gold deposits

These deposits are contained as concordant massive sulfide lenses within interbedded pyritic shale, dolomitic siltstone and tuff. In addition to gold, they also contain lead, zinc, copper and silver. Quartz veining is almost non-existent. The common primary sulfide minerals are sphalerite, galena, arsenopyrite, pyrite, chalcopyrite, pyrrhotite and tetrahedrite. Zinc is the dominant element, followed by silver and gold. The Mount Bonnie and Iron Blow mines in the Pine Creek Orogen are examples of this type of deposit.

Placer deposits

Many of the quartz vein and iron-rich sediment gold deposits have associated eluvial and alluvial gold concentrations, which have been mined to some extent in most goldfields. Gold is usually fine grained, generally less than 1 mm in size, but some coarse nuggets have been reported.

GENERAL CHARACTERSTICS OF GOLD ORES

Grade and resource characteristics

Most gold-quartz vein-type deposits are of small to medium size (1–10 Mt) and have grades from 2–4 g/t Au. A few deposits (eg Mount Todd, Rustlers Roost) are larger and have a lower grade (<2 g/t Au). Toms Gully mine is an example of a relatively high grade (7.6 g/t Au) deposit.

The Callie deposit in the Tanami Region has unusually high tonnage and grade (past production 12.8 Mt @ 5.1 g/t Au; remaining resource 12.77 Mt @ 6.02 g/t Au). Ore tonnages of some operating mines and significant deposits are plotted against grade in **Figure 3** and suggest an inverse relationship between tonnage and grade. Many of the deposits were mined by narrow trenches and underground workings between 1886 and 1915, and yielded much higher grades, often several tens of grams of gold per tonne.

The ironstone-hosted gold deposits of the Tennant Region have generally higher grades and lower tonnages (**Figure 3**). Grades are in the range 5–90 g/t Au and average 15 g/t Au (Ferenczi 1996), but most deposits containing less than 2 Mt and a great many have less than 0.5 Mt. Overall, gold grades are lower (1.2–8 g/t Au) in deposits containing significant copper and bismuth, although there are distinct pods containing high-grade gold.

Grades and tonnages of gold deposits within iron-rich sedimentary rocks fall between those of the quartz-vein and ironstone-hosted deposits (**Figure 3**). Most have grades of 3 to 4 g/t Au, with some as high as 8 g/t Au. Most of these deposits are less than 2 Mt. Cosmo-Howley, the largest of this type, contained 6 Mt at 2.54 g/t Au and its planned underground extension (Cosmo Deeps) contains 8.74 Mt at 4.55 g/t Au.

There are only two polymetallic ore deposits from, which gold has been mined: Iron Blow and Mount Bonnie. In both of these, in the oxidised zone, the grade was about 7 g/t Au and reserves were 15 000 and 480 000 t, respectively. The primary ore, which has not been mined, contains approximately 2 g/t Au. The higher oxidised ore grade suggests supergene enrichment. The primary ore also contains 6.85% Zn at Iron Blow and 9.5% Zn at Mount Bonnie. Copper, lead and silver are present at both deposits.

Coronation Hill is the only deposit where gold is associated with platinum group elements. This deposit contains 6.69 Mt at 6.42 g/t Au, 0.3 g/t Pt and 1.01 g/t Pd.

Although gold has been recovered from several uranium deposits in the South Alligator Valley as a by-product, accurate grades and tonnages are unknown. The ore dump at Eva uranium mine in the Murphy Inlier contained about 14 g/t Au (Ahmad 1982). The Koongarra uranium deposit has a resource of 1.07 Mt at 2.96 g/t Au and the Jabiluka uranium deposit contains 1.1 Mt at 10.7 g/t Au. An additional resource may remain in the tailings.

Most quartz vein and many of the iron-rich sediment-type deposits have associated placers. Alluvials mined in the Pine Creek Orogen account for almost all placer gold production from the Northern Territory. In these deposits, gold is generally fine-grained and of high purity. It is chemically similar to the adjacent vein deposits. Only a few deposits have coarse nuggets; eg Sandy Creek in the Pine Creek Orogen, and deposits in the Davenport Province and the Arunta Region (**Table 2**). The grade of some recently mined placer deposits was about 0.3 g/t Au and the deposit sizes were generally less than 1 Mt.

Ore mineralogy

The principal mineral is native gold, and there are reports of traces of gold tellurides. The gold usually contains a significant amount of silver. Analyses of mine concentrates, bars and gold grains indicate highly variable gold/silver ratios (**Table 3**). There are some indications of a slight increase in Au/Ag ratios with depth, consistent with Ag loss during oxidation. For example, Enterprise Au/Ag ratios increased as the mine deepened, from 3.99 when production started in 1985 to 6.31 in 1993 (Mines and Energy, Northern Territory, records). Concentrates from polymetallic deposits (Iron Blow and Mount Bonnie) contain the highest silver values, 200 g/t and 230 g/t, respectively. These high values may be due to the presence of separate silver-bearing phases.

Gold fineness

The fineness of gold is a measure of the proportion of elemental gold in a deposit and is expressed as parts per thousand. Silver is the main impurity, but other precious and base metals may also be present (eg Cu, Fe and PGE). The fineness is expressed as (Au/Au+Ag) x 1000. Wedekind (1990) provided data on the fineness of gold from the Tennant Creek deposits. It ranges from 700 to 1000, with a lower fineness from deposits in which gold is associated with copper. Wygralak (1996) provided analyses on gold ores from six gold deposits from the Pine Creek Orogen. The silver content varied from 22% (Union Reefs) to 9% (Cosmo Howley). The calculated fineness varied from 779 to 909 and averaged 863.

Supply and demand

Until about 650 BC, gold was mainly used for ornamentation and decoration. From then on, the main use was for monetary purposes, with most production, except that permitted for the manufacture of jewellery, going from the mint into the vaults of most countries (Boyle 1987). This situation changed in 1976, when gold prices were deregulated from a fixed value of US$35/oz and Australian citizens were allowed to own and trade in gold. Also, the backing of gold for monetary purposes has become less pronounced. During the twentieth century, gold was used by most countries as a financial reserve asset against balance of payments and borrowings. It has been considered a good investment, and many people bought gold as a protection against the declining value of paper money. An intriguing fact about gold is that, unlike other mining commodities, most gold produced to date (approximately 150 000 t[4]) still exists today. In 2007, the measured and indicated gold resource of the word was estimated at 90 000 t. In the same year, the total gold production was 2500 t. (http://minerals.usgs.gov/minerals/pubs/commodity/gold).

[4] All gold produced until 2009 could be contained in a 19 m-high cube.

Mine	Nugget weight (g)	Mine	Nugget weight (g)
Sandy Creek	382.5	Howley	248.8
Sandy Creek	124.4	Yam Creek	9.3
Sandy Creek	373.2	McKinley	248.8
Sandy Creek	279.9	McKinley	715.3
Sandy Creek	101.8	McKinley	933.0
Sandy Creek	656.2	McKinley	684.2
Sandy Creek	217.7	Pine Creek	155.5
Sandy Creek	262.7	Pine Creek	93.3
Sandy Creek	404.3	Margaret	404.3
Sandy Creek	435.4	Margaret	1057.4
Sandy Creek	715.3	Margaret	933.0
Sandy Creek	80.8	Margaret	1555.0
Sandy Creek	217.7	Margaret	2488.0
Sandy Creek	31.1	Margaret	2239.2
Sandy Creek	311.0	Margaret	2612.4
Sandy Creek	466.5	Margaret	8956.8
Sandy Creek	311.0	Margaret	2177.0
Sandy Creek	279.9	Margaret	2239.2
Sandy Creek	1306.2	Margaret	777.5
Sandy Creek	124.4	Margaret	21770.0
Sandy Creek	124.4	Wandie	7.75
Sandy Creek	186.6	Wandie	17.0
Sandy Creek	326.5	Wandie	93.3
Sandy Creek	155.5	Wandie	497.6
Sandy Creek	147.7	Wandie	26.3
Sandy Creek	40.3	Wandie	342.1
Sandy Creek	419.8	Wandie	217.7
Sandy Creek	472.5	Wandie	9.3
Watts Creek	124.4	Howley	10449.6
Watts Creek	31.1	Mount Gates	21.7
Fountain Head	933.0	Arltunga	93.3

Table 2. Reported occurrences of gold nuggets from selected alluvial deposits (after Balfour 1987).

The main uses of gold are summarised in **Figure 4**. The industrial uses lies in its high electrical conductivity, chemical inertness, reflectivity, malleability and softness. The most common industrial use is in electronics, in a wide range of products such as the coating of vacuum tubes, electrical contacts, wire leads, printed computer circuits

Mine	Au	Ag	Fineness	Reference
Goodall	87.4	12.0	880	1
Eleanor	84.4	14.9	850	1
North Hercules	87.2	12.2	877	1
Cosmo Howley	89.8	9.4	905	1
Zapopan	86.5	12.3	867	1
Union Reefs	77.4	22.1	778	1
The Granites	94.4	4.1	958	2
Mount Todd	85.0	5.0	944	2
White Devil	87.0	7.0	925	2
Nobles Nob	80.0	7.0	919	2
Rustlers Roost	84.0	9.7	896	2
Union Reefs	64.0	36.0	640	2
Warrego (copper ore)			775–800	3
Warrego (margins of gold ore)			825–850	3
Warrego (gold pod)			925–1000	3

Table 3. Analyses of gold from selected Northern Territory deposits. References: 1 Wygralak (1996), all analyses by Proton Microprobe; 2 Mines and Energy, Northern Territory, records, all analyses are of ore by wet chemical methods; 3 Wedekind (1990), all analyses by Electron Microprobe. Au and Ag analyses in wt%.

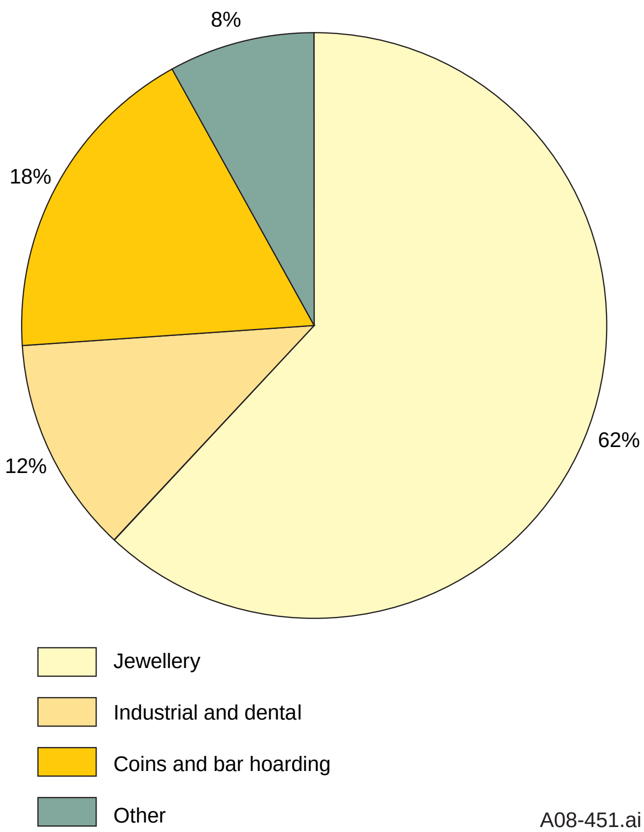

Figure 4. Pie chart showing principal users of gold in 2008 (total world gold supply of 3468 t included 2407 t mine production, 1146 t old gold scrap and 278 other sources; source World Gold Council: http://www.gold.org/).

and radio and television sets. Other industrial uses include lining of chemical and nuclear plants, high-temperature alloys, infrared and thermal reflectors in aircraft and space vehicles[5] and heat shields for jet and rocket engines.

Nearly 80% of current gold production is made into jewellery. Gold is also used for medical purposes; for example, disodium aurothiomalate is used in the treatment of rheumatoid arthritis, and approximately 50 t of gold is used each year in dentistry.

A feature of the 1990s was that gold has increasingly attracted the status of a commodity and less of a financial instrument. Consequently it has suffered a substantial downturn in price, which in July 1999 reached a bottom of $US252.80. This had adverse effects on the Australian gold mining industry in general, and the Northern Territory industry in particular. Since the early 2000s, due to a recovery in the global economy, the gold price has been gradually increasing, reaching a peak of US$1002.80 in March 2008 (**Figure 2**). There is a body of opinion that the price of gold may further rise over the next few years, driven by increased demand from countries like India and some countries in the Middle East. The results of current strong gold prices are reflected by increased mineral exploration.

[5] Nearly 41 kg of gold was used to build the Columbia space shuttle.

PROSPECTING FOR GOLD

Excellent accounts of the history, genesis, geochemistry and prospecting of gold deposits are given by Idriess (1995), which has an Australian perspective, and Boyle (1979, 1987).

The first step in prospecting is a general understanding of the geological setting of existing gold deposits. Almost all known gold deposits of the Northern Territory are located within metamorphosed Precambrian rocks or related alluvial sediments or regolith. This effectively reduces the search to the Pine Creek Orogen, Tennant Region, Murphy Inlier, Arnhem Province, Tanami Region, Arunta Region and Musgrave Province (**Figure 5**). Even in these areas, gold deposits are limited to particular rock types and suitable structures. In most cases, they are located in

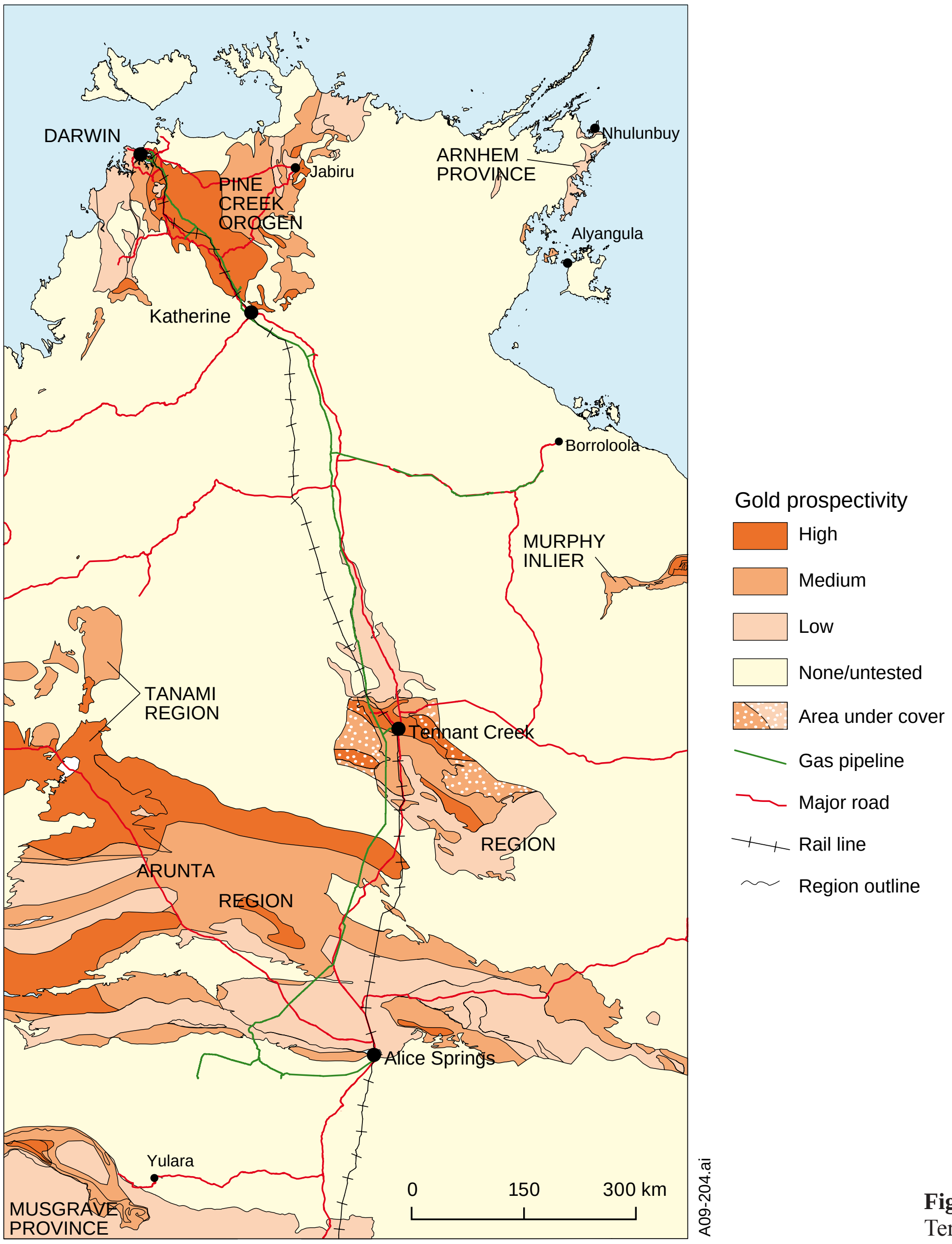

Figure 5. Gold prospectivity of Northern Territory geological provinces.

the vicinity of granitic intrusions. The Arnhem Inlier may also be considered prospective for gold, but has attracted insignificant exploration.

The second step is to carry out a database search on the location and characteristics of gold deposits. The Minerals and Energy InfoCentre of the Northern Territory Department of Regional Development, Primary Industry, Fisheries and Resources (DRDPIFR) has a wealth of information, in the form of exploration company reports, BMR/AGSO/GA publications and NTGS reports, maps and explanatory notes. Historical records are also available.

Many of the known gold deposits of the Northern Territory were discovered in the late nineteenth century by simple prospecting methods, relying on the density contrast between gold and the host rock. Panning (dishing) along creek beds and following leads was the most common exploration method. Current gold exploration techniques are briefly discussed below.

Geochemical methods

Chemical analyses of stream sediments, lags, soil horizons and rocks are currently the most widely used exploration techniques. Australian Institute of Geoscientists (1987, 1988) and Australian Mineral Foundation (Joyce 1984, 1989) publications on gold exploration describe the methods of sample collection and analytical procedures, and provide several Australian examples.

Stream sediment surveys are used for reconnaissance over a large area. Samples weighing 2 to 5 kg are collected from stream channels, then screened to remove coarse material. The screen size can vary considerably from area to area, depending on the size and characteristics of the gold particles, if gold is used as a pathfinder element. If nuggets are expected (eg Sandy Creek area), a larger screen size is required and the coarser fraction should be examined for gold. Gold is analysed at detection limits of 1 to 10 ppb for stream sediments and soils. Other elements analysed include arsenic (associated with most Northern Territory gold deposits), lead, zinc, silver and copper. Many exploration programs within the Northern Territory have used a screen size[6] ranging from 6 mm (mesh 3) to 2 mm (mesh 09). For other elements, including arsenic, the finer 180 µm (mesh 80) fraction is found to be more useful and representative. In many surveys, the entire sample is analysed for gold by the BLEG (Bulk Leach Extractable Gold) method, generally at a detection limit of 1 ppb.

Soil surveys are generally used as a follow up to the stream sediment sampling, in order to define and sharpen the anomaly. The method of sample collection depends on the topography, soil type and characteristics of the soil profile. On topographic highs (eg ridge tops), the upper part of the soil profile is generally enriched in gold (eluvial enrichment, lag). Along hill slopes and in topographic lows, gravity movements of the soil components result in the concentration of gold at the base of the soil profile. In truly residual soil profiles, gold may be present in any part of the profile and it is desirable to sample the whole profile. If other indicator minerals (eg arsenic) are present, then the iron-oxide rich B horizon is more useful, although other soil horizons should not be neglected.

An orientation survey to establish the best soil horizon for sampling is desirable at a n early stage of exploration. For example, in the Rum Jungle area, geochemical surveys that outlined the Woodcutters Pb-Zn-Ag deposit used the C horizon. In the Pine Creek Orogen and Tennant Region, the soil horizons are well developed and most soils are of residual lateritic type, except in the vicinity of active stream channels and along the coastline, where transported soils are present. The flood plains of some large rivers in the northern Pine Creek Orogen are covered with light grey soil, underlain by red-brown soil. Transported iron-rich pisoliths are present in the latter. A reconnaissance study by NTGS (Wygralak 1997) indicated that the light grey topsoil is depleted in all analysed chemical elements in comparison to the red-brown soil horizon – a feature probably related to the heavy leaching of soils in the tropical Northern Territory.

Large areas of the Tanami Region are covered by transported aeolian sand overlying a degraded lateritic profile that is, in turn, underlain by weathered bedrock. Surface soil samples were found to be of little use in this area, and geochemical exploration relies heavily on weathered bedrock sampling by drilling (Ireland 1995). Similar exploration methods were used in the Redback-Dogbolter area, 10 km southwest of the Tanami mine (Henderson *et al* 1995).

Geophysical methods

Geophysical methods are used at various stages of gold exploration, particularly in areas covered by Cenozoic soil. The earliest uses are for area selection and regional structural studies, prior to geochemical surveys. At this stage, airborne magnetic and radiometric surveys are used to interpret and better define the subsurface geology and structure, and the features of the regolith. Most Northern Territory gold deposits are located in the vicinity of major structural breaks. Anticlinal axes and iron-rich rocks are other suitable targets. Many of these features can be identified with the use of airborne geophysics.

Since 1981, NTGS and Geoscience Australia have conducted airborne radiometric surveys over more than 90% of the Territory. In addition, mineral exploration companies have conducted many detailed ground and airborne geophysical surveys in order to define detailed structures. The Minerals and Energy InfoCentre holds the data from most of these surveys.

Effective use of airborne magnetic data has been made for the Tennant Creek ironstone-hosted gold deposits. These deposits were detected as magnetic anomalies from airborne surveys, and were followed up by ground magnetic surveys and drilling.

It seems that few if any gold deposits have a direct geophysical signature, although magnetite- and pyrrhotite-associated lodes would be expected to have a magnetic response. Also, demagnetised zones may be expected in hydrothermal systems involving magnetite.

Although gold deposits in the Tanami Region have no direct magnetic signature, combinations of gravity and

[6] Tyler Standard Screen Sieve Series.

airborne magnetics have proved useful in delineating favourable stratigraphic and structural locations for such deposits.

Seismic methods are employed to investigate deep-crustal structures that may provide conduits for mineralised fluids and to study the 3D architecture of geotectonic units. A major seismic reflection project joint venture between Geoscience Australia, NTGS, Geological Survey of Western Australia, Newmont Australia Ltd and Tanami Gold NL, and involving 720 km of seismic lines was conducted in the Tanami Region in 2005. Several deep structural features likely to control gold mineralisation were located (Lyons *et al* 2006).

ORE TREATMENT: A SUMMARY

Historical gold mining at the turn of the twentieth century relied on the free-milling nature of gold. Alluvial gold was recovered by hand picking, screening and amalgamation. Crushing, grinding, screening, gravity separation and amalgamation constituted the main process for recovering reef gold. As mining was relatively selective and mostly by underground methods, there was relatively little waste, which was normally removed by hand sorting. The ore was hand crushed or fed to stamp batteries. Grinding was followed by gold extraction using gravity and amalgamation processes. Cyanidation was also used, mainly for extraction of gold from tailings.

Current mining and metallurgical practices largely involve open-cut mining and treatment of the ore by crushing and grinding, cyanidation and absorption onto carbon. Heap-leaching operations have been used at some mines. General metallurgical data on selected mines are summarised in **Table 4** and a brief summary of the processes is given below.

Gravity separation

This process is applied to ores containing free-milling, relatively coarse native gold and uses the density contrast between gold and rock particles (gravel, sand, clay and crushed rock). The product is discharged with water on to shaking (Wilfley) tables fitted with riffles. The lighter particles are washed down the table, whereas heavier particles, including gold ore, are caught in the riffles and move separately along the table to be collected.

Amalgamation

This is one of the earliest known methods of separation of gold from gangue, but this process is deleterious to health and the environment and is no longer used. The process relies on the amalgamation of gold in mercury. It was used on free-milling ores containing relatively coarse native gold. The mercury may be in liquid form or present as films on copper or silvered copper plate. Ground and crushed ore was passed over the surface of the plates, which were scraped every few hours to gather the amalgam. The mercury was recovered by distillation, leaving behind the gold.

Cyanidation

Gold is soluble in sodium or potassium cyanide to form aurocyanide. Ore is first ground with lime to -30 mesh size. This pulp is then fed to agitation tanks with a filter bottom and percolated with cyanide solution. Some initial treatment, usually involving pH buffering by lime, is necessary before cyanidation of most types of ores. For sulfide-rich ores, oxidising agents such as air, hydrogen peroxide, chlorine, bromine, cyanogen bromide, ozone or paramagnet are added to the slurry to improve leaching kinetics.

Mine	Ore type	Treatment method	Feed grade (g/t)	Plant capacity (t/day)	Recovery (%)	Reference
Brocks Creek	Free milling, low sulphides	Gravity, cyanide, CIL	1.65	3800	93.00	4
Cosmo Howley	Free milling, high sulphide	Heap leach, CIL	2.39	4600	97.00	1
The Granites	Free milling, high sulphide	Gravity, cyanide, CIP	5.02	3500	94.32	2, 8
Goodall	Free milling, semi-refractory	CIL	1.90	3200	87.40	3
Moline	Free milling, low sulphide	CIL	2.70	2700	84.70	3
Nobles Nob, White Devil	Free milling, low sulphide	Gravity, CIP, MC	20.00	290	95.50	3
Enterprise	Semi-refractory, low sulphide	CIP	3.50	2445	77.90	3
White Range	Free milling, high sulphide	Gravity, CIL	4.80	1500	94.80	3
Union Reefs	Free milling, low sulphide	Gravity, cyanide, CIL	1.40	4600	94.00	4
Tanami	Free milling, low sulphide	CIL	2.50	3800	92.00	4
Mount Todd	Free milling	Heap leach, CIL		17000		5
Rustlers Roost	Free milling, low sulphide	Heap leach, RIL	1.17	4000	80.00	6, 9
TC8	Free milling, low sulphide	CIP	20.00	1 60		7

Table 4. Summary of metallurgical data on selected Northern Territory gold mines. References: 1 Gloyne (1993); 2 Skrypniuk (1993); 3 Sparrow and Woodcock (1993); 4 Acacia Resources (1997); 5 Zapopan (1992); 6 Rustlers Roost Mining (1997); 7 Cuprex (1986); 8 North Flinders Mines (1995); 9 Rabone (1995). Abbreviations: CIL = Caron in leach, CIP = Carbon in pulp, RIL = Resin in leach, MC = Merrill Crow precipitation

Gold precipitation

Prior to the 1980s, recovery of gold from aurocyanide solution was by cementation with zinc dust (the Merrill-Crowe process). Nowadays, most operations employ the activated carbon adsorption method for the recovery of gold. The main advantages are greater gold recoveries and adaptability to small-scale operations. The method is also suitable for low-grade gold ores with low silver contents, which are characteristic of most Northern Territory gold deposits. Mount Bonnie and Iron Blow are the only known deposits with high silver and, in these deposits, silver was first removed by precipitation by sodium sulfide prior to carbon adsorption.

Two types of carbon adsorption are used: Carbon-in-Pulp (CIP) and Carbon-in-Leach (CIL). In some instances, instead of activated carbon, special resins are added (RIL), which adsorb dissolved gold by ion exchange. A typical CIL plant layout is shown in **Figure 6**. The ore passes through a grinding and milling circuit, after, which any coarse gold is recovered by gravity concentration. The pulp is then fed to the leach tanks. In the CIP method, gold is recovered after leaching by adsorption onto activated carbon in a series of tanks, into, which pulp and carbon are introduced counter to the flow. In the CIL process, leaching and adsorption are combined such that carbon is added to the first leach tank. Pure CIL is less common than 'hybrids' CIL; the first few tanks are for leaching and the later tanks are used for adsorption.

Heap leaching

In this process, low-grade ore, particularly from the oxidised zone, is crushed, screened and piled into heaps on polyethylene lined pads (**Figure 7**). Lime is added to the ore to control pH. Cyanide solution is then sprayed over the ore heap. The percolating cyanide dissolves most of the gold, and the "pregnant" fluid is collected in drains at the edge of the heap and pumped to a gold recovery circuit. This process has been used in some Northern Territory mines in the early stages of processing. It has the advantage of low initial capital cost, but generally suffers from low recovery compared with CIL plants. Operations at Mount Todd involved heap leaching of primary sulfide ore crushed to about 2 mm. This process was not successful for the hard, primary ore.

Bacterial oxidation

This is a relatively new method in which artificial bacteria similar to naturally occurring soil bacteria break down sulfide minerals to release otherwise refractory gold from ores. In deposits where there is little free gold and most gold is contained as submicroscopic inclusions within sulfides, the bacterial oxidation method provides an alternative for gold extraction. The bacterial oxidation method has been proposed for gold extraction at Maude Creek.

Smelting and refining

Gold and silver are desorbed from carbon using hot caustic soda and sodium cyanide solution. The resultant gold and silver cyanide solution is then pumped into an electrolytic cell where the precious metals are plated on steel wool cathodes. The loaded cathodes are normally acid treated to dissolve the steel and the gold residue is smelted in a furnace to produce bullion, which is generally a solid solution of gold and silver. Further refining into bullion (99.5% gold) is done offsite by the chlorination method. In this technique, the gold is remelted and chlorine gas is bubbled through it. The base metals and silver form chlorides, which float on the surface and are removed, leaving behind pure gold.

GEOLOGY OF THE NORTHERN TERRITORY

Geological regions

The Northern Territory is dominated by Palaeo- to Mesoproterozoic orogens and basins (**Figure 8**), with localised outcrop of Neoarchaean (2.7–2.5 Ga) granite and gneiss. Palaeoproterozoic orogens of the North Australian Craton form widespread and prospective basement (eg Pine Creek Orogen, Aileron Province, Tanami Region, Tennant Region), with protolith ages most commonly in the range 1.87–1.73 Ga. Further south, the Warumpi and Musgrave provinces represent more juvenile crust with ages of 1.69–1.07 Ga.

Widespread Palaeo-Mesoproterozoic basins (McArthur, Tomkinson, Birrindudu and South Nicholson basins) overlie much of the North Australian Craton and are connected beneath younger basins. These younger Neoproterozoic to Palaeozoic basins were linked for much of their history, but were substantially affected and dismembered by intraplate tectonics in central Australia.

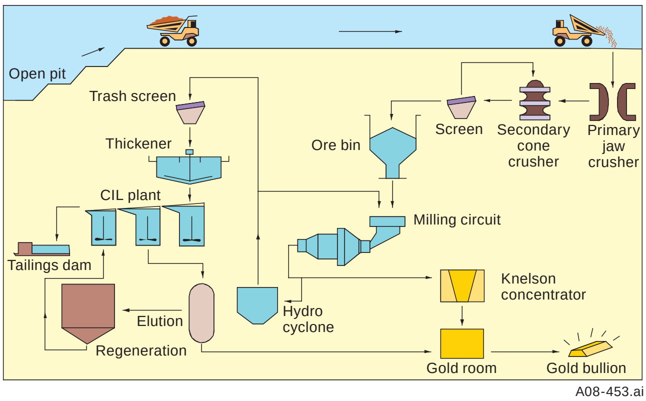

Figure 6. Typical Carbon-in-Leach (CIL) plant: gold processing circuit at Union Reefs mine (redrawn from 1996 Acacia Resources Annual Report).

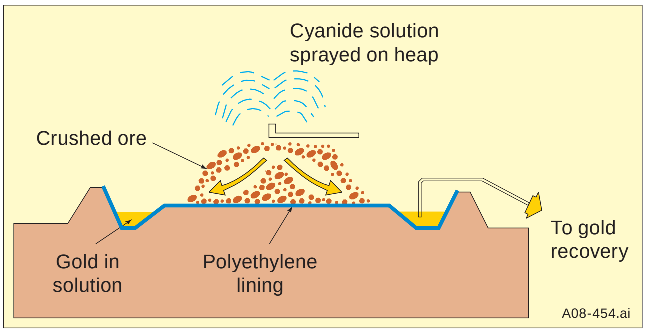

Figure 7. Heap leach process at Union Reefs mine (redrawn from 1996 Acacia Resources Annual Report).

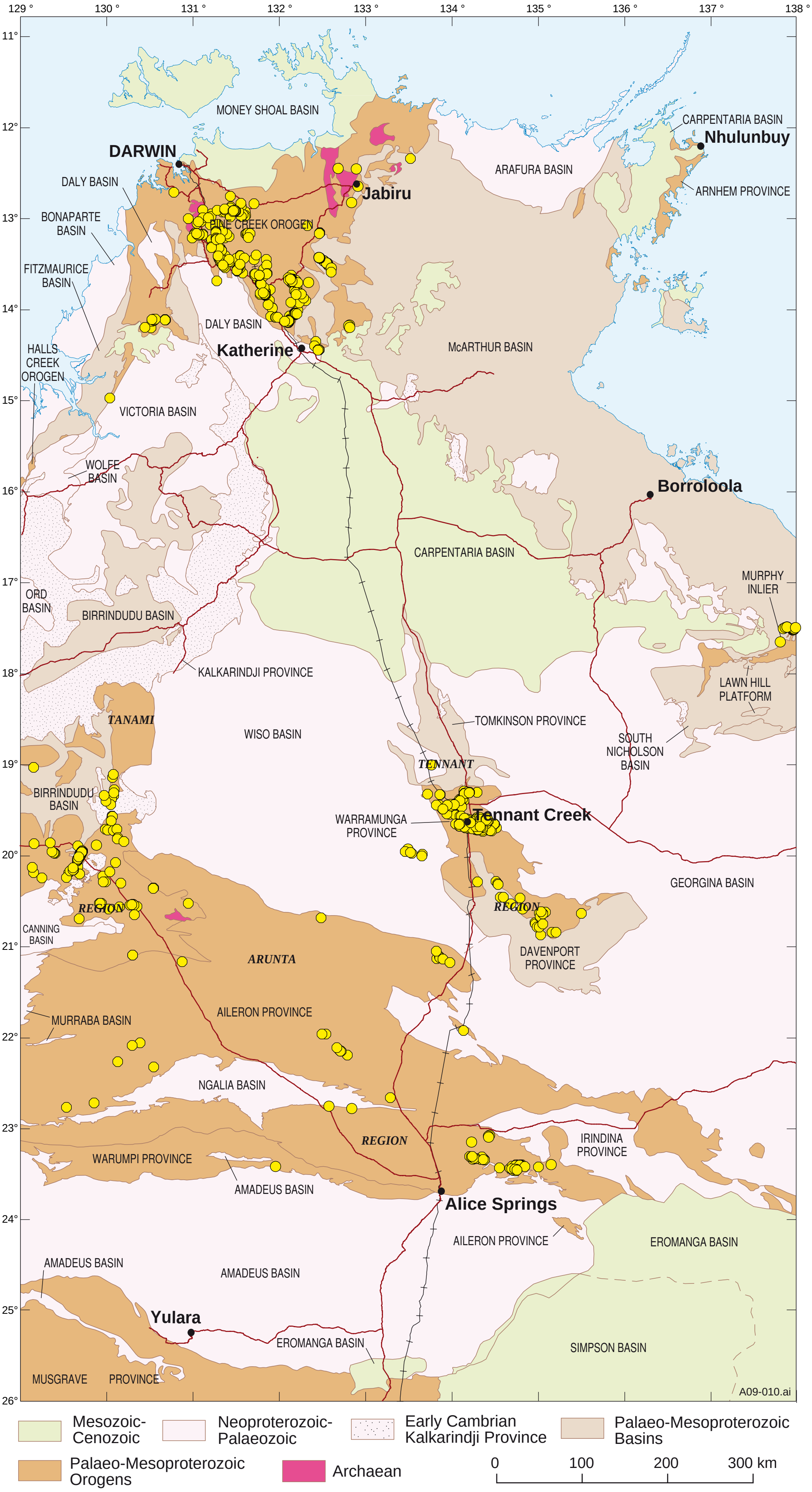

Figure 8. Major Northern Territory geological provinces and distribution of gold occurrences.

The Kalkarindji Continental Flood Basalt Province records a widespread Cambrian flood basalt event over much of the northern part of the Territory. Mesozoic to Cenozoic basins form widespread cover successions and are relatively undeformed.

Archaean inliers

A number of inliers of late Neoarchaean granite and felsic gneiss, with minor metasedimentary rocks outcrop as relatively small, poorly exposed inliers in the Pine Creek Orogen and Tanami Region. Known exposed Archaean basement has protolith ages in the range 2670–2500 Ma (Hollis *et al* 2009a). They form basement to overlying Palaeoproterozoic strata and have been the source for much of the detritus. This Archaean provenance is reflected in the SHRIMP dating of detrital zircons in sedimentary rocks from almost all provinces of the North Australian Craton.

Palaeo–Mesoproterozoic orogens

The orogenic domains of the North Australian Craton include the Pine Creek Orogen, Arnhem Inlier, Murphy Inlier, Warramunga Province, Halls Creek Orogen, Tanami Region and Aileron Province. Rocks of early Palaeoproterozoic age are currently only known in the Pine Creek Orogen, where the Woodcutters Supergroup, which directly overlies Archaean basement, has an age of 2030–2020 Ma (Worden *et al* 2008). Throughout the remainder of the orogenic domains of the North Australian Craton, most sedimentation, magmatism and deformation occurred in the interval 1870–1800 Ma. An exception is the Aileron Province, where significant tectonism and magmatism continued until the early Mesoproterozoic. This more complex evolution for the Aileron Province has been attributed to its proximity to a Palaeoproterozoic plate margin to the south or southeast (Scrimgeour 2006).

The Halls Creek and Pine Creek orogens, Arnhem and Murphy, inliers, Tanami Region and Warramunga Province underwent deformation and metamorphism in the period 1870–1830 Ma. The apparently similar timing of sedimentation, magmatism and deformation throughout much of the North Australian Craton led Etheridge *et al* (1987) to propose that the NAC was affected by a single tectonic event, which they named the Barramundi Orogeny. However, more recent studies have shown the 'Barramundi Orogeny' to reflect a series of spatially and temporally distinct events, with varying styles of tectonism, from intraplate extension (Carson *et al* 2008) to thrusting and crustal thickening (Hollis *et al* 2009b). The evolution of the North Australian Craton during this timeframe is now most commonly attributed to responses to plate margin tectonism, both proximal to the inferred margins and as intraplate responses within the craton (Myers *et al* 1996, Scrimgeour 2006, Cawood and Korsch 2008).

The timing of sedimentation and volcanism varies throughout the NAC. In the Pine Creek Orogen, deposition of the flysch succession and felsic volcanics of the South Alligator group occurred at 1865–1860 Ma, broadly synchronous with deposition of the Warramunga Formation in the Warramunga Province. In comparison, the turbiditic successions of the Tanami Region and Aileron Province (Killi Killi and Lander Rock formations) are likely to have been deposited at 1845–1835 Ma, at a similar time to shallower-marine sandstone and felsic volcanic rocks of the lower Ooradidgee group of the Tennant Region. At 1825–1810 Ma, deposition of sandstone and felsic volcanic rocks occurred in the Pine Creek Orogen (El Sherana and Edith River groups) and in the Tanami Region (Ware Group) and Tennant Region (lower Hatches Creek Group). Younger metamorphosed basin packages, with ages in the range 1810–1750 Ma occur in the Aileron Province, and include rocks interpreted to have been formed in back-arc settings (Scrimgeour 2006).

The southern margin of the NAC has been defined by Close *et al* (2004) as a series of faults that separate the Aileron and Warumpi provinces; these have been collectively termed the Central Australian Suture. South of this suture, the Warumpi Province comprises greenschist- to granulite-facies rocks with ages in the range 1690–1610 Ma. The province has been interpreted as an exotic terrane that accreted onto the NAC at around 1640 Ma (Scrimgeour *et al* 2005a).

In the southwestern Northern Territory, the Mesoproterozoic Musgrave Province represents relatively juvenile continental crust in comparison with the NAC. The main elements of the Musgrave Province within the NT are felsic gneisses with ages in the range 1600–1540 Ma, voluminous granites with ages of 1200–1140 Ma, and rift-related sedimentary and bimodal magmatic rocks with ages in the range 1080–1060 Ma (Edgoose *et al* 2003).

In a general sense, the timing of the dominant phases of granitic magmatism youngs in a southerly direction throughout the Palaeo- to Mesoproterozoic of the Northern Territory, from 1865–1850 Ma in the north, through 1850–1840 Ma in the Warramunga Province, 1820–1790 Ma in the Tanami Region and northern Aileron Province, 1780–1750 Ma in the southern Aileron Province, 1690–1630 Ma in the Warumpi Province to 1200–1140 Ma in the Musgrave Province.

Palaeo–Mesoproterozoic basins

Palaeo- to Mesoproterozoic basins of northern Australia include the McArthur, Tomkinson, Birrindudu, South Nicholson and Fitzmaurice basins, the Davenport Province and the Lawn Hill Platform. With the exception of the Davenport and Fitzmaurice basins, these basins are relatively weakly deformed, with localised areas of higher deformation in fault zones. Metamorphic grade is generally sub-greenschist facies. The McArthur, Tomkinson and Birrindudu basins are all interpreted to be part of a single large basin that is linked at depth beneath the overlying Carpentaria, Georgina, Wiso and Daly basins.

The basal succession of these linked basins has an age in the range 1800–1710 Ma, and is represented by the Redbank package (Rawlings 1999) in the McArthur Basin, the Tomkinson Creek Group in the Tomkinson Province, and the Tolmer and Birrindudu groups in the Birrindudu Basin. This succession is succeeded by a stromatolitic and evaporitic carbonate-sandstone-shale package, comprising the McArthur, Namerinni and Limbunya groups, in each basin respectively, which were deposited at about

1650–1630 Ma. The third package is regionally extensive and represents stromatolitic carbonate and sandstone deposited in sag basins, including the 1620–1580 Ma Nathan group in the McArthur Basin. Predominantly shallow marine sandstone deposition in epicontinental basins represents the fourth package, which includes the Roper Group and South Nicholson Group (ca 1500–1400 Ma).

The Fitzmaurice Basin, which contains the Fitzmaurice Group, is a Palaeo- to ?Mesoproterozoic basin with uncertain lithostratigraphic affinities that underwent deformation in the Palaeozoic.

Neoproterozoic to Palaeozoic

Unconformably overlying the Palaeo- to Mesoproterozoic of the NT is the Neoproterozoic Centralian Superbasin, which following Walter *et al* (1995), is subdivided into four successions (Supersequences 1–4; $P10_1$ to $P10_4$ of Ahmad 2000). This includes Neoproterozoic sedimentary rocks of the Amadeus, Murraba, Ngalia, Wiso, Georgina and Victoria basins. The sedimentary rocks were deposited in an extensive intracratonic basin, controlled largely by extension. Supersequence 1 ($P10_1$) comprises sandstone, carbonate rocks, evaporites and fine siliciclastic rocks (including the Heavitree Quartzite and Bitter Springs Formation in the Amadeus Basin), that are interpreted to have been deposited at 850–800 Ma. Supersequence 2 is marked by glaciogenic (Sturtian glaciation) sedimentary rocks, followed by silt and shale with interbedded carbonate and sandstone (Areyonga and Aralka formations and equivalents). Supersequence 3 represents glaciogenic sedimentary rocks (Marinoan glaciation) at the base, followed by siltstone, shale, and sandstone and carbonate. Supersequence 4 represents a dominantly arenaceous succession that includes the Arumbera Sandstone and equivalents in the Amadeus Basin, the Bukalara Sandstone of the northern Georgina Basin and the Wessel Group of the Arafura Basin. The Centralian Superbasin succession was deformed during the 580–520 Ma Petermann Orogeny and 400–300 Ma Alice Springs Orogeny (Haines *et al* 2001), and these events exhumed basement and led to the dismemberment of the superbasin into its constituent basins.

Extensive regions of northern Australia are covered by volcanic rocks and associated sedimentary rocks of the Early Cambrian (507 ± 4 Ma) Kalkarindji Continental Flood Basalt Province (Kalkarindji Province), which is a Large Igneous Province that extends across vast regions of northern Australia (Glass 2002, Glass and Phillips 2006). In the Northern Territory, it includes the Antrim Plateau Volcanics and Helen Springs Volcanics[7]. Airborne magnetic data shows the province to be a widespread terrane flooring the Ord, Daly, northern Wiso and northern and central Georgina basins.

The Irindina Province (Scrimgeour 2003) forms part of the Arunta Region, and is a highly metamorphosed Neoproterozoic to Cambrian basin that includes correlatives of the Centralian Superbasin. Until the late 1990s, rocks of the Irindina Province were thought to be Palaeoproterozoic in age (Ding and James 1985, Collins and Shaw 1995). The province includes a thick metasedimentary succession (Harts Range Group) with subordinate igneous units, including metabasalt, mafic to ultramafic intrusions, granite and pegmatites. Mafic magmatism in the Irindina Province may be in part related to the same event that resulted in the extrusion of volcanic rocks of the Kalkarindji Province. The Irindina Province is interpreted to be a deep transtensional rift basin that formed within the Centralian Superbasin before being metamorphosed and exhumed in the Palaeozoic.

Large areas of the central to northern Territory are covered by shallow Cambro–Ordovician platform sedimentary rocks, predominantly carbonates, forming the Daly, Ord, central to northern Wiso and central to northern Georgina basins. The southern Georgina, southern Wiso, Ngalia and Amadeus basins contain thicker Palaeozoic successions that include foreland basins associated with Palaeozoic tectonism. The onshore Bonaparte Basin, along the western margin of the Top End, contains sedimentary rocks that range in age from Cambrian to Permian; this succession was affected by syn-sedimentary faulting during the Devonian to Carboniferous.

Mesozoic to Cenozoic

Large areas of the Northern Territory are covered by a relatively thin veneer of Mesozoic to Cenozoic sedimentary rocks. The dominant Mesozoic basins in the Northern Territory are the Eromanga Basin, the Carpentaria Basin (including the former Dunmarra Basin; see Munson *et al* in press) and the Money Shoal Basin, as well as offshore elements of the Bonaparte and Arafura basins. Cenozoic sedimentary rocks are confined to basins of a relatively limited areal extent, and are particularly common in central Australia where they reach depths of up to 250 m.

ARUNTA REGION

The Arunta Region is a vast area of variably metamorphosed metasedimentary and igneous rocks in central Australia that remains underexplored for gold. Most historical gold production in the Arunta Region was sourced from the Arltunga and Winnecke goldfields, which produced 2758 and 41 kg of gold, respectively.

Given the strong geological affinities between the gold-rich Tanami Region and the adjacent Aileron Province of the Arunta Region, gold exploration programs have being conducted over areas of the northern and western Arunta Region. This has led to discoveries of new gold prospects, for example in the Lake Mackay and Reynolds Range regions (Exodus Minerals Ltd, ASX Announcement, 6 May 1998, Tanami Gold 2006), although extensive areas remain unexplored. The Arunta Region is also attracting increasing exploration interest for iron-oxide copper-gold mineralisation.

Regional geology

The Arunta Region comprises polymetamorphic terranes that cover an area of 200 000 km^2. It has a complex

[7] Antrim Plateau Volcanics and Helen Springs Volcanics are synonymous Nutwood Downs Volcanics and Peaker Piker Volcanics, respectively.

stratigraphic, magmatic and tectonic history that spans the Palaeoproterozoic to the Palaeozoic. Early geological frameworks for the Arunta Region (Shaw *et al* 1984, Stewart *et al* 1984, Collins and Shaw 1995), have been substantially revised by NTGS remapping, complemented by geochronology and other specialist studies from Geoscience Australia and universities (eg Hand and Buick 2001, Buick *et al* 2005). In particular, this has led to a revised subdivision of the Arunta Region into three provinces with distinct protolith ages and histories; the 1860–1700 Ma Aileron Province, the 1690–1600 Ma Warumpi Province, and the Neoproterozoic to Cambrian Irindina Province (Scrimgeour 2003).

The Aileron Province (Scrimgeour 2003) comprises Palaeoproterozoic crust in the Arunta Region that formed as part of the North Australian Craton prior to 1700 Ma. It contains most known gold mineralisation in the Arunta Region. Almost all known metasedimentary successions in the Aileron Province are believed to have been deposited within the interval 1860–1740 Ma, and the majority of magmatism occurred in the interval 1820–1700 Ma. Major tectonothermal events occurred at 1810–1790 Ma (Stafford Event), 1780–1760 Ma (Yambah Event) and 1735–1690 Ma (Strangways Event). The Aileron Province contains units that are considered to be direct stratigraphic correlatives of units in the Tanami Region to the northwest and Tennant Region to the northeast. This includes the ca 1840 Ma Lander Rock Formation, which covers large areas of the northern and western Aileron Province and is a correlative of the Tanami Group in the Tanami Region. Towards the southeast, the province is increasingly affected by what has been interpreted to have been a Palaeoproterozoic convergent margin on the southern margin of the craton. Parts of the Aileron Province were strongly reworked in the early Mesoproterozoic Chewings Orogeny and in a series of intraplate events during the Palaeozoic, including the 450–300 Ma Alice Springs Orogeny.

The Warumpi Province is an east-trending terrane that extends along the southern margin of the Arunta Region, west of Alice Springs. The province was defined by NTGS after regional studies identified that the terrane has distinct protolith ages and isotopic characteristics from the remainder of the Arunta Region (Scrimgeour 2003, Close *et al* 2004, Scrimgeour *et al* 2005a). The province is characterised by rocks with a protolith age in the range 1700–1600 Ma, including metasedimentary successions dated at 1660–1640 Ma and 1640–1600 Ma, and magmatic suites at 1680–1660, 1640–1630 and 1610–1600 Ma. It has been interpreted as an exotic terrane that accreted to the NAC at ca 1640 Ma (Scrimgeour *et al* 2005b).

The Irindina Province is a highly metamorphosed Neoproterozoic to Cambrian basin that includes correlatives of the Centralian Superbasin. The province includes a thick metasedimentary succession (Harts Range Group) with subordinate Palaeozoic igneous units, including metabasalt, mafic to ultramafic intrusions, granite and pegmatites. Until the late 1990s, rocks of the Irindina Province were thought to be Palaeoproterozoic in age (Ding and James 1985, Collins and Shaw 1995), but a large amount of geochronology has confirmed that the protoliths of these high-grade metasedimentary rocks were deposited in the Neoproterozoic and Cambrian (Buick *et al* 2005, Maidment 2005). The close similarity between the detrital zircon signatures of the Harts Range Group and the Amadeus and Georgina basins, coupled with similar changes in provenance with time, indicates that the Harts Range Group includes high-grade metamorphic equivalents of the unmetamorphosed basin successions (Buick *et al* 2005, Maidment 2005), although it formed a much deeper sub-basin in the late Neoproterozoic to Cambrian. The Irindina Province was metamorphosed at granulite- to amphibolite-facies conditions during the Ordovician Larapinta Event, and was exhumed during the Alice Springs Orogeny.

The overlying Amadeus Basin comprises a 9000 m-thick Neoproterozoic to Palaeozoic sedimentary succession, which formed part of the much more extensive Centralian Superbasin. The base of the Amadeus succession is formed by the Neoproterozoic Heavitree and correlative Dean quartzites, which are conformably succeeded by carbonate sedimentary rocks, shale and evaporite of the Bitter Springs Formation (Wells *et al* 1970, Lindsay and Korsch 1991). The latter is in turn, succeeded by a diverse succession of glacial sedimentary rocks, shale, redbeds, orthoquartzite, carbonate rocks and evaporite. Sedimentation in the Amadeus Basin concluded with the deposition of molasse conglomerate and sandstone of the Pertnjara Group.

Gold mineralisation

Significant gold mineralisation occurs in a zone of greenschist-facies deformation, associated with structural interleaving of the Arunta Region and basal Amadeus Basin in nappe-thrust complexes formed during the Alice Springs Orogeny.

The main gold-bearing areas are the Arltunga and Winnecke goldfields, east of Alice Springs. Mineralisation consists of quartz veins containing auriferous pyrite and minor chalcopyrite. These are hosted by the basement rocks of the Arunta Region and are also found within deformed Heavitree Quartzite and Bitter Springs Formation of the Amadeus Basin succession.

The timing of mineralisation in these goldfields is likely to be largely related to the Carboniferous Alice Springs Orogeny. Warren *et al* (1974, 1975) suggested two episodes of gold mineralisation; the first was related to the basement Arunta Region succession, and the second involved remobilisation into cover sedimentary rocks during the Alice Springs Orogeny. The age of the lodes in the Heavitree Quartzite is presumed to be 322 Ma (Carboniferous), based on K-Ar dating of muscovite associated with quartz pods from the Arltunga Nappe Complex (Stewart 1971). Later $^{40}Ar/^{39}Ar$ studies have generally confirmed these dates (Dunlap and Teyssier 1995). Wygralak and Mernagh (2008a) reported $^{40}Ar/^{39}Ar$ ages of sericitic alteration related to ore-stage quartz veining in the range 342–320 Ma.

Gold-quartz veins

Gold-quartz vein deposits are present in a variety of rock types including quartzite, tonalite, schist and gneiss of the deformed Heavitree Quartzite, and the Atnarpa Igneous Complex, Cadney Metamorphics and Bitter Springs

Formation. Economically significant deposits are within the Heavitree Quartzite at White Range, where gold is coarse grained and often visible to the naked eye. Pyrite is the most common sulfide, but minor chalcopyrite and galena are also generally associated with auriferous quartz veins. Most veins are discordant to bedding and schistosity.

Arltunga goldfield

The Arltunga goldfield is located some 110 km northeast of Alice Springs and covers an area of approximately 110 km^2 (**Figure 9**). Alluvial gold was discovered in this region in 1887 and reef gold shortly thereafter (Hossfeld 1937c). A government battery was erected in 1897. During the same year, gold was discovered in the most productive part of the goldfield, the White Range area. Mining activities were conducted on a more or less constant level until 1912, after, which it started to decline and the Government Battery was sold in 1934. Total recorded production amounted to 466 kg, excluding any alluvial gold won from the area. The main problem with the field was the scarcity of water. Several wells were dug, but no major water supplies were obtained.

During 1934–1936, small, but rich reefs were discovered at Claraville about 4 km northeast of Arltunga. A small battery was erected and some gold was produced.

During 1979–1980, high gold prices attracted some interest to the White Range area. In 1983, White Range Mines Pty Ltd constructed a modern treatment plant that was capable of recovering free gold, but was unsuitable

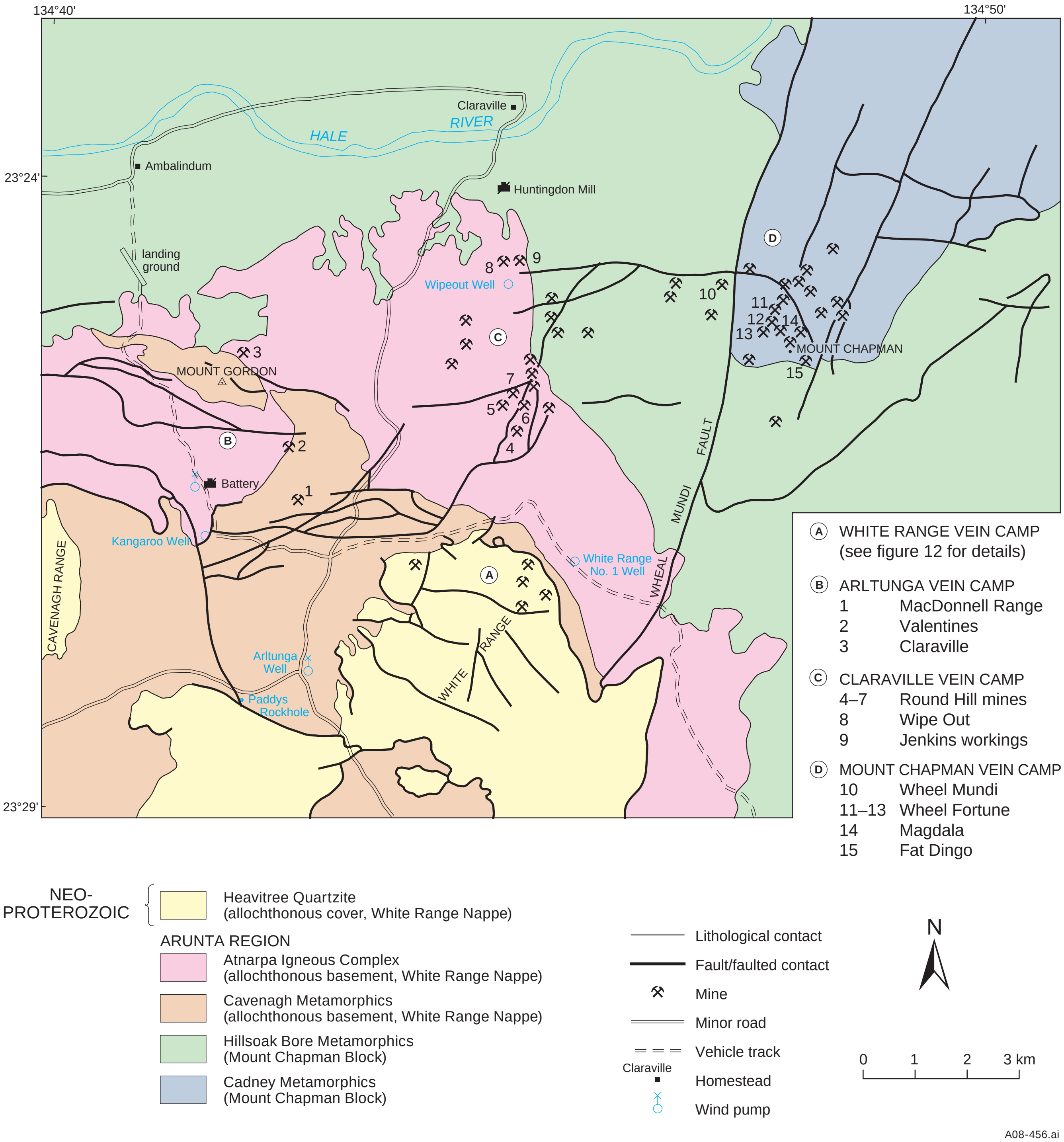

Figure 9. Generalised geology of Arltunga goldfield (after Mackie 1986).

for sulfide treatment (Mackie 1986). During 1989–1991, the same company carried out large-scale open-cut mining operations (**Figures 10**, **11**).

Recorded reef gold production from the Arltunga goldfield includes 4.8 kg from alluvial deposits in 1887–1890, 466 kg between 1890–1984 (Mackie 1986) and 1726 kg produced from 0.7 Mt of ore (2.5 g/t Au) at White Range during 1989–91 (Cowie 1993). Re-treatment of the waste rock dump commenced in February 1998 (total resource of 1.9 Mt at 0.8 g/t Au), to produce 147.3 kg Au to December 1998. Therefore, the total recorded gold production from the Arltunga goldfield between 1887 and 1998 was 2344 kg Au[8].

On the basis of location and geology, the Arltunga goldfield can be divided into four separate areas called "vein camps".

White Range vein camp provided 81% of the gold produced by the Arltunga battery during 1899–1934 (Mackie 1986). It was the only area subjected to modern mining operations. Historically, the biggest producers were the *Luces* and *Excelsior* mines, which, together with several other old workings, were incorporated into the 1989–91 mining operation.

The White Range reefs, which have been mined to a depth of 30 m, comprise quartz veins striking 070–090°, often arranged in an en echelon pattern; they dip 60–70°S and are hosted by the Heavitree Quartzite within the White Range Nappe (**Figure 11**). Auriferous quartz occupies tension gashes, fractures and breccia zones related to the Alice Springs Orogeny.

The reefs are composed of milky quartz, which contains veins, stringers and small pods of pyrite (**Figure 12**), together with chalcopyrite, minor covellite and chalcocite. At the surface, sulfides are oxidised to goethite, which forms cellular boxworks. Gold is fine grained, up to 0.3 mm, and is associated with an iron oxide boxwork. In the primary zone, gold forms minute inclusions in chalcopyrite, and to a lesser extent, in pyrite (Mackie 1986). Where reefs intersect siltstone interbeds, sericitic and argillic alteration can be observed along vein edges.

Claraville vein camp is situated 4.5 km north of White Range. There, the mineralisation is located in shears trending north-northeast and hosted by retrograded tonalite, gneiss and granite of the Atnarpa Igneous Complex. The important workings are *Wipe Out*, *Jenkins* and *Round Hill*. The lodes comprise narrow zones (ca 1m wide) of 0.01–0.3 m-thick near-vertical veins composed of ferruginous quartz, calcite and siderite. Gold is associated with goethite. No pyrite occurs in the workings, but it may be present at depth (Warren *et al* 1974).

Mackie (1986) reported 41.7 g/t Au, 2.0 g/t Ag and 0.07% Cu in a sample from the Round Hill workings. If the concentration of auriferous veins proved sufficient, future large-scale bulk mining could be considered.

Mount Chapman vein camp is located 6 km northeast of White Range and comprises numerous small workings, including *Wheal Fortune*, *Wheal Mundi*, *Magdala* and *Fat Dingo*. The Mount Chapman camp is bounded to the east by the Wheal Mundi Fault, which strikes 015° for about 10 km. Narrow auriferous quartz veins associated with shear zones are often arranged in en echelon, and strike parallel to the Wheal Mundi Fault. The main reefs dip 80° west and are hosted by gneiss, schist and calc-silicate rocks of the Cadney Metamorphics. Gold occurs as free grains or is associated with sulfides. In some workings (eg Magdala), the most common sulfide is chalcopyrite, which is altered near the surface to iron oxides, bornite and malachite. Sulfides and gold also occur in the wallrock.

Wheal Fortune workings reached a depth of 36 m and entered massive sulfides. A sample of massive sulfide-quartz ore taken by Matthews (1905) from the nearby ore dump assayed 132 g/t Au.

Arltunga vein camp includes mines within a 3 km radius of the Arltunga Battery. The main producers were *McDonnell Reef*, *Claraville* and *Valentine*. Reefs strike 060–110° and dip steeply north or south, except the McDonnell Reef, which has a shallow dip (15°N). The host rock comprises retrograde granite, tonalite and schist of the

[8] According to Mines and Energy, Northern Terrritory records of the Northern Territory Geological Survey, total gold production from the Arltunga and Winnecke goldfields is higher and amounts to 2799.4 kg Au.

Figure 10. Mining operations at White Range mine. Open cut is in Heavitree Quartzite.

Atnarpa Igneous Complex. Part of the Valentine workings are also hosted by metasedimentary rocks of the Cavenagh Metamorphics.

Apart from iron oxides occupying boxwork, the quartz reefs contain pyrite, minor cuprite and malachite. Some reefs (Claraville) contain a considerable amount of silver-bearing galena. Alteration includes chlorite, sericite and kaolin.

Winnecke goldfield

The Winnecke goldfield forms a 15 km-long easterly-trending belt southwest of the Gardens homestead. The Winnecke goldfield was discovered at the close of the nineteenth century and by 1903, a substantial part of the field was under claim (Hossfeld 1940c). Initially, gold was treated at the Arltunga Battery, but in 1905, a new battery was erected at the Winnecke goldfield. Most extensive mining activities in the field took place in 1901–1905 and, to a lesser extent, between 1933 and 1937. Some mining was also carried out thereafter. Total recorded production from this goldfield is 41.4 kg Au including 3.9 kg Au produced from alluvial deposits. Hossfeld (1940c) considered that the actual production may have been much higher, because a considerable amount of gold won in the early days was not officially recorded.

Deformed and retrogressively metamorphosed rocks of the Arunta Region basement host most of the gold. Some mineralisation also occurs in deformed and metamorphosed Heavitree Quartzite (eg *Ciccone*) and the Bitter Springs Formation of the Amadeus Basin succession (eg *Patsys Show*).

Two types of gold mineralisation can be distinguished. The main type consists of quartz veins, in which gold is concentrated in portions of the veins composed of cellular

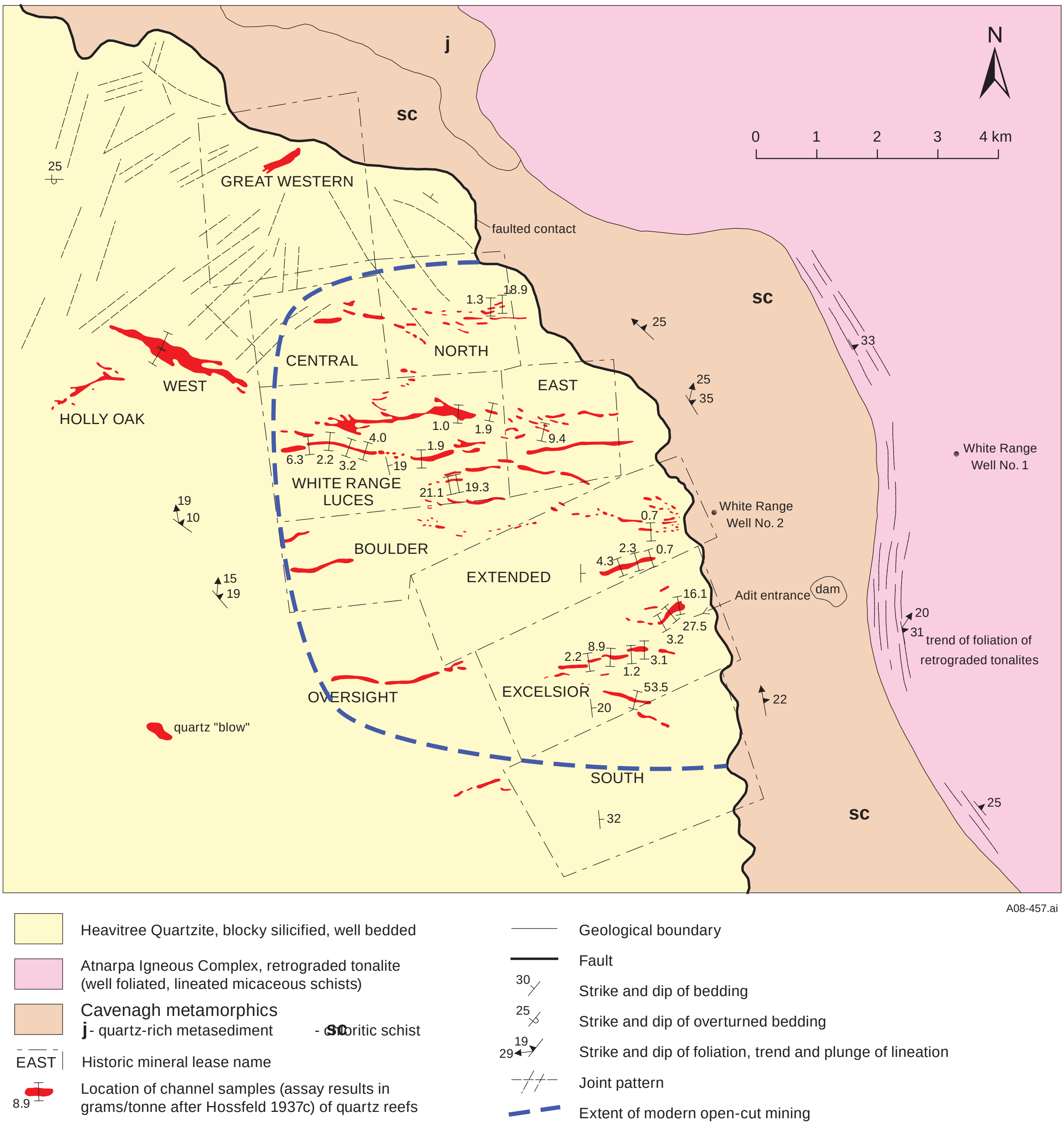

Figure 11. Geology and historic mining tenements in White Range vein camp (after Mackie 1986).

goethite. These concentrations form irregular patches in otherwise barren pods and "blows" of milky white quartz. The goethite is formed by oxidation of pyrite, which occurs in unoxidised ore about 12 m below the surface. The second type includes stratabound mineralisation in altered quartz-muscovite-kaolinite schist, graphitic schist or sericitic schist. Both styles of mineralisation are present in the Golden Goose workings.

During the mid-1980s, extensive exploration at the Winnecke goldfield was conducted by Australian Anglo-American Ltd (Piggot 1984, 1985), concentrating on the Golden Goose, Coorong and Ciccone workings. Sampling of the underground workings at Golden Goose returned 3.76 g/t Au over a horizontal distance of 18 m at a depth of 39–41 m (cut-off grade 1 g/t Au). This indicates that economic gold grades persist below the zone of oxidation. Subsequent drilling (four holes totalling 380.7 m) failed to intersect economic mineralisation, but the drillholes were possibly too shallow to fully test the gold potential of the primary zone (Piggot 1985).

Other gold occurrences

Several small, but possibly significant occurrences are located in the northern Aileron Province, including *Lander 1*, *Aileron Gold Reef* and *Pine Hill*, located north and northwest of the Reynolds Range. These occurrences are hosted within shale, schist and phyllite of the Lander Rock Formation. This unit is a possible stratigraphic equivalent of the Tanami Group and Warramunga Formation, which host the Tanami and Tennant Creek goldfields. In these occurrences, gold is contained in quartz veins and is associated with pyrite and arsenopyrite.

Figure 12. Quartz vein containing patches of auriferous pyrite, White Range mine.

Exodus Minerals Ltd reported an apparently different style of mineralisation in the Reynolds Range region, at the *Falchion* and *Sabre* prospects, which are hosted within the Lander Rock beds (Exodus Minerals Ltd, ASX Announcement, 6 May 1998). These prospects lie within a prospective corridor that includes the Callie and The Granites gold mines, and which extends through to the Coyote gold mine area in Western Australia, some 300 km to the northwest (**Figure 13**).

The Sabre-Falchion anomaly extends for 3 km along strike. Mineralisation is present as multiple pods of stockworks or sheets of centimetre-scale quartz veins within altered metagreywacke. Individual mineralised pods are 50–100 m long and some of them are probably plunging. Concordant fine- to medium-grained mafic rocks that are present in this succession are also mineralised.

Drill sampling gave peak values of 25 g/t Au and 3.3% Sb (best intersection 30 m at 2.5 g/t Au) at Sabre, and 14 g/t Au and 7.2% Sb (best intersection 12 m at 3.9 g/t Au and 4.2% Sb) at Falchion. Silver values of up to 300 g/t were also encountered.

At the *Abrolhos* prospect, 7 km west-southwest of McDiarmid Hill in MOUNT THEO[9], wide zones of low-grade gold mineralisation have been intersected by drilling, with higher grade intervals including 4 m at 2.5 g/t Au.

Historical gold workings occur at *Waldrons Hill*, near the northern margin of the Aileron Province, in a shear zone within rocks mapped as Lander Rock Formation, and dump material from the workings has assayed 5 ppm Au (Warren *et al* 1974).

The Lake Mackay area was effectively unexplored until after 2000, when Newmont Australia and then Tanami Gold NL began exploration for gold in amphibolite-facies metasedimentary rocks of the Lander Rock Formation. The *Tekapo* prospect (**Figure 14**) is a gold-copper prospect hosted by high-grade Lander Rock Formation, 30 km west-northwest of Mount Nicker. The prospect was discovered by Tanami Gold in 2005, as a gossanous ironstone that was traced in sporadic outcrops and lag surface material over a strike length of almost 500 m. Surface sampling of the ironstone in July 2006 returned assay results peaking at 3.1 g/t Au. A drill program at Tekapo in 2006 returned an intersection of 16 m at 3.4 g/t Au. (Tanami Gold NL, ASX Announcement, 27 September 2006). Follow-up drilling intersected significant copper mineralisation including 4 m at 2.7% Cu and 4 m at 3.27 g/t Au. Pink-red haematite alteration has been observed in fresh rock, suggesting that this may be an iron-oxide copper-gold system (Tanami Gold NL, ASX Announcement, 27 September 2006). Other significant prospects includes *Dodger,* which has rock chip samples assaying up to 10.8 g/t Au and 12.2% Pb, and a best drill intercept of 3 m at 2.3 g/t Au (Tanami Gold NL, ASX Announcements, 30 July 2004 and 28 October 2004).

9 Names of 1:250 000 mapsheets are in upper case.

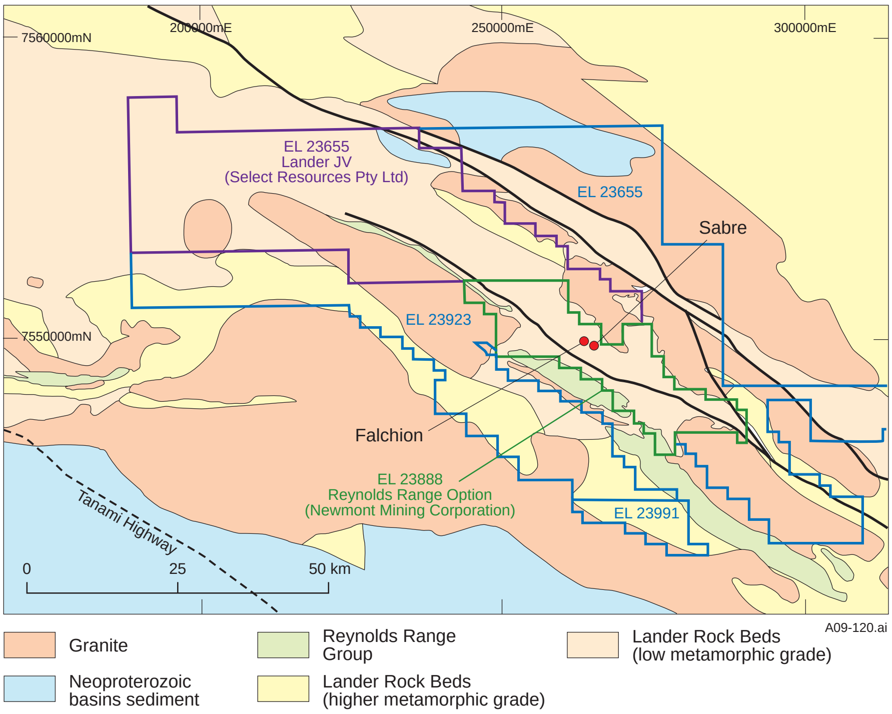

Figure 13. Geological location of Sabre and Falchion prospects (adapted from Tanami Gold Quarterly Report, 31 December 2005).

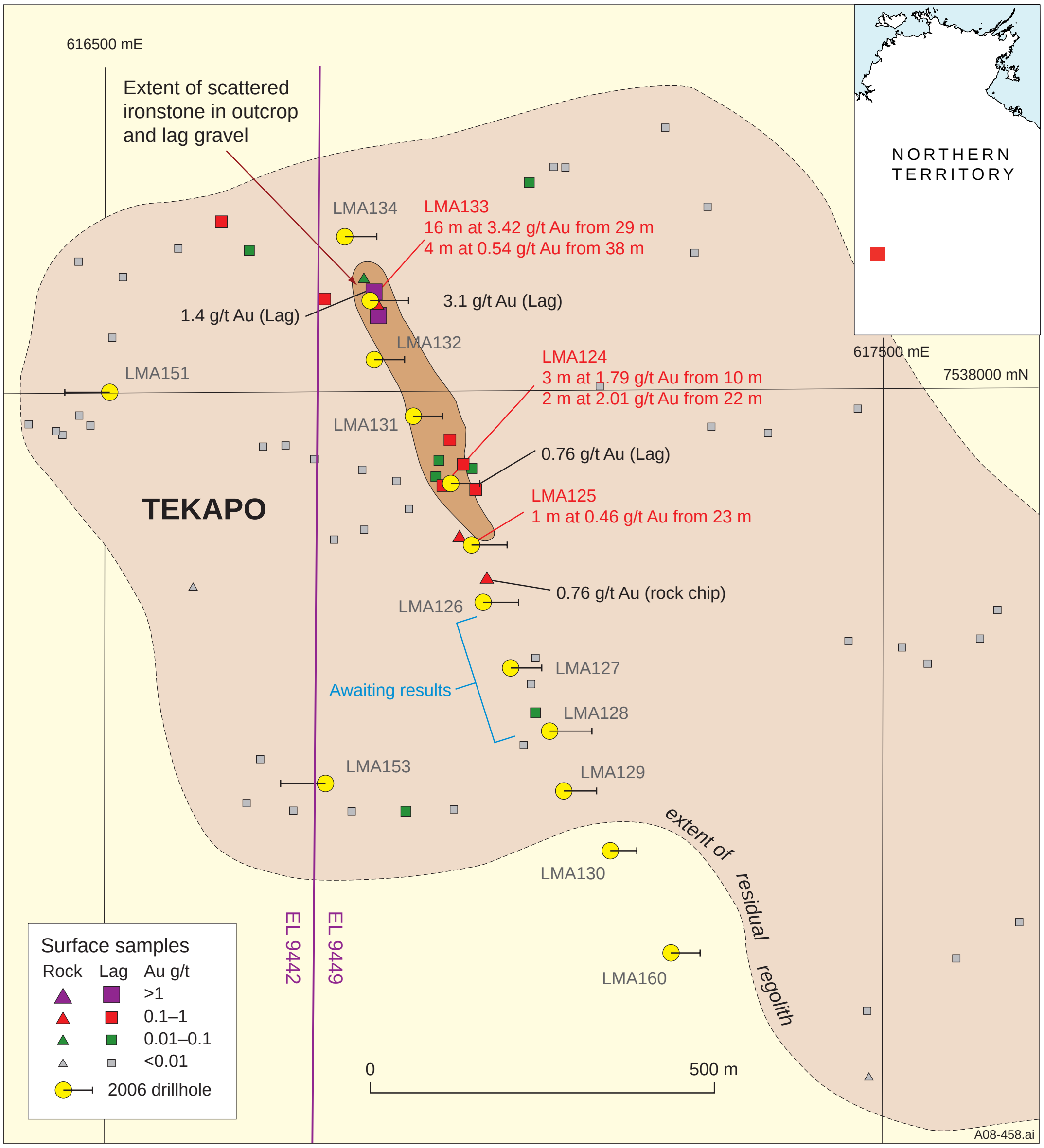

Figure 14. Tekapo prospect (from Tanami Gold 2006).

Polymetallic deposits

Gold also occurs within some base metal deposits in the Arunta Region. The *Johnnies Reward* Cu-Pb-Au-Zn-Ag prospect was originally interpreted to be a VHMS deposit (Warren and Shaw 1995), but is now considered to have more affinities with IOCG deposits (Huston *et al* 2006). It is hosted by the lower part of the Cadney Metamorphics, which consists mainly of metapelite, quartzofeldspathic gneiss and felsic granulite (op cit). The host unit consists of an apparently stratiform body of diopside-tremolite-magnetite rock that extends for about 200 m along strike and is up to 50 m wide. The footwall to the lode rock at Johnnies Reward is characterised by quartz-garnet-biotite-feldspar gneiss, with minor magnetite, spinel and orthopyroxene. Chalcopyrite and pyrite are present at depth (Chuck 1984, 1985). The most significant Au grades (up to 10 g/t) are present within these garnet-rich footwall rocks. Initial drilling of the deposit by Geopeko Ltd in 1965 intersected 17 m grading 0.45 g/t Au and 0.26% Cu (Mackie 2002). In 1982, Alcoa of Australia Ltd, drilled five diamond holes over the prospect, four of which returned significant mineralisation, with the best gold intersections being 5 m grading 3.34 g/t from 98 m, and 6 m grading 2.53 g/t from 109 m. These two intervals were within a 50 m interval that averaged 0.91 g/t Au (Chuck 1984, 1985). In 1988, Tectonic Resources NL re-assayed these intervals using the fire assay technique, increasing the average grade of the 50 m composite interval to 1.83 g/t and a 32 m interval in another hole to 1.06 g/t (from 0.74 g/t: Mackie 2002). The company undertook soil sampling and a series of 15 shallow reverse circulation drillholes. Most of these holes returned significant Cu-Au intersections, with the best result of 15 m grading 1.04 g/t Au and 0.81% Cu (re-assay in 1997; Mackie 2002). On the basis of lead isotope data, Huston *et al* (2006) proposed that mineralisation at Johnnies Reward occurred at around 1795–1770 Ma.

A number of other base metal deposits in the Arunta Region contain anomalous gold. These include the the *Clark* and *Mount Hardy* copper prospects in MOUNT DOREEN (Fruzetti 1971), which are hosted in quartz veins and pegmatite within the Lander Rock Formation. Rock chip samples have yielded up to 1.3 g/t Au, 10 g/t Ag and 3% Cu (Clark prospect), and 4.3 g/t Au, 7 g/t Ag and 6% Cu (Mount Hardy 1; Tanami Gold NL, ASX Announcement, 19 August 2002). The *Home of Bullion* mine, 27 km east of Barrow Creek, was mined for copper, lead, zinc and minor silver, but had traces of gold (Hossfeld 1937a, Haines *et al* 1991 and references therein).

Ore genesis

The mineral assemblages, together with the structure and metamorphic setting are indicative of epigenetic, mesothermal gold mineralisation. Burlinson and Mackie (1986) reported fluid inclusion decrepitation studies on quartz samples from Arltunga. Observations of thin sections showed the presence of CO_2–bearing inclusions, which decrepitated at about 250°C.

Wygralak and Mernagh (2008a) reported homogenisation of CO_2–bearing inclusions in the range 240–340°C. Varying liquid/vapour ratios in fluid inclusions indicate critical conditions and effervescence of CO_2. The authors also noted that samples with the highest gold grades did not contain CO_2, indicating that its loss could be the main precipitation mechanism. $^{40}Ar/^{39}Ar$ dating of hydrothermal sericite associated with gold mineralisation returned ages of 368–308 Ma, interpreted as indicating an association with the Alice Springs Orogeny.

The model for ore genesis in Arltunga Goldfield, as proposed by Burlinson and Mackie (1986), is reproduced in **Figure 15**. It was suggested that gold was hydrothermally leached from volcanic assemblages of the basement complex by fluids associated with a greenschist-facies retrograde metamorphic event during the Alice Springs Orogeny, and deposited in structurally favourable sites. The presence of volcanics is probably not a prerequisite and gold could have been derived from metasedimentary rocks.

Structural control plays an important role in gold mineralisation in the Arltunga and Winnecke areas, which are located close to regional thrusts and nappes generated during the Alice Springs Orogeny. However, apart from the spatial association, their exact role in the mineralisation process is unclear.

There is some evidence that auriferous pyrite was precipitated in localised zones of rapidly reduced pressure resulting from local rock failures, such as small-scale faults, shears and other discontinuities, appearing within quartz lodes during structural movements of the White Range Nappe (**Figure 16**). According to Sibson *et al* (1988), such a mechanism produces cyclic variations between supralithostatic and hydrostatic pressures, causing phase separation and the precipitation of auriferous pyrite.

Gold prospectivity

An increasing body of geological knowledge on the Arunta Region (eg Scrimgeour 2004, 2006) suggests that it has significant potential for new gold discoveries. Large areas of the Aileron Province are at metamorphic grades of less than mid-amphibolite facies, and remain prospective and under-explored for gold. Such areas include the

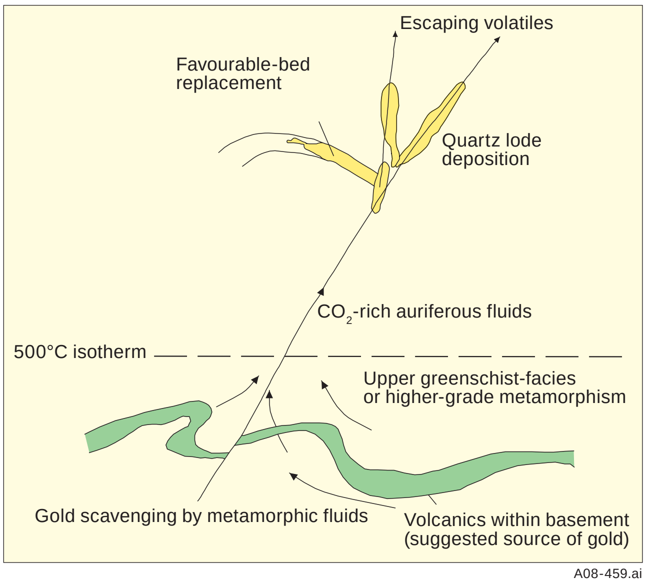

Figure 15. Model for genesis of auriferous quartz veins at Arltunga goldfield (after Burlinson and Mackie 1986).

Lander Rock Formation and other metasedimentary units in the southwestern Aileron province in LAKE MACKAY, MOUNT DOREEN and northern MOUNT RENNIE, where limited exploration in greenschist- to middle amphibolite-facies rocks has been encouraging. Similarly, the northern Aileron Province, where low-grade Lander Rock Formation is stratigraphically equivalent to the Tanami Group, has a high potential for orogenic gold mineralisation similar to that in the Tanami. The gold prospectivity of the Arunta and Tanami regions is summarised in **Figure 17**. It takes into consideration the composition, provenance and timing of hydrothermal fluids in the Tanami and Arunta regions, as studied by Wygralak and Mernagh (2008a). On the basis of these criteria and similarities with the Tennant and Tanami regions, the northern Arunta Region, including the entire western part of the Aileron Province (west of so-called 'CO_2 line' of Wygralak and Mernagh 2008a), is considered to have high potential. In comparison, the eastern Arunta Region, particularly east of the Jervois polymetallic deposit, is considered to be prospective for iron-oxide copper-gold mineralisation. There is an increasing body of evidence that iron-oxide copper-gold mineralisation in the Aileron Province may be spatially and genetically related to 1780–1760 Ma granitic magmatism (Whelan *et al* 2009).

The Warumpi Province, along the southwestern margin of the Arunta Region, is unexplored for gold, but is locally prospective. A stream sediment survey conducted by NTGS in 2000 identified a number of gold anomalies, and re-sampling of the *Haasts Bluff* copper prospect identified that it is an IOCG deposit containing anomalous gold. Identified gold prospectivity is largely within the amphibolite-facies Haasts Bluff Domain, where there is iron-oxide copper-gold potential in the Iwupataka Metamorphic Complex, and orogenic gold potential within felsic volcanic and sedimentary rocks of the Peculiar Complex. Structural interleaving of the Warumpi Province and basal Amadeus Basin sedimentary rocks during the Alice Springs Orogeny, in a belt extending from Mount Sonder west to Mount Liebig, is associated with greenschist-facies retrogression, and has potential for Arltunga- and Winnecke-style gold mineralisation.

Figure 16. Arltunga goldfield. Strongly sheared ore-stage quartz vein from Great Western mine.

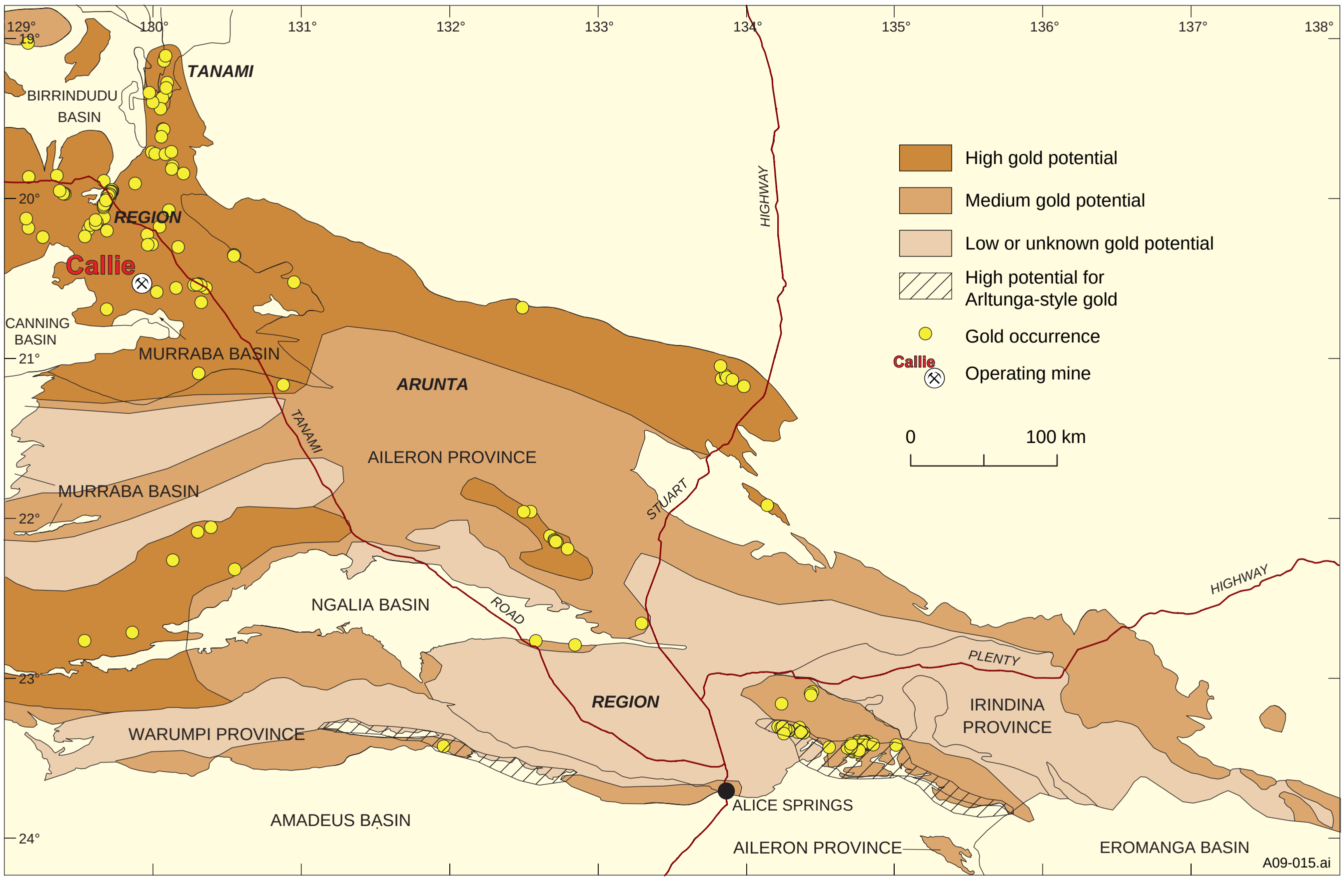

Figure 17. Gold prospectivity of Arunta and Tanami regions.

MURPHY INLIER REGION

During 1956–1960, several small uranium deposits were located in the Murphy Inlier and the bordering southern McArthur Basin. Small-scale uranium mining of some of these deposits occurred in the early 1960s. Although free gold was known to be present in the uranium ores, little systematic exploration has taken place. Analyses of dump material from the *Eva* mine indicated an average grade of 11 g/t Au (Ahmad 1982). Kratos Uranium (1981) reported values ranging from 1–16 g/t Au in drill core from the *Northeast Westmoreland* deposit. Ahmad *et al* (1984) reported on the presence of palaeoplacer gold in the Westmoreland Conglomerate, and this observation was confirmed by NTGS in 2007 (Wygralak and Mernagh 2008b).

Regional geology

The Palaeoproterozoic Murphy Inlier (**Figure 18**) comprises an easterly trending belt, up to 40 km wide, of felsic volcanics (Cliffdale Volcanics), comagmatic granite (Nicholson Granite Complex) and metasedimentary rocks (Murphy Metamorphics). The metasedimentary rocks comprise greywacke, siltstone, shale, and locally, calc-silicate rock and banded iron formation (Rawlings *et al* 2008), and have stratigraphic affinities to those in other inliers of the NAC, such as the PCO and Tennant Region. They were dated (SHRIMP detrital zircon age) at 1853 ± 4 Ma (Wygralak *et al* 2009), prior to the intrusion of the granite and the extrusion of coeval felsic volcanics (Ahmad and Wygralak 1990). A major unconformity separates the metasedimentary rocks from the overlying Cliffdale Volcanics.

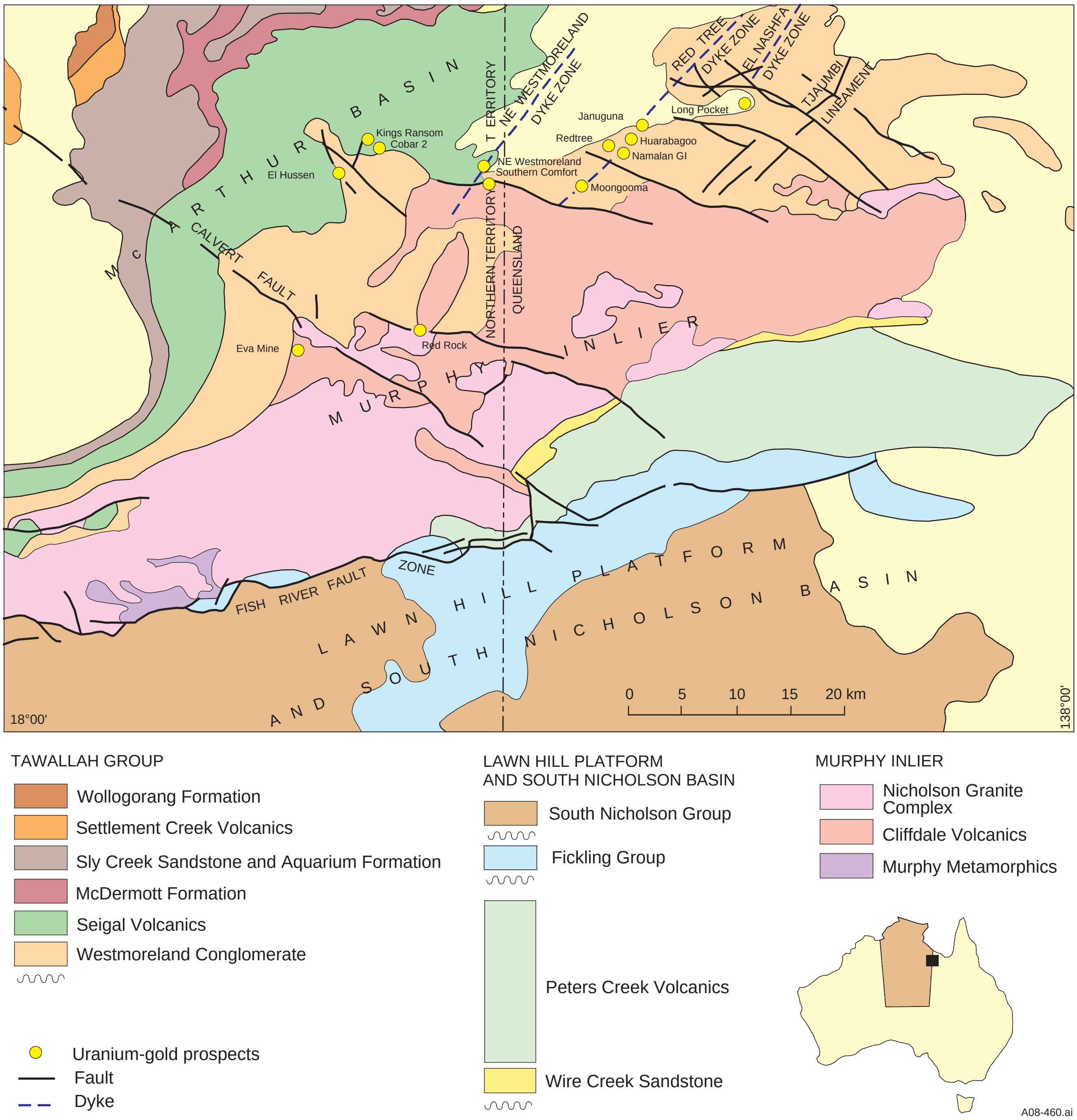

Figure 18. Regional geology and mineral occurrences of Murphy Inlier.

The Palaeoproterozoic tectonic setting of the Murphy Inlier resembles a collisional continental margin (Hanley 1996). It is likely that this basement belt acted as a depositional barrier between the McArthur Basin and Lawn Hill Platform during much of their history.

The basal sandstones of the overlying McArthur Basin and Lawn Hill Platform successions, the Westmoreland Conglomerate and Wire Creek Sandstone, respectively (**Figure 18**), were deposited on the older orogenic rocks after a prolonged period of erosion. This succession is essentially undeformed and unmetamorphosed except for major faulting (generally reverse) along the edge of the Murphy Inlier. The basal sandstones are also intruded by a series of northeast-trending dolerite dykes, which may be feeders to overlying volcanic rocks in the Tawallah Group.

Gold deposits

There are no known separate gold deposits, but significant gold is associated with uranium deposits of the region (Eva mine). Pitchblende is the main primary uranium mineral with minor brannerite. Traces of galena, pyrite, marcasite, chalcopyrite and bornite are present. Gold is present as globular grains up to 10 µm in size. In the volcanic rocks, mineralisation is within microfractures, whereas in the sandstone, it is present in the matrix. A preliminary survey conducted by Ahmad *et al* (1984) indicated the presence of widespread millimetre-sized gold grains in matrix of the upper unit of the Westmoreland Conglomerate. Several grains of gold were also found in the matrix of the conglomeratic bottom unit of the Westmoreland Conglomerate at 0221395mE 8059025mN (**Figure 19**). The ultimate source of the detrital gold grains is unknown. The transport direction of fluvial sediments comprising the Westmoreland Conglomerate is from the northeast (Wygralak *et al* 1988) and the most likely sources of gold are probably Palaeoproterozoic igneous and metasedimentary rocks under cover, located to the northeast of the currently exposed part of the Murphy Inlier.

Initial results of a pending NTGS project indicate that gold is also associated with copper mineralisation hosted by the Seigal Volcanics. A single sample from the *Dianne* mine returned 10.5% Cu and 0.4 g/t Au.

Ore genesis

The genesis of gold in the uranium deposits of the Murphy Inlier has not been investigated. Ahmad and Wygralak (1989) suggested that the uranium in these deposits was derived from leaching of the overlying Westmoreland Conglomerate by groundwater, and that precipitation occurred at the reduction interface between the volcanics and the sandstone. This mechanism may not be responsible for gold precipitation. It is interesting to note that detrital gold grains occur in both the bottom and top parts of the 1400 m-thick succession of Westmoreland Conglomerate, which comprises four upwards-fining fluvial cycles.

Gold prospectivity

This region is largely untested, as most exploration efforts have focused on uranium. Similarities to the Pine Creek Orogen in tectonic setting and stratigraphy, including the presence of a lower greenschist-facies greywacke, shale and siltstone succession intruded by late granite, indicate good potential for gold. During 1990–1991, Carpentaria Exploration Pty Ltd carried out gold exploration in the Benmarra area (Hitchman and Simpson 1991). This work produced a number of low-order gold anomalies with one peak value of 50.8 ppb (*Fenceline Anomaly*). Follow-up stream sediment sampling confirmed the anomaly, but soil and rock chip sampling failed to locate any zones of mineralisation. It was concluded that the Fenceline Anomaly was sourced in veinlets in a narrow fracture (Simpson 1990b).

The palaeoplacer gold potential of the Westmoreland Conglomerate and the potential for gold associated with copper mineralisation in the Seigal Volcanics requires further assessment.

This area has strong lithological and stratigraphic similarities with the South Alligator River Region and may also host Coronation Hill-style Au-Pt-Pd deposits.

PINE CREEK OROGEN

The Pine Creek Orogen (PCO) has been explored for gold for over a century since the first discoveries at the Finniss River in 1865 and at Tumbling Waters in 1868 (Jones 1987). These first discovered occurrences were uneconomic. In 1870, a hole dug for the construction of the overland telegraph line at Yam Creek yielded alluvial gravel containing coarse gold. This led to many significant discoveries and by 1881, mining activity was widespread throughout the central PCO. All major gold mines in the region were discovered by the turn of the century. A substantial quantity of gold was produced in the period 1884–1915, with a peak in 1891–1895.

Modern gold exploration commenced in 1980, when increased prices and improved mining and metallurgical technology boosted exploration. This resulted in systematic

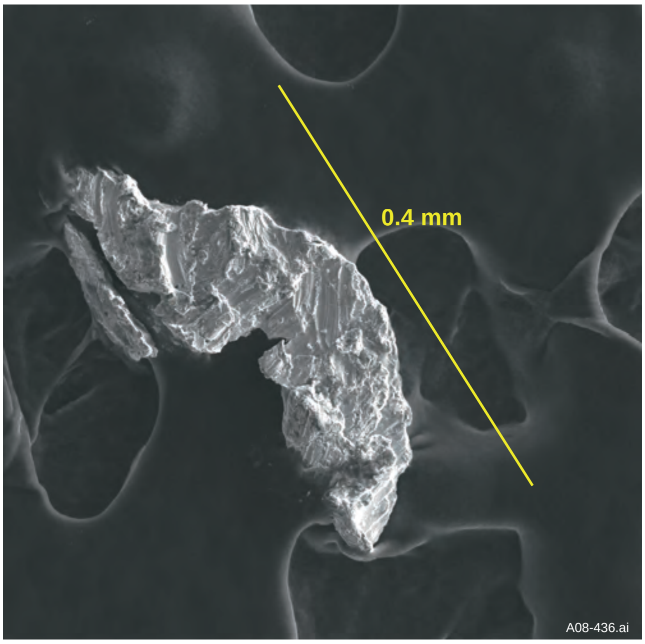

Figure 19. SEM image of gold grain from matrix of conglomeratic basal unit of Westmoreland Conglomerate at 0221395mE 8059025mN.

geological mapping, geochemical surveys and drilling, mostly around previously known occurrences. A number of previously known occurrences such as Enterprise, Cosmo Howley, Golden Dyke, Woolwonga, Mount Bonnie and Mount Todd were re-evaluated and subsequently mined. New orebodies were discovered at Batman, Goodall, Moline Dam, Glencoe, Rustlers Roost, Sundance and Toms Gully.

A decrease in gold price during the 1990s to $US250 resulted in the stagnation of gold exploration for several years from the late 1990s. This trend was reversed in 2005, when GBS became an active gold explorer and miner in the PCO.

Total gold production from the PCO until the end of 2007, excluding minor recent alluvial operations, amounted to 99.2 t (records held by NT Minerals and Energy). The PCO includes nearly half the gold occurrences of the Northern Territory. Almost all are located within a 100 km-wide northwest-trending belt between Darwin and Katherine.

In late 2008, the operating mines included Toms Gully and a group of mines centred around Brocks Creek, which included Fountain Head, Rising Tide and Brocks Creek (formerly Zapopan). Cosmo Howley Deeps and Maud Creek were planned to be in operation in 2009. Mining operations and the majority of gold exploration in the PCO were dominated by GBS Gold Australia Pty Ltd (GBS). Gold was being processed by a centrally located treatment plant at Union Reefs. In late 2008, these operations were placed on care and maintenance, and were subsequently purchased by Crocodile Gold Australia.

Regional geology

The geology, stratigraphy, metamorphism and structural setting of the Pine Creek Orogen are detailed in several studies (Walpole *et al* 1968, Needham *et al* 1980, Needham and DeRoss 1990, Stuart-Smith *et al* 1993, Ahmad *et al* 1993, Ahmad *et al* 2006, Hollis *et al* 2009a, b, Ahmad and Hollis in prep). The metamorphosed and deformed Palaeoproterozoic succession is exposed over an area of ca 66 000 km^2 and is unconformably overlain by the relatively undeformed McArthur Basin to the east, and by the Victoria and Daly basins to the west and southwest (**Figure 20**).

From west to east, the PCO can be divided into three domains: the Litchfield Province, Central Domain, and Nimbuwah Domain (Hollis *et al* 2009a). The Litchfield Province represents an area of high-temperature, low-pressure

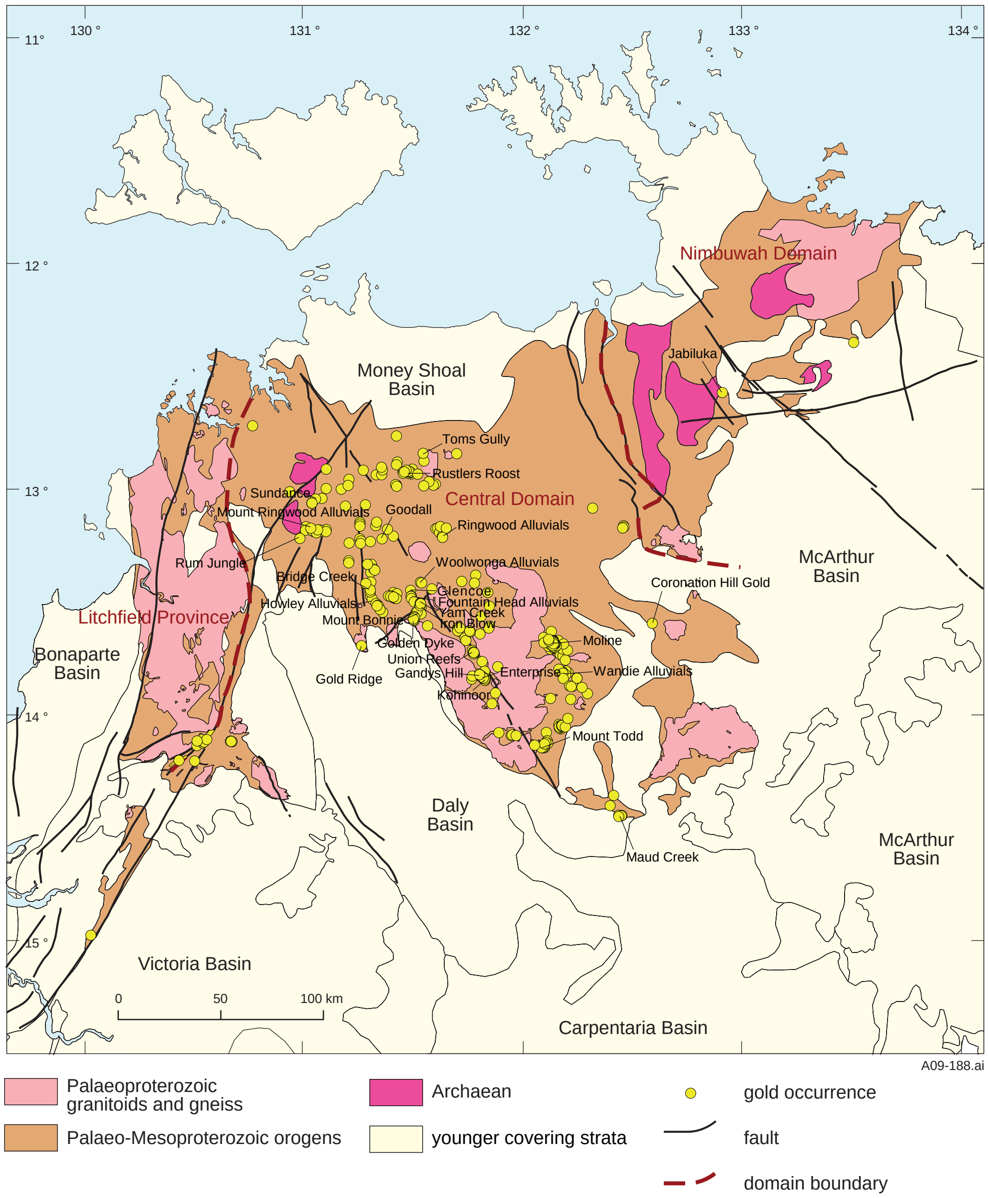

Figure 20. Regional geology and gold deposits of the Pine Creek Orogen.

greenschist- to granulite-facies metasedimentary and meta-igneous rocks. The Central Domain contains greenschist-facies metasedimentary rocks and simple structures dominated by upright northwest- and north-trending folds. The Nimbuwah Domain is characterised by amphibolite-facies Palaeoproterozoic metasedimentary rocks and granite, with widespread gneissic Archaean basement and upright to recumbent folds (Hollis *et al* 2009b).

The PCO succession unconformably overlies Neoarchaean (ca 2670–2500 Ma) granitic basement, which is exposed in the Rum Jungle Complex of the Central Domain, and the Nanambu Complex and Kukalak gneiss in the Nimbuwah Domain (Hollis *et al* 2009a). The PCO comprises an alternating succession of sandstone and shale, with minor carbonate and volcanic rocks. Dolerite sills (Zamu Dolerite and equivalents) intruded the succession prior to deformation and metamorphism.

The timing of deposition of the PCO succession is constrained between 2470 and 1860 Ma. Ahmad *et al* (2006) and Ahmad (2007) divided the succession into two supergroups. The older *Woodcutters Supergroup* includes the Manton and Mount Partridge groups and equivalent strata. This supergroup unconformably overlies the Archaean basement and comprises current-bedded and ripple-marked fluvial to shallow-marine sandstone, intertidal stromatolitic carbonate rocks and shale, including carbonaceous and pyritic shale. SHRIMP U-Pb geochronology on zircons from the tuffaceous sedimentary rocks from the Mount Partridge Group have yielded ages of ca 2020 Ma (Worden *et al* 2008), which are interpreted to reflect the timing of deposition of the Woodcutters Supergroup. The younger *Cosmo Supergroup* is represented by the South Alligator and Finniss River groups and equivalent strata. This succession is more widespread than the unconformably underlying Woodcutters Supergroup and comprises BIF, mudstone and tuff, succeeded by a monotonous flysch succession. Tuffaceous sedimentary rocks in the Gerowie Tuff of the South Alligator Group have yielded SHRIMP U-Pb zircon ages of 1861 ± 3 Ma and 1863 ± 3 Ma (Worden *et al* 2008), and zircon from the Warrs Volcanics in the Finniss River Group has yielded an age of 1862 Ma ± 3 Ma (Carson *et al* 2005). There thus appears to be a major depositional break between the Woodcutters and Cosmo supergroups, extending over a period of about 150 My.

Recent detrital zircon geochronology across the Pine Creek Orogen (Carson *et al* 2008, Hollis *et al* 2009b) suggests that the metamorphosed successions in the Litchfield Province represent stratigraphic equivalents of the Woodcutters and Cosmo Supergroups. In comparison, the Palaeoproterozoic succession in the Nimbuwah Domain (Nourlangie Schist and Cahill Formation) has a different provenance to sedimentary rocks in the central Pine Creek Orogen, and was deposited in the interval 1900–1870 Ma (Hollis *et al* 2009b).

Regional deformation and metamorphism occurred across the PCO in the interval 1865–1850 Ma. In the Nimbuwah Domain in the east, high-pressure mid- to upper amphibolite-facies metamorphism occurred at 1865–1860 Ma, accompanying intrusion of granites of the Nimbuwah Complex and regional west-directed compressional deformation. In the Litchfield Province in the west, high-temperature low-pressure metamorphism occurred at ca 1853 Ma (Carson *et al* 2008), probably in an extensional environment. The timing of upright deformation and low-grade metamorphism of the Central Domain is less well constrained, but must postdate the deposition of the Finniss River Group at ca 1860 Ma.

In the Central Domain, the earliest deformation, D_1, caused north-trending monoclinal warping, recumbent north-trending isoclinal folding and shear zones. D_2 deformation is represented by thrusting and recumbent folding. The D_3 deformation event was more widespread and is represented by north- to northwest-trending non-cylindrical, closed to tight folds. These folds are an important structural control for the vein-type mineralisation in the Central Region.

D_4 deformation was associated with granitic intrusions and produced open, small-amplitude regional folds, which are responsible for the formation of elongated basins and domes. D_5 deformation produced steeply plunging polyclinal kinks and drag folds associated with dextral movements along major faults.

A major period of igneous activity, minor deformation and rift-related sedimentation occurred in the Central Domain at 1835–1800 Ma and this is termed the *Cullen Event* (Ahmad and Hollis in prep). It included the formation of grabens and the deposition of two unconformity-bounded packages (El Sherana and Edith River groups) containing clastic sedimentary rocks and felsic volcanics (Needham *et al* 1988). The 1830–1800 Ma granites of the Central Domain have predominantly I-type characteristics and have magnetite as a common accessory. Magnetic susceptibilities range from 10^{-3} to 10^{-4} emu/g (Bajwah 1994). Many of these granites appear to be minimum melts and indicate crystal fractionation (Ferguson *et al* 1980a). In contrast to the I-type Cullen Event granites in the Central Domain, the Litchfield Province has S-type granites with ages in the range 1862–1855 Ma. In the Nimbuwah Domain, I-type granites have ages typically in the range 1865–1860 Ma (Worden *et al* 2008).

Albite-epidote hornfels is present in all contact aureoles, commonly with a narrow, inner continuous zone of hornblende-hornfels. The effects of contact metamorphism are seen up to 10 km away from granite contacts. Gravity data (Lewis *et al* 1995) suggest that granitic rocks are present virtually everywhere in the PCO at a depth of 1–5 km. However, the gravity data cannot distinguish between Archaean basement and Palaeoproterozoic granites.

The Central Domain, where I-type granites dominate, contains the majority of the gold, base metal and tin deposits, as well as stratabound gold and polymetallic deposits. The Litchfield Province S-type granites are related to Sn-Ta bearing pegmatites (Ahmad *et al* 1993, Frater 2005).

Gold deposits

There are over 250 gold occurrences in the Pine Creek Orogen; most of these are located in the Central Domain. The Litchfield Province contains a few gold occurrences, and the Nimbuwah Domain also contains uranium-gold deposits. On the basis of their shape, gangue and ore mineral associations, the gold deposits can be divided into the following types:

- Gold-quartz veins, lodes, sheeted veins, stockworks and saddle reefs.
- Gold in iron-rich sedimentary rocks.
- Polymetallic stratabound gold deposits.
- Gold in association with uranium.
- Gold in association with platinum group elements.
- Other primary gold deposits.
- Placer deposits.

Gold-quartz veins, lodes, sheeted veins, stockworks and saddle reefs

Concordant and discordant gold-bearing quartz veins are widespread and are usually located within, or close to anticlinal hinge zones**.** Fault-filling and en echelon veins in shear zones are also present. Some occurrences are within a stockwork of millimetre-thin quartz veinlets. Most are however in quartz veins of thickness in the range 0.1–2 m.

Although some coarse free gold is present, most is sub-microscopic within arsenopyrite and, to a lesser extent, in other sulfides. In the oxidised zone, which extends down to about 50 m, most gold occurs as free metal.

Most lodes trend northwest or north-northwest and have steep dips. The spatial distribution suggests that deposits are confined to two northwest-trending zones; namely the Pine Creek Shear Zone, which is a geological expression of the Noonamah–Katherine Lineament, and another zone to the east, which may be related to the Noonamah–Mount David Lineament. Lodes in the northern extension of the Howley Anticline trend north, whereas in the Brocks Creek Zapopan-Fountain Head area, they have a west-northwest trend, but in both these areas, the lodes follow fold axes.

Greywacke, shale and siltstone are the most common wall rocks. The most common stratigraphic units that host the gold-bearing quartz veins are the Burrell Creek, Mount Bonnie and Koolpin formations.

All deposits of this type are located in the contact aureole of the post-orogenic granites, some distance away from the granite–sediment contact. None of the deposits are hosted within granite and the quartz veins do not continue into the granite. It appears that the northwest-trending shear zones, lineaments and anticlinal hinges, as well as the contact metamorphic aureole have played a role in the localisation of the gold-bearing quartz veins.

Some important deposits are discussed below. For smaller occurrences, the reader is referred to the NTGS Mineral Deposit Database (MODAT) and the references given therein.

Bridge Creek

Exploration drilling conducted by Northern Gold NL in the Adelaide River area, starting in the early 1990s, has resulted in a re-evaluation of the previously known Bridge Creek prospect and the discovery of several new prospects.

Bridge Creek prospect is located next to the Stuart Highway, some 40 km south of Adelaide River township, on the western limb of the Howley Anticline. Rich, but localised quartz stringers, 5–40 cm wide, have been mined intermittently at this locality since 1873 for a total recorded production of 37 kg Au. A recently calculated total resource for this prospect is 1.04 Mt ore at 1.6 g/t Au (Northern Gold 2005).

Mineralisation is of two types: sediment-hosted stratabound, and veins within dolerite (Cooper 1990). The stratabound type is associated with the gradational contact between carbonaceous mudstone of the Koolpin Formation and the overlying Gerowie Tuff. The mineralised envelope plunges 30° south-southwest and follows the mudstone-tuff contact. The mineralisation forms a stockwork of veins carrying (in order of abundance) pyrite, chalcopyrite, bornite, sphalerite and galena. Most gold occurs as inclusions in chalcopyrite and pyrite (Partington *et al* 1994). The vein mineralisation is contained around shears and fracture zones in dolerite. Gold is associated with an alteration assemblage of actinolite, albite, chlorite, biotite, carbonate and sulfides at vein margins. A significant amount of gold occurs as free metal, the remainder being associated with pyrite and arsenopyrite.

The nearby *Western Arm* prospect is located in an anticline in the Mount Bonnie Formation and Gerowie Tuff. The total resource consists of 1.78 Mt of ore averaging 1.4 g/t Au (Northern Gold 2005). Gold is located in shear-parallel quartz veins and stockwork zones. It is also disseminated in alteration zones in the host greywacke. The main sulfides are pyrite and arsenopyrite, plus minor chalcopyrite, galena and sphalerite. The richest mineralised pockets contain up to 120 g/t Au (Partington *et al* 1994).

Several other prospects including *Kazi* (resource 0.68 Mt @ 2.9 g/t Au) and *Bons Rush* (0.54 Mt @ 2.5 g/t Au) were discovered in this area by Northern Gold NL. The combined resource of this area amounts to 7.5 t Au (Northern Gold 2005).

Brocks Creek goldfield

Brocks Creek goldfield lies 60 km northwest of Pine Creek township. It is located along the southern margin of the Burnside Granite and includes the Brocks Creek (former Zapopan), Faded Lily, Burgan, Alligator, Crocodile, John Bull, Rising Tide, Brittania and several smaller deposits (**Figures 21**, **22***)*.

Most of these deposits occur discontinuously for about 5 km along the southern limb and hinge zone of the east-southeast-trending Zapopan anticline. Mineralisation forms concordant veins and stockworks, stratabound replacement, or is associated with late vuggy quartz veins and minor breccias (Şener 2004).

Brocks Creek (Zapopan) mine was initially worked between 1885–1915 by underground methods. Tailings were treated intermittently until 1933. Tailings were also vat-leached in the early 1990s, during eluvial mining operations in the Faded Lily mine area. The mine produced a total of 829 kg Au over this period. Five separate reefs were mined, ranging in grade from 13.2 to 42.6 g/t Au.

The auriferous quartz veins, trending 280° and dipping 55–60° west, are in tuff and siltstone of the Gerowie Tuff. The lodes occupy the hinge zone of the tight, east-southeast-striking Zapopan Anticline, which plunges 40° east. To the west, the anticline is terminated by a northeast-oriented fault. Some stratiform mineralisation, hosted by pyrite-chlorite-garnet-chert rocks, is also present.

Post-1980 exploration included soil and auger geochemical sampling and limited diamond drilling (Dann 1982). The potential of the prospect was reviewed again in 1987 by Zapopan NL (Goulevitch 1987), followed by extensive reverse circulation and diamond drilling in 1988–1989. This delineated an indicated resource of 0.193 Mt at 3.9 g/t Au over a strike length of 200 m to a depth of 75 m. An additional inferred resource of 0.2 Mt at 6–7 g/t Au was established along a down-plunge extension (Zapopan 1989). Solomon Resources NL and Acacia

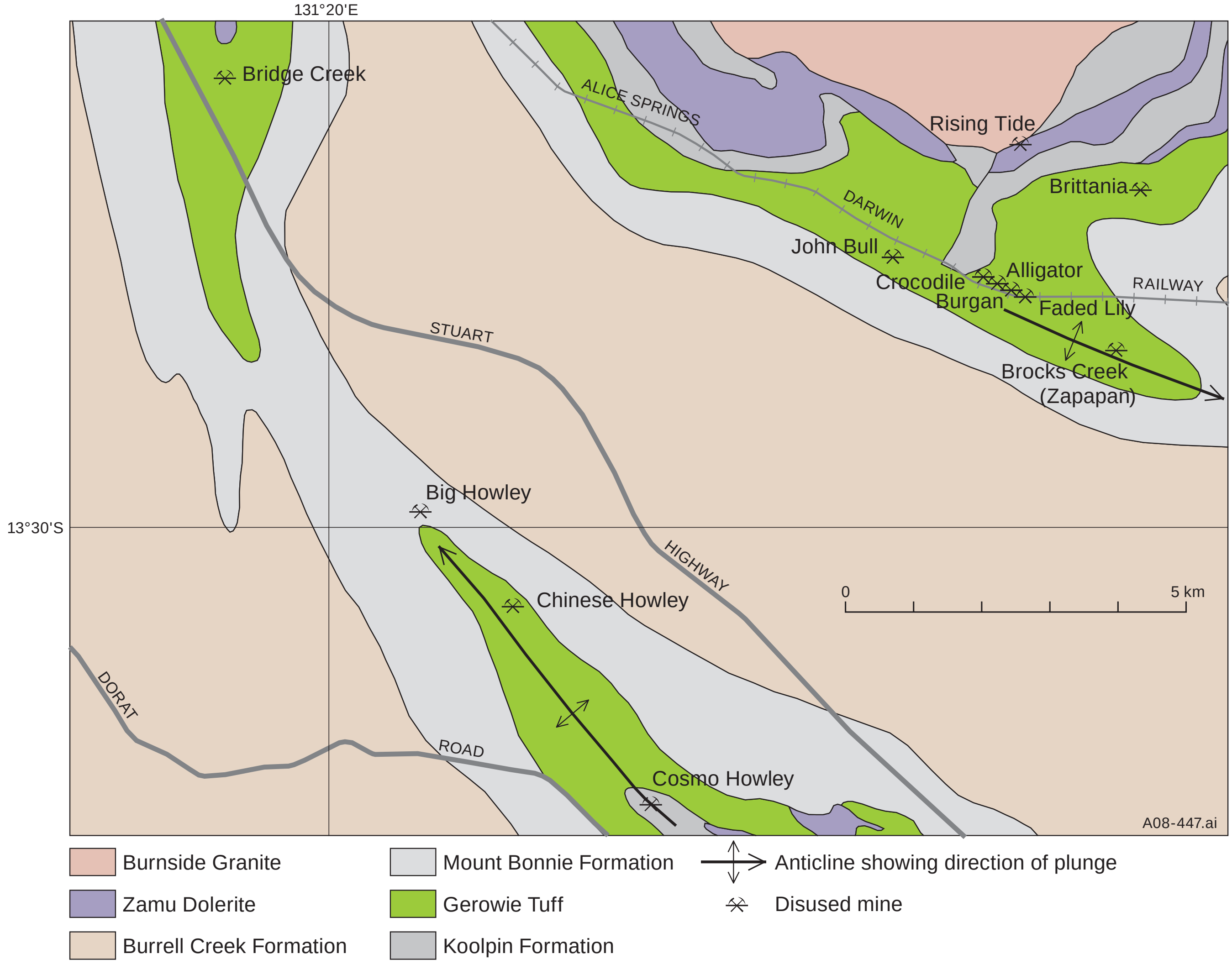

Figure 21. Main deposits in Brocks Creek and Howley areas.

Figure 22. Alligator mine open pit (looking west).

Resources Ltd have subsequently conducted extensive exploration.

A drilling program undertaken by GBS Gold during 2006 successfully confirmed the down-plunge continuity of mineralisation and total ore reserves (JORC complaint) of 0.247 Mt @ 13.05 g/t Au were documented. Underground mining of the deposit commenced in 2007, but operations ceased in late 2008. Mining operations resumed in November 2009, after a change in ownership to Crocodile Gold Australia.

The *Faded Lily* and *Alligator* deposits consist of dominantly concordant auriferous quartz stockworks, localised along a shear zone parallel to the Zapopan Anticline. At Faded Lily, mineralisation is localised at the faulted contact between massive black shale and thinly bedded grey, white and black siltstone and shale of the Gerowie Tuff. Mineralisation is present within quartz veins and along vein margins within a graphitic shear zone; gold is associated with arsenopyrite and pyrite. Up to 10% pyrite and 5% arsenopyrite are present in the ore zones. Small visible grains of gold are commonly observed in higher-grade zones.

At *John Bull*, mineralisation occurs in a series of up to 1.5 m–thick, steep, parallel, quartz veins that are 10–20 m apart. These veins occur off the main Zapopan–Brocks Creek shear zone and are related to a conjugate set of quartz veins.

Although another local anticlinal structure lies some 3 km north of the Zapopan anticline, the nearby *Rising Tide* deposit is not related to it. The lodes are hosted by the Koolpin Formation and Zamu Dolerite (**Figure 23**), and appear to be stratabound (Miller *et al* 1998). Mineralisation occupies the contact between pyrrhotitic, carbonaceous metasedimentary units of the lower Koolpin Formation and Zamu Dolerite intrusives, in proximity of the southern margin of the Burnside Granite. The ore body forms two sub-parallel tabular zones, dipping shallowly to the southeast. Mineralised zones are up to 15 m thick and comprise extensive quartz-limonite veins in schistose, sericitic and tourmaline-bearing carbonaceous graphitic shale. Some mineralisation also forms quartz-pyrite-pyrrhotite veins in fine-grained amphibolite. The gold grade indicates supergene enrichment and the entire mineralisation appears to be related to reverse faulting associated with the nearby intrusion of the Burnside Granite. The mineralised lodes are recognised to a vertical depth of 65 m and the deposit has a strike length of 800 m.

Fountain Head

The Fountain Head mine is located about 10 km east of Brocks Creek. There, stratiform gold and base metal mineralisation is hosted by ironstone and fine-grained carbonaceous and tuffaceous metasedimentary rocks of the Mount Bonnie Formation, located in the north-northeast-trending Margaret Syncline and associated parasitic folds.

Gold mineralisation extends over a strike distance of 1800 m and represents two styles. The first style comprises a succession of interbedded phyllite, greywacke, tuff and chert, which hosts mineralisation in a series of gently southeast-plunging saddle reefs. The highest grades occur in the hinge zone of the Fountain Head Anticline, in particular along the contact between phyllite and greywacke units. Gold is associated with quartz veins containing pyrite, arsenopyrite and free gold.

The second style of mineralisation represents sheeted quartz veins, hosted by a fault-bounded greywacke unit.

The indicated resource comprises 1.985 Mt @ 1.7 g/t Au plus an inferred resource of 0.661 Mt @ 1.6 g/t Au (GBS Gold International Inc News Release to the Toronto Stock Exchange, 7 November 2007).

North Point

The North Point deposit is located approximately 10 km southeast of Brocks Creek. During 2002, airborne magnetic geophysical, Landsat and SPOT remote sensing

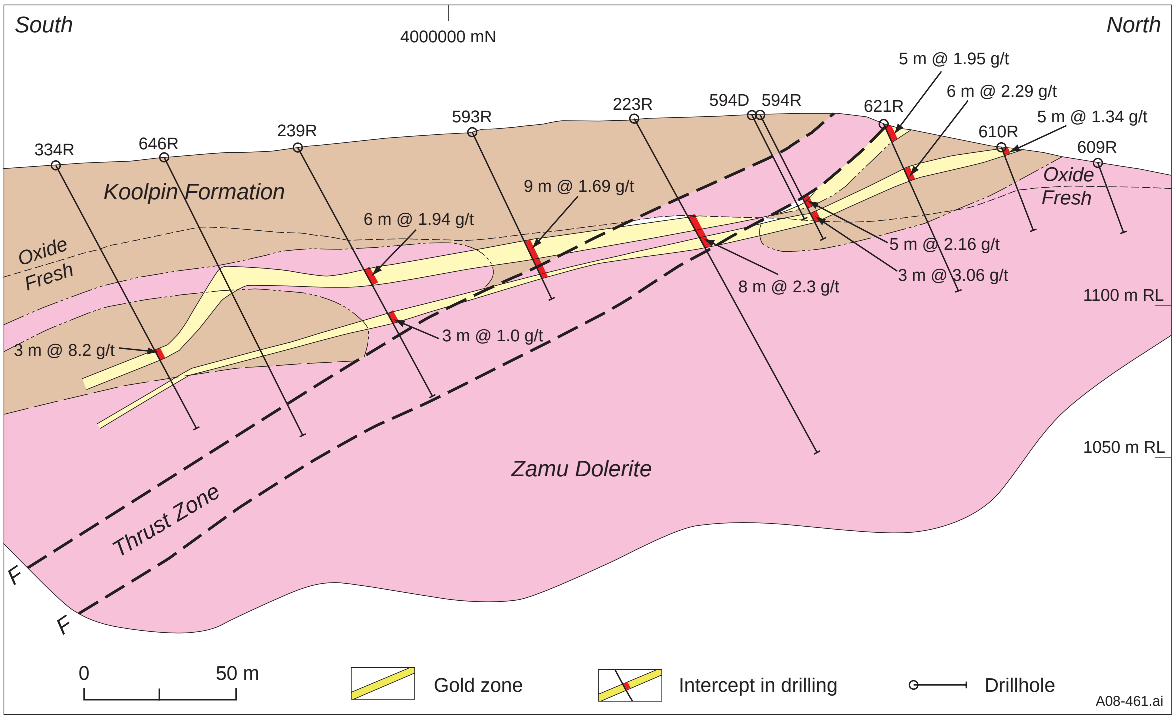

Figure 23. Cross-section of Rising Tide orebody (courtesy of Acacia Resources Ltd).

and GIS topographic data provided the basis for structural interpretation and targeting definition over the North Point area. Mineralisation is within ironstone and fine-grained carbonaceous to tuffaceous sedimentary units of the Mount Bonnie Formation, which have been openly folded about a north-northeast-trending syncline and associated parasitic folds. The mineralisation at North Point occurs within a linear, northerly-oriented, multiple lode system that dips conformably with bedding at 45° west. The system is reasonably continuous along strike for about 300 m and down-dip for 60 m. Drilling by GBS has identified two main lodes. The main lode comprises a steeply dipping continuous zone of mineralisation with an average downhole thickness of 3.4 m. The second lode has a similar geometry, with most of the 3.2 m-thick lode located in the northern half of the deposit. Resources have been estimated at 278 000 t averaging 2.3 g/t Au.

Goodall

This closed mine is situated 30 km east of Adelaide River township at the northern extension of the Howley Anticline. WJ Fisher discovered the orebody in 1981 during reconnaissance helicopter rock-chip sampling of gossans. Systematic costeaning and subsequent drilling delineated an initial resource of 4.25 Mt at 2.35 g/t Au. This was mined between April 1988 and September 1993, eventually producing 7.1 t Au from 4.095 Mt of ore with a head grade of 1.99 g/t Au (Quick 1994).

The host rock consists of flysch-like Burrell Creek Formation. In the main open cut, the host rock is a greywacke-shale succession and a prominent 30–35 m-thick shale unit can be traced throughout the pit.

The host rocks have been regionally metamorphosed to lower greenschist facies, producing extensive chloritisation and locally pervasive carbonate alteration. Contact metamorphism followed and produced cordierite spotting in shale. Hydrothermal alteration associated with the mineralised zone includes sericite, carbonate, K-feldspar, tourmaline and apatite.

The mine is located along an upright anticline, plunging 30–35° to 320° with a strong axial-planar cleavage. Two sets of joints are present; the more pronounced is a closely spaced east-trending set that dips steeply south. The other set trends north and dips steeply east. Numerous small faults with displacements of 2 m run subparallel to both sets of joints. The east-trending faults resulted from a tensional regime and contain quartz with comb textures.

The north-trending system is represented by high-angle reverse faults. There is also a small group of low-angle east-dipping thrusts.

Six extremely altered lamprophyre dykes cut the fold axis. The dykes strike 060° and dip southeast. Some dykes predate mineralisation, whereas others are mineralised.

Mineralisation is within a north-trending zone of quartz stockwork consisting of sub-parallel, thin quartz-sulfide veins (**Figure 24**). The mineralised zone is 750 m long, up to 50 m wide and at least 400 m deep, but grades reputedly diminish with depth. The zone is sub-parallel to the fold and is centred about 60 m east of the anticlinal axis. Both discordant and concordant veins are present.

Gold occurs as 5–10 µm-sized blebs in pyrite and arsenopyrite. Minor amounts also occur in quartz and chlorite. Other ore minerals include sphalerite, galena, chalcopyrite and pyrrhotite, as well as minor tetrahedrite, tennantite, bismuthinite, native bismuth and gersdorffite. Oxidised minerals include digenite, chalcocite, covellite, bornite, scorodite and wittichenite. Gangue minerals are quartz, chlorite, sericite, carbonates, K-feldspar, tourmaline and apatite.

SHRIMP U-Pb geochronology of monazite associated with the gold veins was carried out by Şener *et al* (2003) and Şener (2004). Approximately half of the analyses show unacceptably high common Pb contents and were excluded, leaving a main data group of 26 analyses. These samples give a mean age of 1751 ± 15 Ma with a moderate excess scatter (MSWD = 2.9). If eleven ages older than the Shoobridge Event are excluded, the remaining 15 analyses yield an age of 1727 ± 11 Ma with a low excess scatter (MSWD = 1.2). This is considered to be the age of gold mineralisation (Şener 2004). This age is younger that the overlying El Sherana/Edith River/Katherine River groups, which have no auriferous veins. It is also about 100 My

Figure 24. Sheeted auriferous quartz-sulfide veins at Goodall mine.

younger than the intruding granites; the significance of this age is ambiguous and is possibly affected by later alteration processes (Ahmad and Hollis, in prep).

Glencoe

Magnum Exploration Ltd discovered this deposit in 1985, using a rock-chip sampling program. The lodes are hosted in the Mount Bonnie Formation within a 300–340°-trending, gently southeast-plunging asymmetrical anticline. Three styles of gold mineralisation are present: (1) sub-vertical quartz-filled fractures parallel to the axial plane of the anticline, (2) lenticular, sub-vertical quartz veins at a considerable distance from the axial plane, and (3) stratabound concentrations within carbonaceous metapelite. The first style of mineralisation is economically the most important. Ore assemblages include arsenopyrite, pyrite and traces of chalcopyrite. Gangue minerals are chlorite, quartz, tourmaline and carbonaceous matter.

The estimated resource is 1.5 Mt at 1.9 g/t Au. The deposit was trial mined to a depth of about 10 m by four closely spaced open cuts and the ore was treated at the Mount Bonnie plant in 1988–1989. It is estimated that about 49 000 t ore was mined during this period (I Milligan, Magnum Exploration Ltd, pers comm 1990). Although no good records are available, it is estimated that about 112 kg Au was produced, giving a recovered grade of 2.3 g/t Au.

In 2005, the Glencoe prospect was explored by Australasia Gold Ltd. Four discrete zones of mineralisation, termed the Western, North Central, Mid Central and South Central mineralised zones, were identified (**Figure 25**). Exploration revealed highly complex mineralisation, but indicated a broad continuity of the principal mineralised shears within each of the four zones.

Moline goldfield

The Moline goldfield (including *Northern Hercules* and *Eureka*) is a northwest-trending area, 12 km long and 6 km wide, centred 2.5 km southeast of Moline Dam. Gold is hosted in hosted both in quartz veins (this section) and by iron-rich sedimentary rocks of the Mount Bonnie Formation (see Gold in iron-rich sedimentary rocks, below). The area includes some 30 abandoned pits and prospects that produced 4.5 t Au between 1882–1992. Most production has been from recent (1988–1992) open-pit mining.

Gold was discovered at Northern Hercules in 1882 by Chinese miners. Underground mining of the high-grade (31 g/t Au) oxidised veins continued sporadically until 1957, producing 1.15 t Au (Stuart-Smith *et al* 1988). Re-treatment of tailings was carried out by Pacific Goldmines NL in 1987–1988, recovering about 300 kg Au from 0.2 Mt of tailings (Pacific Goldmines 1987, 1988). Open-cut mining of the lode system between 1989–1992 by Moline Management Pty Ltd recovered 3.1 t Au from 1.6 Mt of ore at 2.14 g/t Au (Register of Australian Mining 1997/98).

The Northern Hercules mine lies within interbedded greywacke, siltstone and carbonaceous phyllite of the Mount Bonnie Formation. Bedding is overturned, strikes 285° and dips 60° south.

Mineralisation is in the form of discordant, steeply dipping, subparallel, sulfide-bearing (pyrite±arsenopyrite, chalcopyrite, sphalerite and galena) vein-quartz lodes. Four Au-bearing quartz lodes with a maximum width of 23 m have been mined from a shear zone up to 80 m wide (Miller 1990). High-grade ore is commonly located in the bends of the shear zone, suggesting a dilational jog control mechanism for gold mineralisation (Moline Management 1992).

Gold is present as 1–80 µm-sized inclusions in arsenopyrite and, occasionally, in pyrite and chalcopyrite. Visible gold in pyrite aggregates has been seen in drill core and erratic repeat assay data indicate that coarse gold is present (Miller 1990).

The *Cornwall* mine is a quartz-vein deposit located 4 km south-southeast of Northern Hercules. This deposit was discovered in 1989 and was mined for 5024 t of ore grading 2.6 g/t Au (Moline Management 1991). The deposit lies within tightly folded metagreywacke and slate of the Burrell Creek Formation. Bedding strikes northwest (300°) and dips steeply (65°) southwest. The gold mineralisation is associated with ferruginous quartz veinlets within shear zones and the gossanous rims of massive quartz veins (Moline Management 1992). The main gold-bearing shear strikes 350° and is vertical. It can be traced for over 200 m and is up to 4 m wide.

Other minor workings are *Kindergarten*, *Highway*, *Four* (also known as *Moline North*) and *Arm*.

Since the cessation of mining in 1992, a number of companies have undertaken exploration in this area. Newcrest Mining Ltd have carried out deep drilling beneath the Moline and Tumbling Dice pits. Geochemical surveys and preliminary RC drilling of anomalies was conducted by Compass Resources Ltd and Northern Gold NL. Some encouraging results were obtained, but were not followed up until 2006, when GBS commenced a renewed phase of exploration in this area. No results have yet been released from this phase of exploration.

Maud Creek goldfield

The historic Maud Creek goldfield is located about 20 km east of Katherine. It was worked between 1890–1892 and 1932–1940 for a recorded production of 16.8 kg of gold (Crohn 1961a, Walpole *et al* 1968). Such small production is attributed to the very fine nature of the gold and a high sulfide content of the ore. A sampling program by Cottle (1937a) revealed gold grades ranging from trace amounts to 26.1 g/t Au and copper values of up to 6%. Mineralisation is hosted within the Maud Dolerite.

In 1985, a geochemical survey of the area by CSR Ltd revealed a 1.3 ppb gold anomaly about 1 km to the west of the historical Maud Creek gold mine. A follow up of this anomaly by Placer Exploration Ltd in 1987 resulted in highly anomalous gold values and finally, the discovery of the *Gold Creek* deposit. This deposit is located at the southern end of a quartz-haematite breccia, subcropping over a north–south strike length of approximately 1 km. Unlike the mineralised lodes at Maud Creek, those at Gold Creek are within the Tollis Formation, which is represented by lithic sandstone and siltstone to the west and mafic tuffs to the east. The latter probably belong to the Dorothy Volcanic Member.

Mineralisation at Gold Creek is associated with intense quartz veining, largely concentrated within a discrete lode at the southern end of a north-trending fault. The latter separates the mafic tuffs to the east from sedimentary rocks to the west. Fine-grained mafic to intermediate dykes are present in the mine succession, specifically in the immediate footwall to the deposit. The orebody is characterised by stockworks and massive quartz veining, silica flooding, brecciation, and intense graphitic and chloritic alteration. Sulfides constitute roughly 5% of the orebody and comprise pyrite and arsenopyrite with gersdorffite. These minerals are present as disseminations and there are massive intervals

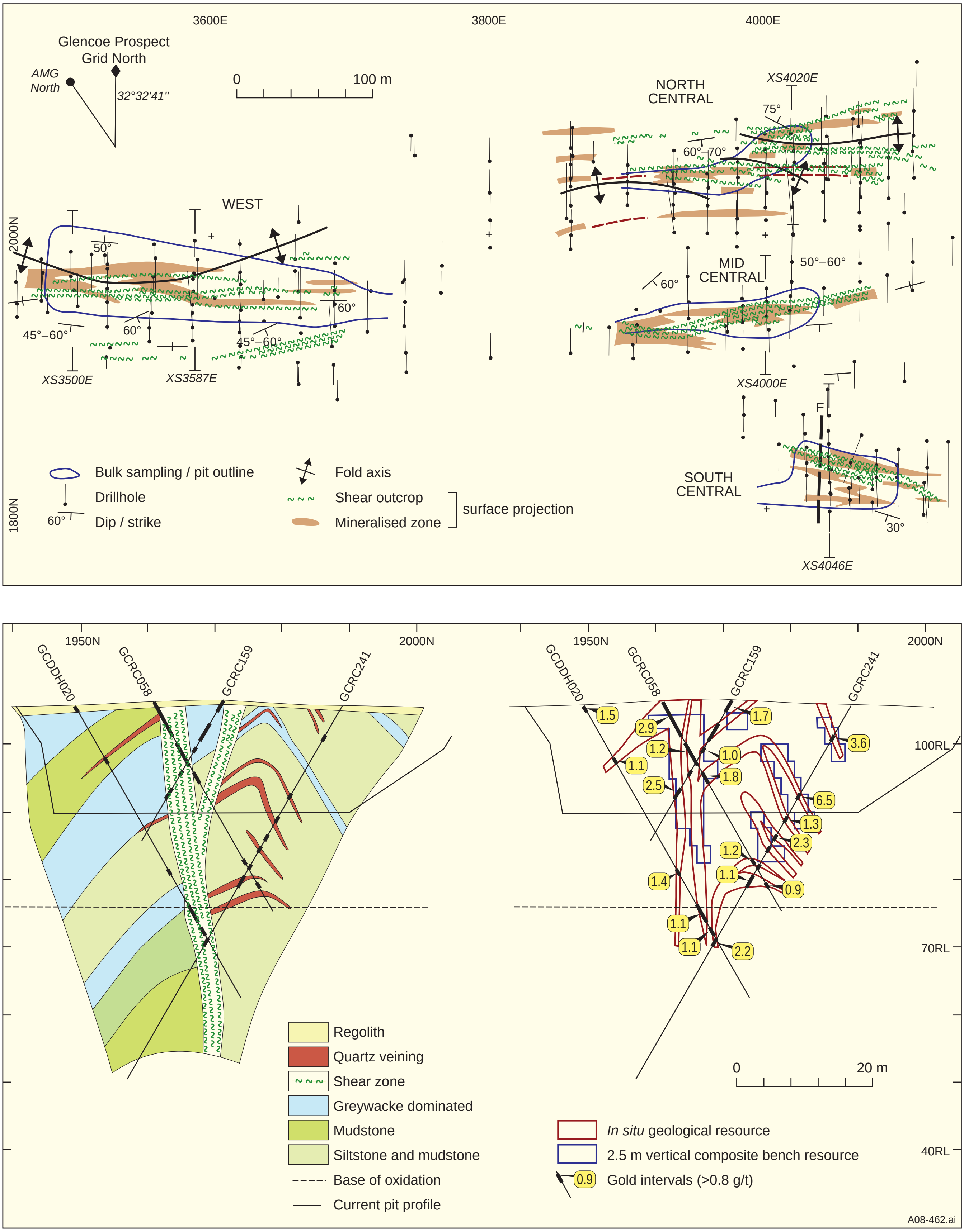

Figure 25. Geology of Glencoe deposit (from Australasia Gold 2005).

containing up to 50% pyrite. The orebody is 10–20 m thick, 150–200 m long, east dipping and steeply doubly plunging.

In 2000, Anglo Gold Ltd mined about 180 000 t of oxide ore averaging 3.5 g/t Au and processed it at the Union Reefs mill.

The Maud Creek goldfield was recently explored by GBS. The company identified three main zones of mineralisation: (i) the Main Zone (**Figure 26**) contains 80% of the mineralisation and is located on the north-striking sheared contact between mafic tuffs and sedimentary rocks. The mineralisation envelope is bounded by northeast-trending faults with the higher-grade zone following a northeast-trending fault along the tuff–sediment contact; (ii) Hangingwall lodes, located within dilational zones hosted by hangingwall tuffs and bound by northeast-trending faults; (iii) Eastern Shear Lodes, which form a southerly-plunging pipe-like structure and include several mineralised lodes around the contact aureole of the tuff and the Maud Creek Dolerite.

The current resource of the Maud Creek goldfield is estimated at 9.3 Mt averaging 3.1 g/t Au (indicated) and 1.1 Mt averaging 2.4 g/t Au (inferred; Playford and Kerr 2007). GBS proposed that gold could be extracted in a heap leach by a bio-oxidation process suitable for refractory gold ore, followed by a standard carbon-in leach method.

Mount Todd goldfield

Gold was discovered at the historic Mount Todd goldfield in about 1902 and early production was between 1902 and 1914 (Walpole *et al* 1968). It was mined predominantly by underground operations from three reefs, namely *Tollis*, *Jones Brothers* and *Quigleys*, and produced some 27 kg of gold from 893 t of ore, averaging 30.2 g/t Au (Cottle 1937b). Some exploration and mining continued subsequently and in 1937 the Mines Branch drilled five diamond drillholes at the Jones Brothers Reef (Hossfeld and Nye 1941). In 1986–1988, Pacific Goldmines NL commenced open-cut mining at several locations (*Alpha*, *Bravo*, *Delta*, *Golf* and three pits in Quigleys reef). This company produced 94 000 t ore at 3.6 g/t Au (Poxon and Hein 1994).

In the late 1980s, Billiton Australia Gold Pty Ltd, in a joint venture with Zapopan NL, extensively explored this area and discovered the Mount Todd deposits in 1988. In 1992, Zapopan NL acquired Billiton's equity and continued a major exploration program until 1996, when the lease was acquired by Pegasus Gold Australia Pty Ltd. The exploration program involved geochemical surveys, geological mapping, geophysical surveys and extensive drilling, leading to the delineation of the *Batman* deposit (also known as *Yimuyn Manjerr*). In June 1999, the total proved and probable reserves were stated to be 91.2 Mt at 1.01 g/t Au, and the resource at the nearby Quigley deposit was estimated at 5.449 Mt averaging at 1.73 g/t (General Gold Resources 1999).

Mining at the Batman pit took place between 1993 and 2000, and at the Golf and Tollis pits in 1996. To the end of March 2000, when production ceased, the deposit had produced 347 484 oz (10 816 kg) gold. Gold recovery averaged 62% from the oxidised ore (0.88 g/t Au) and 58–60% from the transition ore (1.07 g/t Au; Gold Gazette, 15 December 1995, Mines and Energy, Northern Territory, records).

In late 1995, construction began on Phase II of the project, involving milling and CIL treatment of the primary ore. This $200 million project was expected to have a minimum of eight years mine life and produce just over one tonne (32 150 000 ounces) of gold per year at an estimated cost of US$265/oz.

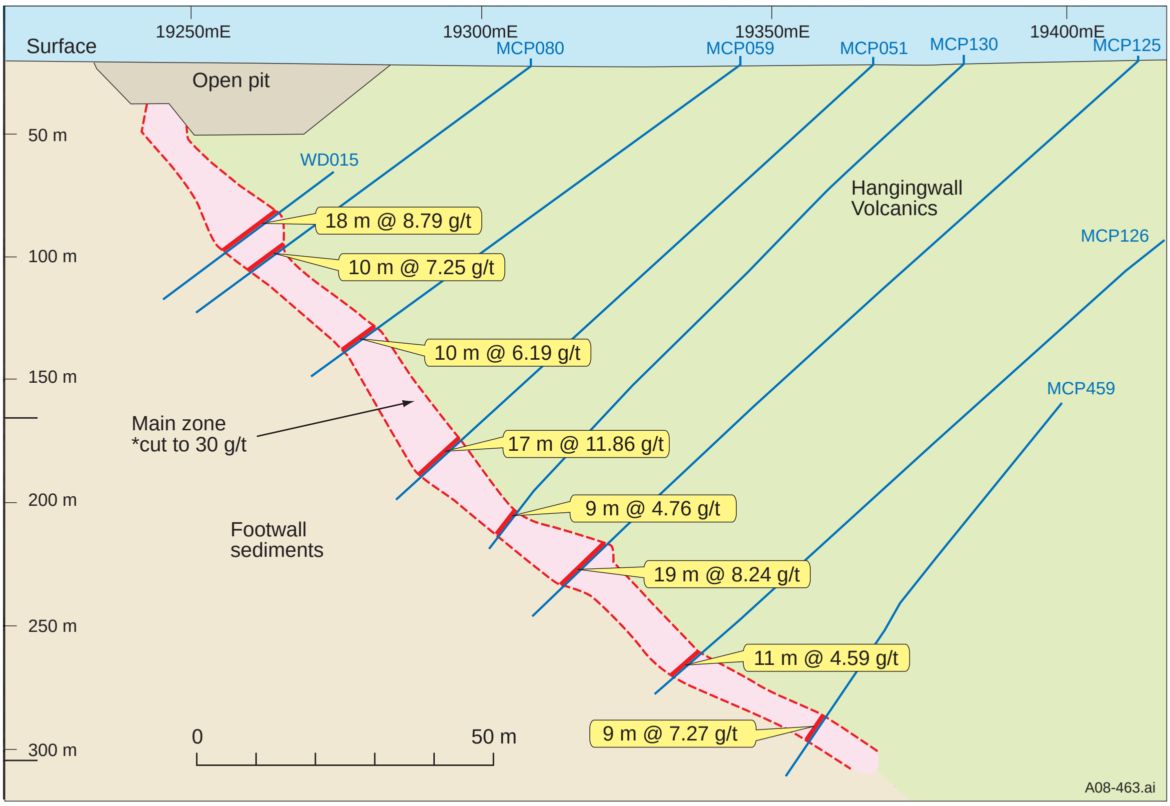

Figure 26. Maud Creek goldfield: Main zone orebody (courtesy of GBS Gold).

The project encountered significant problems with the operating costs exceeding the feasibility level. The factors included: a lower than expected gold recovery due to the refractory character of the ore (recovery of 74% versus the feasibility estimate of 84%; milled grade 1.07 g/t Au), higher power cost of crushing (extremely hard hornfelsed ore); and higher cyanide consumption due to a higher than expected copper content. Deteriorating gold prices and a lack of positive results for exploration near the Batman pit further complicated this project and in November 1997, the mining operation ceased.

In 2007, the Batman deposit was taken over by the Canadian company Vista Gold Corporation (Vista). In March 2008, this company announced a Canadian NI 43-101-compliant measured and indicated resource ranging from 4.72 Mt @ 2.62 g/t Au for 398 000 oz Au at a cutoff grade of 2 g/t Au to 126.36 Mt @ 0.83 g/t Au at a cutoff grade of 0.30 g/t Au; and an inferred resource ranging from 0.55 Mt @ 2.35 g/t Au for 42 000 oz Au at a cutoff grade of 2 g/t Au to 126 Mt @ 0.58 g/t Au for 2 370 000 oz Au at a cutoff grade of 0.30 g/t Au (Vista 2008).

Gold mineralisation in the Mount Todd area occurs along a 5 km-long, north-northeast-trending zone within greywacke and siltstone of the Burrell Creek Formation. At the Batman open cut (**Figures 27** and **28**), this succession consists of interbedded greywacke, shale and minor tuff. Four upward-fining cycles have been identified, each commencing with greywacke, which grade upward to more shale-dominated units (Ormsby *et al* 1998). The rocks strike 325° and dip 55° southwest, and were weakly to moderately hornfelsed by nearby intrusions of the Cullen Batholith (Yenberrie and Tennysons leucogranites). Two thin lamprophyre dikes have been mapped in the mine pit. The dominant metamorphic assemblage consists of cordierite, muscovite, biotite and chlorite. At places (eg Golf pit), the host rock shows a distinctive banding produced by thin laminae of iron oxides. The Batman deposit lies on a northeast-trending magnetic lineament, which possibly reflects a deeper crustal structure related to the Pine Creek Shear Zone (Poxon and Hein 1994, Koerber 1989).

Three sets of faults are recognised in the area: (i) first-order, northwest-trending strike-slip faults; (ii) second-order

Figure 27. General view of Batman open cut in (**a**) November 1996 and (**b**) May 2007.

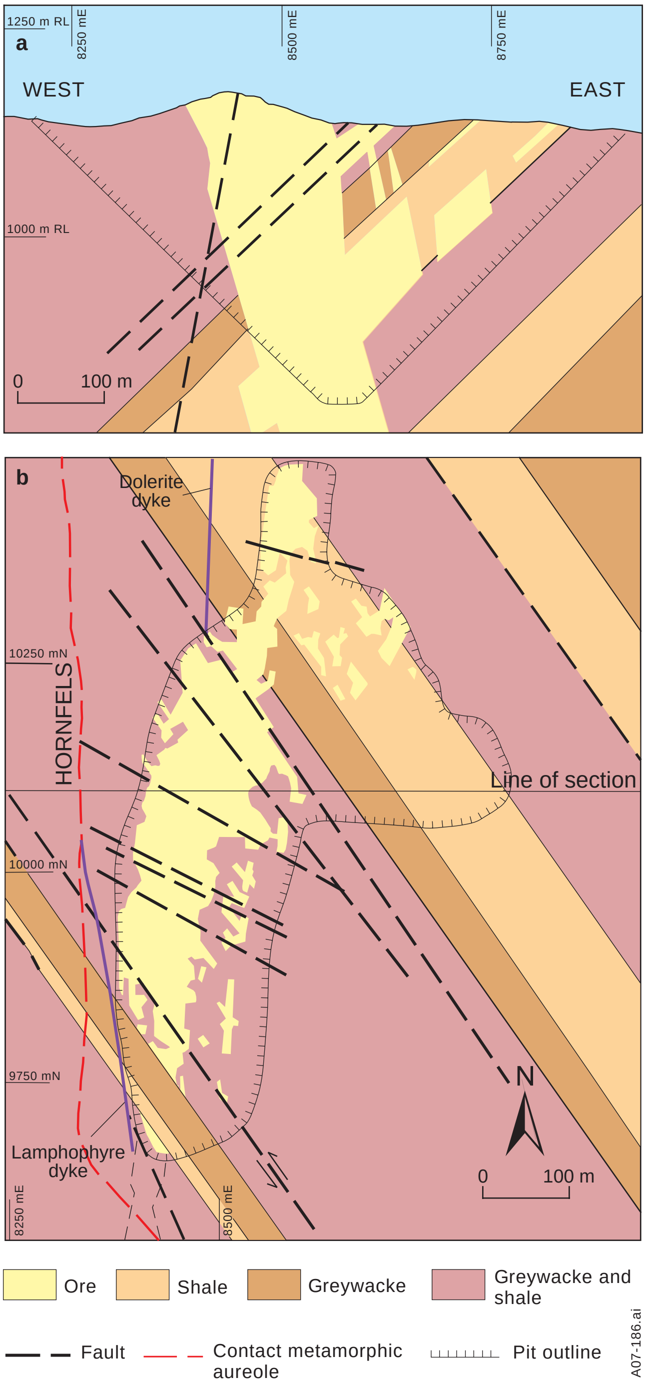

Figure 28. Generalised (**a**) geological cross-section and (**b**) plan of Batman deposit (modified after Ormsby *et al* 1998).

northwest-trending strike-slip faults; and (iii) prevalent third-order northwest- to northeast-trending strike-slip, normal and reverse faults. The last two types are closely associated with the mineralisation.

Two types of veining are present in the area: (i) earlier auriferous quartz-sulfide veins of crack-seal type; and (ii) later calcite-base metal veins composed of dogtooth quartz, calcite, galena, sphalerite, pyrite, arsenopyrite and chalcopyrite.

There are also two types of mineralisation. The first type comprises bedding-parallel stockwork zones of 1–30 mm-thick stringers and veinlets, composed predominantly of iron oxides with varying amounts of quartz (**Figure 29**). Such mineralisation occurs, for example, at the Batman, Alpha, Bravo and Delta deposits. At the Batman deposit, the zone of stockwork extends over an area 1500 m long, 300 m wide and at least 450 m deep. To the south, mineralisation terminates against strongly hornfelsed sedimentary rocks, and to the north, the mineralised zone appears to be cut off by a northwest-trending fault. Most gold is within quartz veins and their margins, with only a minor amount extending into the wall rock. The mineral assemblage of the quartz stockwork type includes pyrrhotite, pyrite, chalcopyrite, arsenopyrite, marcasite, bismuth, bismuthinite, galena, sphalerite, cubanite, talnakhite [$Cu_9(Fe,Ni)_8S_{10}$, hedleyite ($Bi_{14}Te_6$)] and loellingite. In spite of this complex assemblage, most of the gold occurs as 2–60 µm-sized inclusions in vein quartz. Minor amounts of gold are associated with chalcopyrite, bismuth and bismuthinite (Poxon and Hein 1994). Gangue minerals comprise quartz, tourmaline, biotite, muscovite and chlorite.

The second type of mineralisation comprises 0.5–1 m-thick, well defined lodes of massive brecciated iron oxides (eg Jones Brothers reef, Golf). In some places (eg Golf, Quigleys reef), both types occur together, ie massive lodes are surrounded by zones of ferruginous stockwork.

Detail studies indicate that despite the differences in the two styles of mineralisation, the deposits are similar in vein/lode morphology, tectonic history, alteration assemblages and relative geological timing. The differences in mineralogy are attributed to gross metal and sulfide zonation around the Cullen Batholith (Hein 2003a).

Hein (2003b) recognised three deformation events in the Mount Todd area. D_1 is represented by conjugate buck quartz veins and close to tight, northeast to north to northwest-trending asymmetric folds (F_1). This deformation is interpreted to have preceded the intrusion of the Yanberri Leucogranite and coincided with peak deformation and metamorphism. D_2 is associated with west-trending open folds and preceded the emplacement of the Tennysons Leucogranite. It is also associated with the development of auriferous quartz veins. D_3 is characterised by reactivation of strike slip faults.

Şener (2004) undertook SHRIMP dating of monazite within the auriferous quartz veins. Approximately two-thirds of the analyses had unacceptably high common Pb and some data were affected by technical problems. After omitting the problematic data, 11 analyses on 4 monazite grains yielded a mean age of 1854 ± 16 Ma, with a low excess scatter (MSWD = 0.4). These ages are interpreted as representing an earlier generation of monazite, which was incorporated into the veins from the wallrock by mechanical processes.

Şener (2004) also provided SHRIMP U-Pb geochronological data on gold associated hydrothermal xenotime for the Mount Todd deposit. Twenty-three analyses on 7 xenotime grains from 3 polished thin-sections gave a mean age of 1812 ± 11 Ma with a high excess scatter (MSWD = 3.4). After rejecting eight distinct age outliers (<1800 Ma and >1835 Ma) from the main group, 15 analyses are left that yield an age of 1819 ± 8 Ma with a low excess scatter (MSWD = 0.4), which is considered a definitive age for the gold mineralisation at Mount Todd. This age grouping coincides with the intrusion of the Cullen Granite (Ahmad and Hollis, in prep).

Pine Creek goldfield

The Pine Creek goldfield comprises a 1 km-wide and 6 km-long, northwest-trending belt, centred 0.5 km west of Pine Creek township. It includes 15 hard rock and numerous alluvial workings that together constitute the most productive goldfield in the PCO (**Figure 30**).

The old workings consisted of numerous pits, shafts, adits and alluvial/eluvial diggings above the water table in oxidised ore. In the *Enterprise*, *Elsinore*, *Kohinoor* and *Eleanor* mines, underground workings reached a depth of about 80 m.

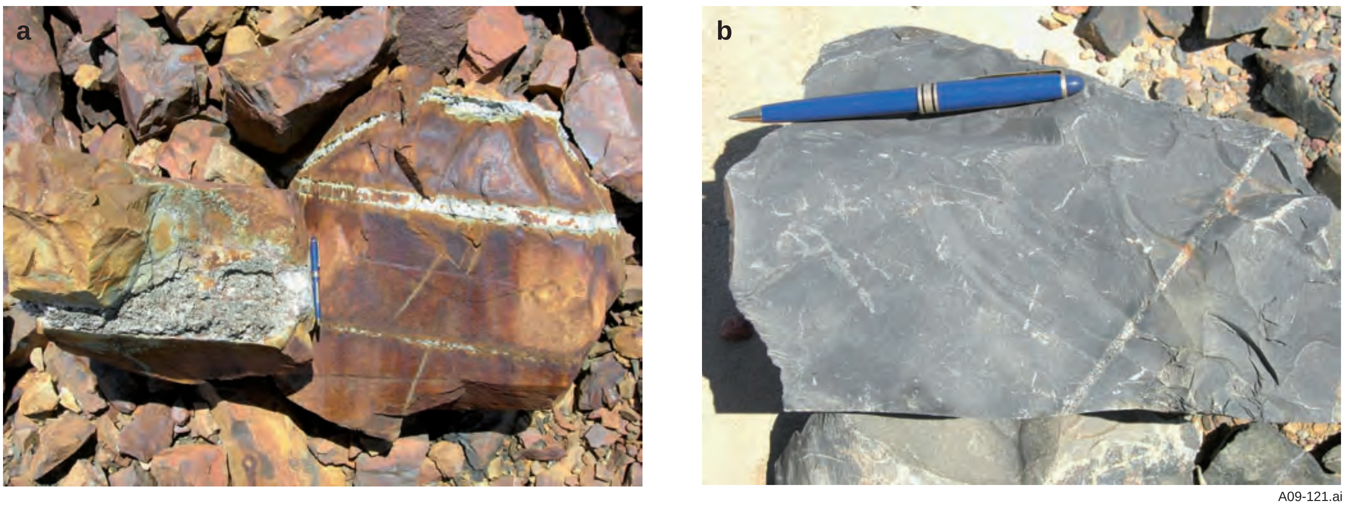

Figure 29. Auriferous quartz veining from Batman deposit. (**a**) 0xidised zone. (**b**) Primary zone (note hornfels host).

From the discovery of gold in the early 1870s to 1915, 124 960 t of ore were treated, yielding an average of 32 g/t Au from the batteries and 7.8 g/t Au from the cyanide works. The reported total production to 1915 was 2.3 t Au (Hossfeld 1936a). The actual production was probably higher, because no systematic record was maintained before 1884 and because a large quantity of alluvial gold won by Chinese tributers was unrecorded. Since 1980, due to increased gold prices and improvements in gold extraction and mining techniques, exploration activities in the field have intensified. As a result, the first mining venture of the modern era, the Enterprise mine, began operations in October 1985 and mining continued until 1995.

The Pine Creek goldfield is adjacent to the western margin of the Pine Creek Shear Zone in sheared and contact-metamorphosed phyllite and greywacke of the Mount Bonnie and Burrell Creek formations. The Mount Bonnie Formation consists of shaly sedimentary rocks interbedded with greywacke and tuffaceous units. A thin carbonaceous shale horizon containing chert nodules has been used as a marker horizon in defining a tight, southeast-plunging F_3 anticline (Enterprise anticline) at the Enterprise mine. Two similar anticlines (Czarina and Kohinoor) are present to the east. The axes of all three anticlines trend 320–340° and plunge 15–55° southeast (**Figure 30**).

Mineralisation is structurally controlled in saddle reefs and, less commonly, in discordant quartz veins in faults and shear zones. Minor amounts of gold are also disseminated in the wallrock adjacent to quartz veins. Hossfeld (1936a) listed sixteen saddle reefs (eight in the Enterprise anticline, three in the Czarina anticline and five in the Kohinoor anticline) and these were the focus of early mining. The western limbs of these reefs are usually more persistent laterally and at depth. Old workings have usually followed the contact zone between the reefs and wallrock, leaving the central parts of the quartz veins untouched.

The Enterprise mine is the largest in the Pine Creek goldfield and is the sole producer of the modern era. It produced 19.4 t Au from ore averaging 2.7 g/t Au before production ceased in 1995. Mineralisation occupies a transitional zone of greywacke, shale and chert between the Mount Bonnie and Burrell Creek formations. The wallrock contains up to 1% disseminated sulfides; mainly pyrite, but also arsenopyrite and pyrrhotite. Four informal lithological units (**Figure 31**) have been identified in the mine area (Dann and Delaney 1984, Cannard and Pease 1990). Although the sedimentary rocks have been subjected to deformation and metamorphism, primary sedimentary structures, including load casts, flame structures and cross-bedding, are still preserved.

The Tabletop Granite is exposed 1 km west of the Enterprise mine and may lie at a depth of about 1 km in the mine area. A gravity survey conducted by NTGS in 1989 about 2 km north of the Enterprise mine indicated the

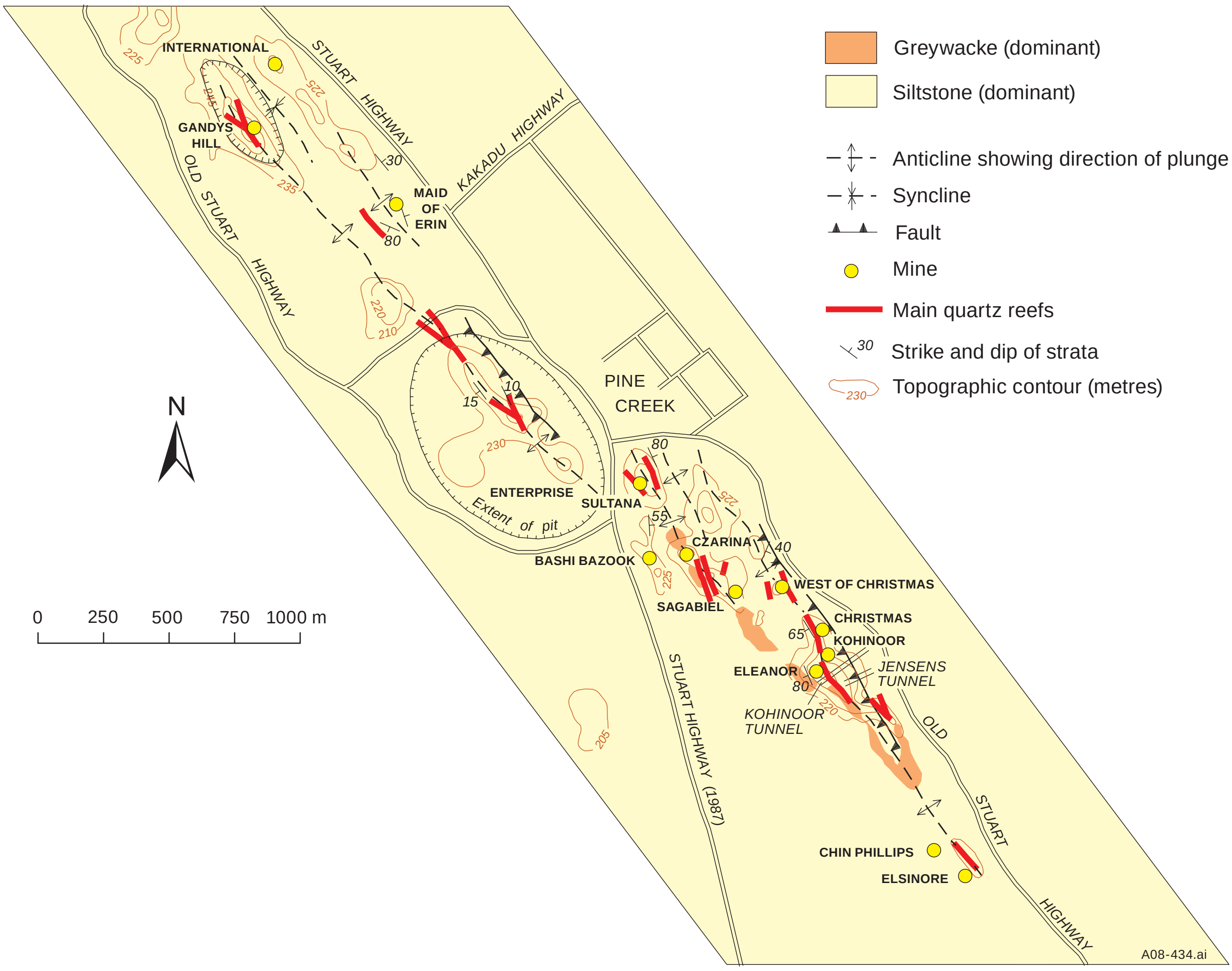

Figure 30. Gold occurrences and simplified geology of Pine Creek goldfield.

presence of granite below the Burrell Creek Formation at a depth of about 2 km (TL Findhammer, NTGS, pers comm 1989).

Mineralisation at the Enterprise pit (**Figure 32**) is confined to the Enterprise anticline, which strikes northwest. It is generally symmetrical, but in places the axial plane dips 80° southwest. Several faults exist in the mine area: the largest, the Eastern Fault Zone, can be traced for 600 m, dips 60–70° southwest and strikes northwest. This fault is displaced by younger north-trending faults, and in the southern part, it is displaced by a near-vertical, 060°-trending fault. The younger faults do not carry auriferous quartz veins, but in places, host late-stage galena-quartz veins.

Gold is present as free grains and is also contained in arsenopyrite (**Figure 33**). Other sulfides include pyrite, pyrrhotite, marcasite, chalcopyrite, galena, sphalerite, bismuthinite, tetrahedrite and covellite. Rare native copper and bismuth are present.

The *Gandys Hill* deposit (also known as *Carlton Hill*) contained a mined resource of 2.4 Mt @ 2.5 g/t Au. This deposit occupies a structural setting similar to that of the Enterprise deposit and has a similar ore mineralogy.

Other deposits in the Pine Creek goldfield including *Kohinoor*, *Eleanor*, *Czarina* and *Maid of Erin* were investigated by drilling during the late 1980s, but no resources were outlined. During early 2008, some low-grade ore (0.7 g/t Au), treated as a waste by the previous miner, was used by GBS to blend with the higher-grade ore from the Brocks Creek (Zapopan) mine and was treated at the Union Reefs plant.

Ringwood mines

The *North Ringwood*, *Ringwood* and *South Ringwood* mines occupy an area of about 55 km, east of Adelaide River Township. About 87 kg of gold was produced from these mines between 1894 and 1902 (Crohn 1968). Several shafts, small open cuts and pits are grouped in three locations along a 6 km-long line. Mineralisation is hosted by isoclinally folded and heavily cleaved greywacke and slate of the Burrell Creek Formation, which strikes 330–350° and is subvertical. The sedimentary rocks are sheared and lie within the northwestern extension of the Pine Creek Shear Zone. The lodes consist of concordant quartz veins, including saddle reefs. Ore minerals comprise arsenopyrite, pyrite and free gold.

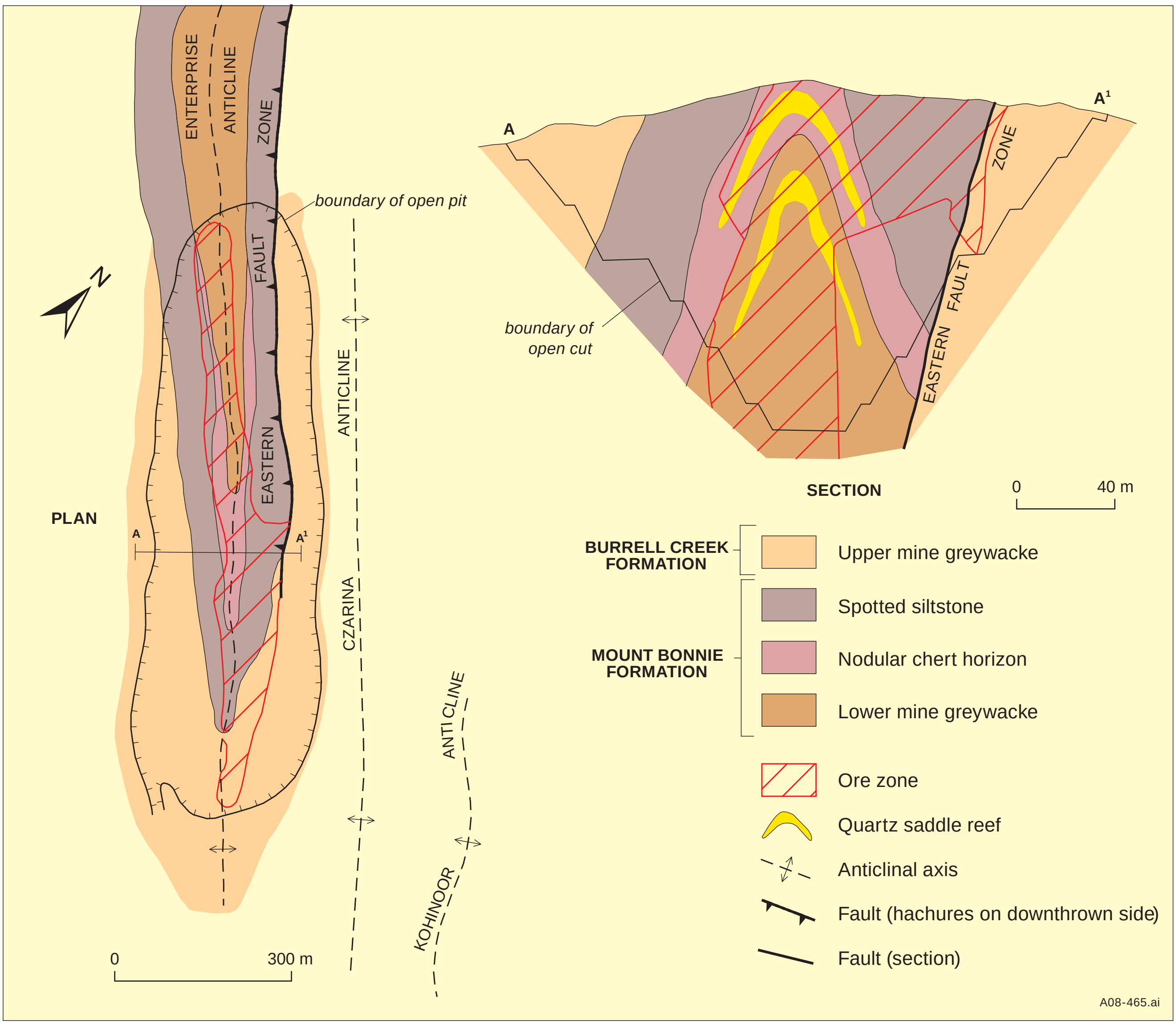

Figure 31. Geological plan and cross-section of Enterprise (Pine Creek) mine (modified after Cannard and Pease 1980).

In 1978, NTGS drilled four diamond holes at the North Ringwood mine (Newton 1979). Two zones of gold mineralisation were intersected (0.5 m grading 60 g/t Au and 2.5 m at 3.1 g/t Au). This drilling confirmed that mineralisation continued to a depth of at least 40 m beneath the workings, but further drilling was required to prove the existence of an orebody. During 1988–1989, major exploration programs, including extensive drilling, were carried out by several companies (eg WR Grace Australia Ltd, White Industries Ltd), but results have not been released. At the time of writing, gold mineralisation in the Ringwood area remains a subject of interest for unlisted private companies, but details of exploration activities are not available to the public.

Rustlers Roost

This deposit, 90 km southeast of Darwin, was discovered in 1948 by Jim Escreete during a prospecting trip, which was targeting unexplored country south of Mount Bundey. Alluvial gold was found over a large area, and trenches and shallow pits were dug over a gold-bearing gossanous ironstone. This identified the *Sweat Ridge*, *Dolly Pot*, *Beef Bucket* and *Backhoe* prospects. A five-head stamp battery was erected at Pighole on Mount Bundey Creek, 4 km east of the workings. It is estimated that 200–250 t of ore was mined for the production of about 3.7 kg of gold (Rabone 1995).

In 1977, Ben Hall and Cameron Cleary were granted EL 1473 over the area, which became known as Rustlers Roost. The area has since been explored by Engineering Excavations NT Pty Ltd in 1978, Northern Metals Pty Ltd/Aurex Pty Ltd in 1981, Naron Investments in 1985, Kintaro Gold Mines NL in 1988, and Pegasus Gold Australia Ltd in 1988. In 1990, the latter company outlined a resource of 4.8 Mt at 1.6 g/t Au. Further exploration by Valdora Minerals NL led to the identification of 8.1 Mt at 1.2 g/t Au in 1993. Additional exploration increased this resource to

Figure 32. Open cut at Enterprise (Pine Creek) mine in 1991. Dashed lines show position of anticlinal axis in pit. Compare with cross-section in **Figure 31**.

Figure 33. Ore-stage quartz vein with auriferous arsenopyrite from Enterprise mine. Note cordierite pseudomorphs resulting from contact metamorphism in host greywacke.

34 Mt at 1.17 g/t Au (Rabone 1995). Production by the heap leaching method commenced in June 1994. The initial plan was to combine the open pits at Sweat Ridge, Dolly Pot, Beef Bucket and Backhoe into a single large pit. Lower gold prices, low grades and poor recoveries forced the closure of operations in early 1998. Total production to March 1998 was 3425 kg Au and 337 kg Ag from 4.58 Mt of ore (Mines and Energy, Northern Territory, records).

In 2002, Rustlers Roost was purchased by a Canadian Company, Valencia Ventures Inc. The company conducted a feasibility study (assuming US$450/oz gold price and Australian dollar exchange rate USD/AUS = $0.75) and reported the remaining total reserves at 13 Mt @ 1.2 g/t Au (Valencia Ventures Inc, Press Release to the Canadian Stock Exchange, 8 May 2006).

Gold is present in a stockwork of thin quartz-sulfide stringers and stratiform iron-rich beds within the Mount Bonnie Formation (**Figure 34)**. Dolerite dykes intrude the host succession. Mineralisation extends over an area of 1.5 km x 0.5 km and is cut off to the south by a north-trending fault that dips 75° east. The rocks are weakly metamorphosed to sub-greenschist facies and there is no observed contact metamorphism. The deposit is located at the crest of the south-plunging Dolly Pot Anticline. This anticline is asymmetrical, with limbs dipping 35° east and 50–70° west. Mineralisation occurs in both limbs.

Several gold-bearing lenses are present in this deposit and have variable strike directions. Most gold occurs in dark dolomitic, carbonaceous and pyritic shale, as well as in flat-lying discordant quartz veins. The ore assemblage includes gold (grains 1–50 µm), pyrite, arsenopyrite, chalcopyrite, marcasite, pyrrhotite and sphalerite. The oxidised ore extends to a depth of 80 m.

Figure 34. Open cut at Rustlers Roost mine in 1996, showing ore zone in centre, which comprises iron-rich sediments.

Spring Hill

Spring Hill, located 26 km northwest of Pine Creek township, has been worked intermittently since the 1870s by several shafts to a depth of 105 m and has a 427 m-long adit (Taube 1966). Total recorded production is 679 kg, mostly from the oxidised zone.

The host rock comprises sandstone, siltstone and shale of the Mount Bonnie Formation. The workings are located near the axis of a tight south-plunging anticline. Mineralisation is present in four separate zones, named *Hong Kong*, *Main*, *Middle* and *East*. The quartz sulfide lodes occupy shear zones that transgress the hinge of the anticline. They are 180 m long and vary in thickness from 0.4 to 1.5 m (Taube 1966). Four main styles of veining are present: sheeted vein systems, leader veins, bedding parallel veins and saddle reefs (Western Desert Resources 2007).

The leader veins occupy a tension gash axial plane cleavage that strikes north-northwest and dips steeply east. Historical mining exploited the larger high-grade veins associated with the named lodes. The gold is associated with pyrite, galena and arsenopyrite. Most of the ore came from the oxidised zone and had a grade of about 30 g/t Au. The gold was free and coarse-grained. Kaolin and limonite were associated with the mineralisation.

The sheeted veins are best developed in the Hong Kong zone, which has a north–south length of approximately 1 km and a width of about 100 m. They contain lower-grade, but higher-tonnage ore. Within the zone, bedding dips steeply west and the mineralised veins dip 70° southeast. The veins vary from several millimetres to 0.5 m in width and the vein density is up to 15 per metre (Western Desert Resources 2007). The mineralised quartz veins contain pyrite, but the gold is free milling in the oxide, transitional and sulfide zones.

In 1988, the Spring Hill Joint Venture was formed between Ross Mining NL and the Shell Company of Australia Ltd (predecessor of Acacia Resources Ltd) and an extensive exploration program commenced. It included airborne magnetics, stream sediment sampling, rock chip sampling and mapping, followed by trenching and milling. Since 2007, Spring Hill has been owned by the newly formed Western Desert Resources Ltd. In December 2007, Minmet quoted the indicated and inferred resource (based on 1999 data) to be 12.75 Mt @ 0.8 g/t Au.

Toms Gully

This deposit is located about 90 km southeast of Darwin and was discovered as a result of stream sediment geochemical survey in 1986 by Carpentaria Exploration Company Pty Ltd. It was extensively drilled and evaluated in the following year, leading to the establishment of ore reserves of 380 000 t averaging 8.4 g/t gold (Simpson 1990, Sheppard 1992). Open-cut mining commenced in 1988 and continued until 1991, for a total production of 75 000 oz gold from 356 651 t of ore averaging 9.23 g/t Au

(Minmet, June 2007). In 2005, Renison Consolidated Mines NL completed a resource drilling program and calculated the remaing resources at this deposit to be 1.82 Mt @ 8.1 g/t Au (Minmet, June 2007). In June 2007, Toms Gully was sold to GBS and in December 2007, this company announced to the Toronto Stock Exchange a probable reserve of 0.74 Mt @ 7.1 g/t Au (**Figure 35**).

This orebody comprises a quartz-sulfide vein striking 90°, dipping near the surface at 30–40° south, but gradually flattening to sub-horizontal at depth (Tsuda *et al* 1994). The quartz-sulfide vein averages about 1 m in thickness, but the mineralisation continues into the adjacent wall rock giving an average thickness for the orebody of about 2 m (**Figure 36**). Only the eastern half of the 800 m exposed strike length is of ore grade and this ore shoot extends southwest down plunge for over at least 1500 m. The quartz vein is banded, showing multiple generations of blue-grey quartz (**Figure 37**). Mineralisation is restricted to the central and eastern parts of the reef. The fault hosting the mineralised lode has been interpreted as a thrust (Sheppard 1992). Patchy sub-economic mineralisation is present in the altered siltstone in the hangingwall. A steeply dipping discontinuous Pb-Zn-Ag-Cu lode, up to a metre thick, overprints gold mineralisation at the eastern end of the lode. The north-northeast and northeast faulting has resulted in metre-scale or decametre-scale displacements of the mineralised vein.

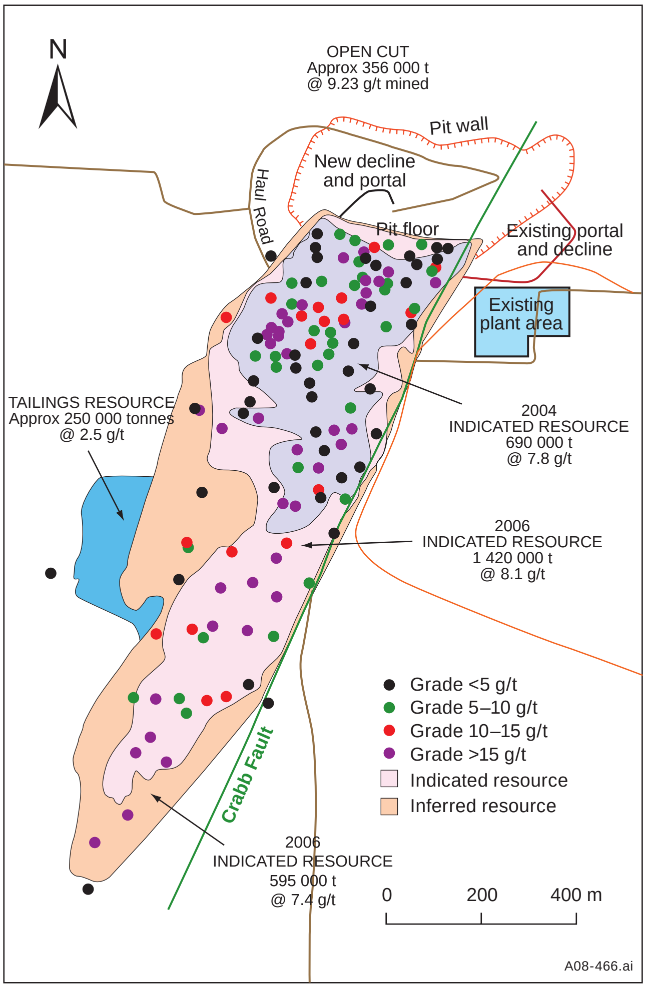

Figure 35. Plan view of orebody at Toms Gully mine (courtesy of Renison Consolidated Mines NL).

The host rock comprises folded carbonaceous siltstone and mudstone of the Wildman Siltstone and has been regionally metamorphosed to lower greenschist facies. Intrusion of the nearby Mount Bundey Granite has resulted in the development of andalusite-bearing hornfels. Pyrite and arsenopyrite are the main sulfides and are present in the ratio 2:1. Minor loellingite, galena, sphalerite, chalcopyrite and pyrrhotite are also present.

Figure 36. Mineralised quartz vein at Toms Gully mine, prior to mining. Vein is exposed in centre and edges of vein have been excavated. Width of vein is approximately 2 m.

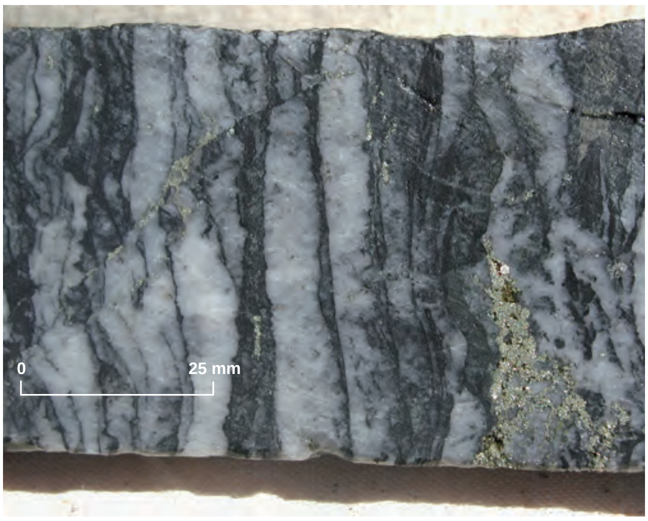

Figure 37. Laminated quartz vein with auriferous pyrite from Toms Gully mine.

Union Reefs goldfield

The Union Reefs goldfield, 15 km north of Pine Creek township, was discovered in 1873 by prospectors Adam Johns and Phil Saunders (Jones 1987, Hossfeld 1936b). It produced 1.76 t Au from 0.58 Mt of ore during 1873–1906 (Walpole *et al* 1968).

The goldfield has had a long exploration history, including two government-funded diamond drillholes in 1905–1906, believed to be the first exploration drillholes ever drilled in the Northern Territory. Four more diamond holes were drilled in 1913–1914 (Brown 1906, Jensen 1915). During 1963–1965, the Bureau of Mineral Resources carried out a plane table survey and recorded all old workings. Geophysical surveys were also undertaken and 13 holes were drilled at the *Millars*, *Prospecting Claim*, *Crosscourse* and *Union Central* lodes (Shields *et al* 1967). Seven percussion holes were also drilled. During 1969–1970, four additional diamond holes were drilled by the Northern Territory Mines Branch (Shields 1970). In 1984, Enterprise Gold Mines NL undertook structural and geological reinterpretations and further diamond drilling. This company identified an inferred resource of 1.3 Mt at 1.72 g/t Au (oxide ore) and 0.6 Mt at 1.62 g/t Au (sulfide ore) within a series of discrete and interconnected ore zones in the central part of the field (Enterprise Gold Mines 1986).

The old workings consisted of 1600 pits, open cuts and shafts concentrated in an area 5 km long and 450 m wide in two subparallel northwest-trending zones, 200 m apart. The western zone is known as the Union Line and the eastern zone as the Lady Alice Line. The Lady Alice Line hosts the *Millars*, *Ping Ques*, *Lady Alice* and *Lady Alice North* workings. The Union Reefs Line hosts the *Union South*, *Crosscourse*, *Union Central*, *Millars Prospecting Claim* and *Union North* workings (**Figure 38**).

The lodes lie within the Pine Creek Shear Zone and are hosted by greywacke, slate and minor conglomerate of the Burrell Creek Formation. Bedding strikes to 330° and dips steeply. The rocks are strongly deformed by a series of tight isoclinal folds that are overturned to the northeast and in many places, are dislocated by bedding-parallel shears (**Figure 39**). The isoclinal folds form an anticlinorium with an average plunge of 25° south. Dolerite dykes intrude the metasedimentary succession.

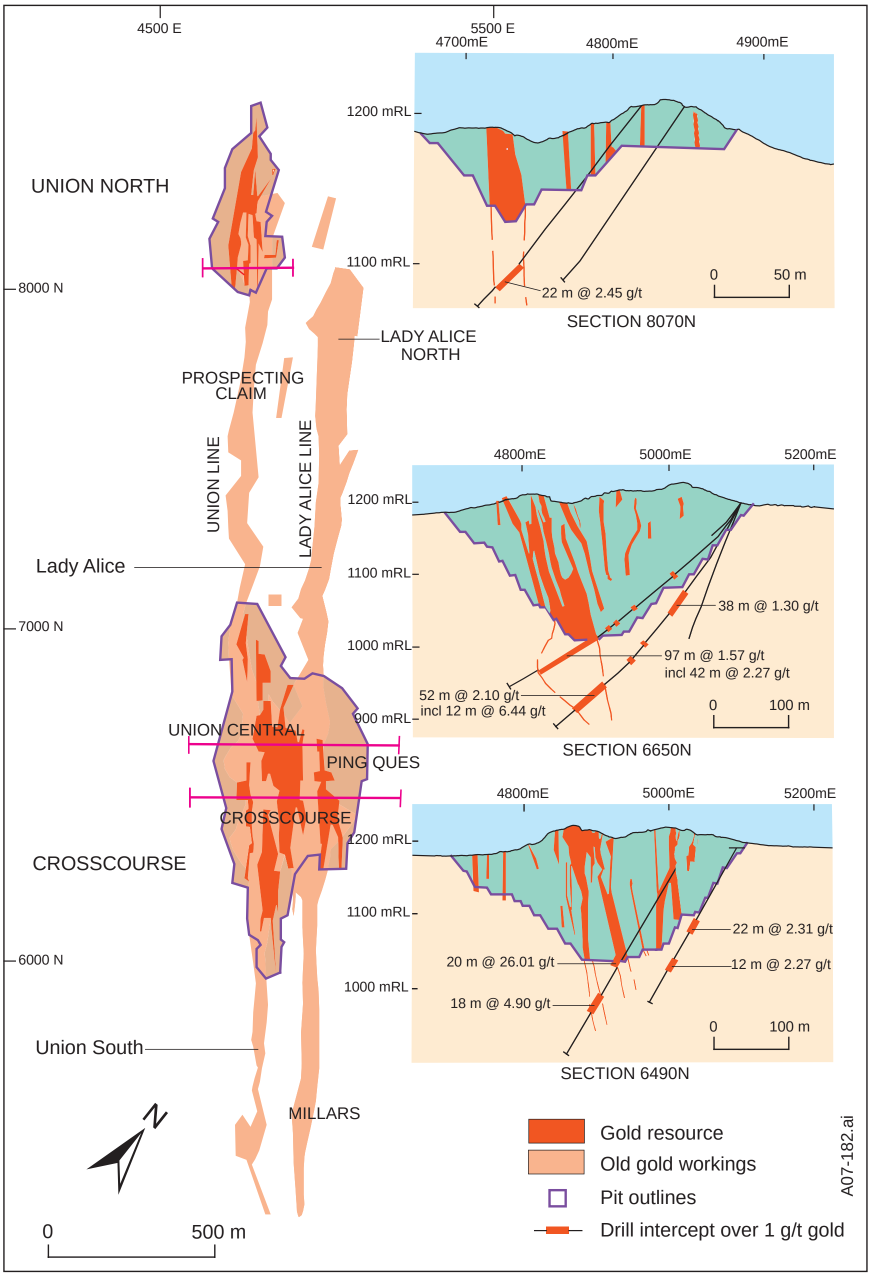

Figure 38. Generalised geology of Union Reefs mine (modified after Acacia Resources Ltd Annual Report for 1996).

In 1991, the Shell Company of Australia Ltd purchased the Union Reefs tenements and carried out detailed exploration, resulting in resource delineation and open-cut mining by Acacia Resources Ltd in January 1995. As of December 1998, the total resources were estimated to be 17.6 Mt at 1.7 g/t Au. Another orebody, Union North, was delineated a few kilometres north of the main open cut (**Figure 38**). In April 1994, the estimated total reserves at this orebody 8.1 Mt at 2.21 g/t Au (Newton *et al* 1998). When mining ceased in July 2003, total production by Acacia Resources/AngloGold had amounted to 20 2 Mt @ 1.47 g/t for 27.15 t Au (Zia Bajwah, GBS Gold Australia Pty Ltd, pers comm 2009).

Hellsten *et al* (1994) described three types of quartz-sulfide veins associated with mineralisation, in the form of stockworks, sheeted veins and thick quartz reefs (**Figure 40**). The quartz reefs are generally located in sheared slate. Stockwork veining is restricted to greywacke. Sheeted veins tend to occur in thinly interbedded intervals (**Figure 41**). The three vein styles may occur separately or may merge. The lodes generally outcrop as en echelon, northwest-plunging lenses parallel to near-vertical shears trending 010°, 330° and 355°. Steeply-plunging saddle reefs up to 3 m thick are zoned with barren quartz in the centre and mineralised margins (**Figure 42**).

The primary sulfides are pyrite, arsenopyrite, galena, sphalerite, marcasite and pyrrhotite. Gold is present as small free grains and sub-microscopic inclusions in sulfides. A crude mineral zonation can be distinguished, whereby sphalerite and galena tend to be marginal to gold-pyrite-arsenopyrite zones. Coarse visible gold is mainly confined to selvages of larger quartz veins and is present as single grains and clusters up to 5 mm diameter in cracks within quartz veins (**Figure 43**). The gangue minerals are quartz, chlorite, calcite, dolomite and albite. Small rich shoots, which have grades of up to 60 g/t Au and 25 g/t Ag over a true width of 2 m, have been intersected in the primary zone (Shields *et al* 1967, Turner 1990).

Şener (2004) carried out SHRIMP U-Pb geochronological studies on xenotime from the Union Reefs deposit. Approximately half of the analyses showed unacceptably high common Pb contents and were discarded. The remaining 10 analyses on 5 small xenotime grains from 3 polished thin-

Figure 39. Crosscourse Lode. Tight isoclinal folding and shearing on southeast pit wall.

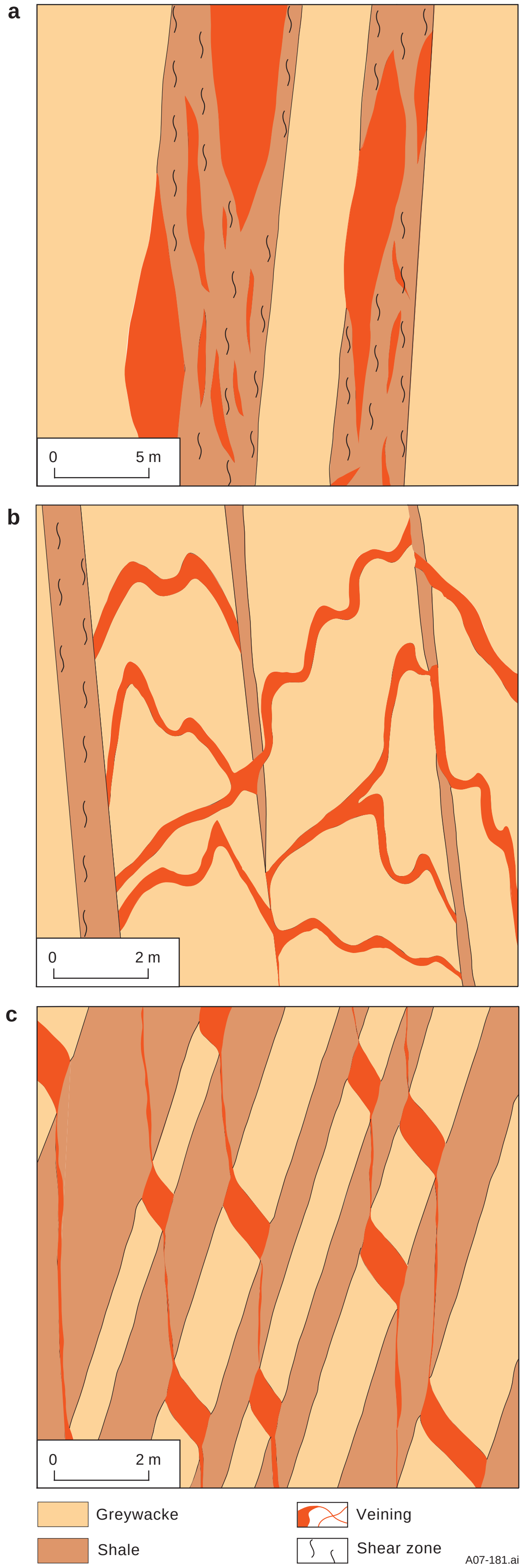

Figure 40. Auriferous quartz veins at Union Reefs (modified after Hellsten *et al* 1994). (**a**) Lode-style veins within sheared, dominantly shale wall rock. (**b**) Folded stockwork-style veins typical of Crosscourse mineralisation. (**c**) Sheared veins typical of Union North.

section fragments yielded a mean age of 1698 ± 18 Ma, with moderate excess scatter (MSWD = 1.5). This significance of this date is uncertain, as it does not coincide with any known event in the PCO (Ahmad and Hollis, in prep).

Although no mining has been carried out at Union Reefs goldfield since 2003, the treatment plant at Union Reefs was used in 2007–08 by GBS to process ore from gold deposits in the PCO (**Figure 44**).

Woolwonga

The Woolwonga mine is situated about 50 km northwest of Pine Creek township and was worked during 1871–1908 by underground methods. The total production was 205 kg of gold from 7457 t of oxidised ore and a further 26 kg of gold from the cyanide leaching of 4600 t of tailings (Stuart-Smith 1985). The grade of the oxidised ore averaged 27.1 g/t Au and the primary ore carried about 3 g/t Au (Walpole *et al* 1968).

In 1985, Dominion Mining Ltd commenced an extensive exploration program comprising geological mapping, costeaning and drilling. It outlined recoverable mining reserves of 2.1 Mt averaging 2.78 g/t Au and a preliminary resource estimate of 5 Mt at 3 g/t Au (Kavanagh and Vooys 1990). Mining commenced in July 1991 and the ore was hauled some 28 km to the Cosmo Howley CIL treatment plant. The mining operation was completed in early 1995, producing 130 000 oz of gold at

Figure 41. Auriferous, sheeted quartz veins in sheared southeast wall of Crosscourse Lode.

Figure 42. Steeply plunging saddle reef at old workings near Union Reefs mine. Note that old workings follow margins of reef leaving barren central part untouched.

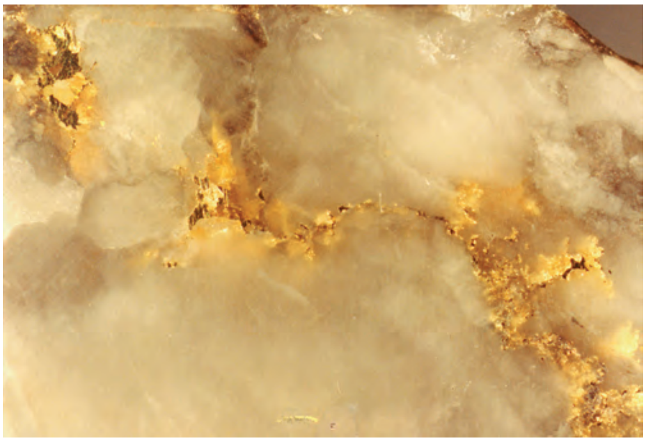

Figure 43. Coarse free gold in quartz from Union Reefs mine (length of photograph 15 mm).

Figure 44. Treatment plant at Union Reefs mine.

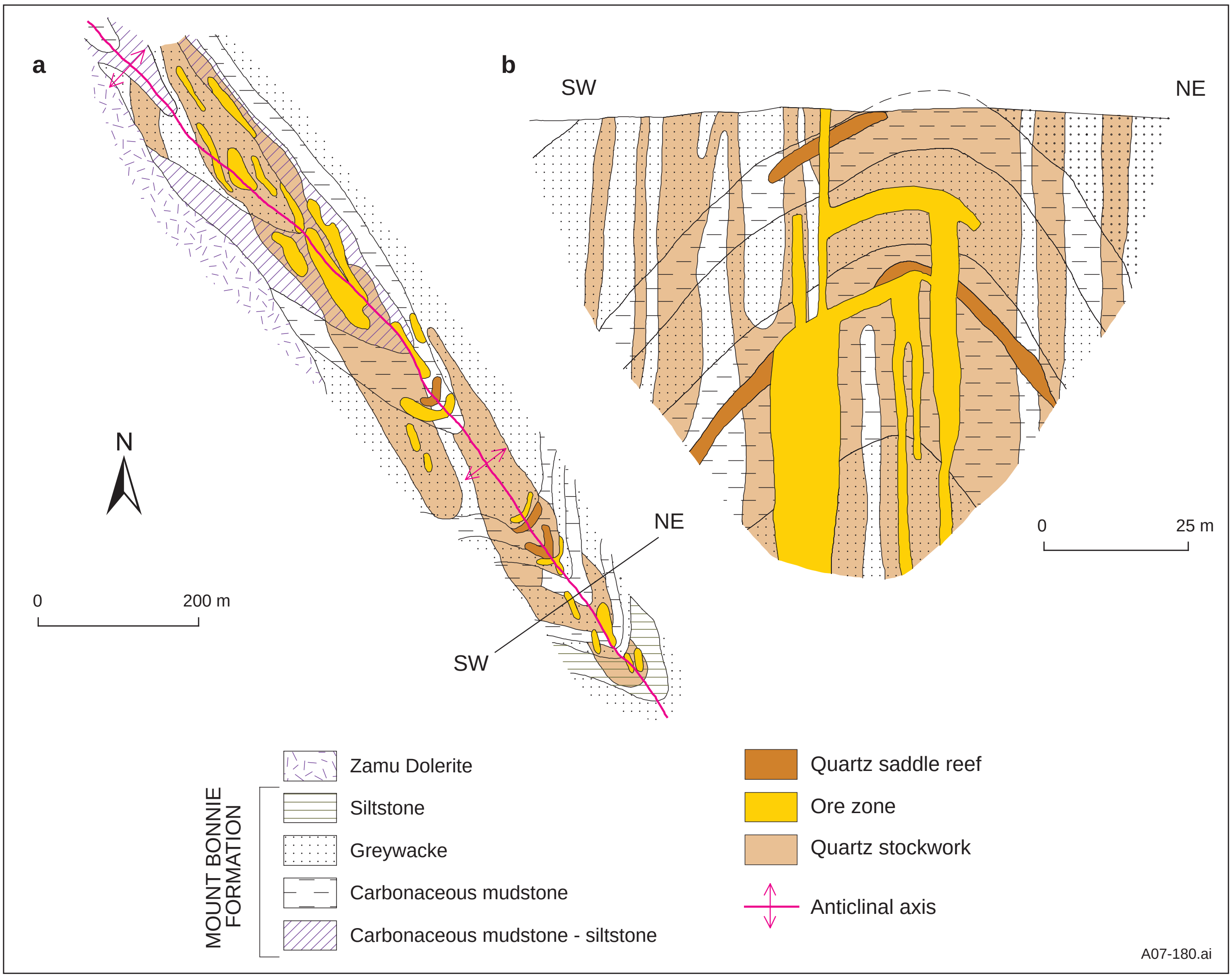

Figure 45. Generalised geological (**a**) plan and (**b**) cross-section at Woolwonga mine (modified after Kavanagh and Vooys 1990).

at an average grade of 2.8 g/t Au (Minmet, December 2007). In 1997, Northern Gold NL acquired Woolwonga and commenced an exploration program that including drilling to test southerly extensions of the mineralisation along strike (Northern Gold 2003). In 2005, GBS Gold Australia Pty Ltd (GBS) acquired the leases, but in early 2009, due to a downturn in the industry, the operation was placed on care and maintenance.

Mineralisation is structurally controlled (**Figure 45**) and occurs in quartz veins associated with faults, shears and zones of brecciation within a moderately tight anticline (**Figure 46**), striking 310° and plunging 35–40° southeast. A shear zone striking 330° cuts the anticline; this is probably related to the Pine Creek Shear Zone. Quartz veining comprises saddle reefs, subvertical veins, stockworks associated with shear zones, and subvertical veins parallel to the axial plane of the anticline and to the dominant cleavage. The host rocks consist of tuffaceous greywacke, mudstone and carbonaceous mudstone of the Mount Bonnie Formation, frequently in upward-fining turbiditic successions. The rocks are black in colour due to a high carbon content.

The richest gold mineralisation occurs at the intersection of the 330°-striking shear zone with the anticlinal axis, and at the brecciated margins of quartz saddle reefs. The predominant ore mineral association is arsenopyrite and pyrite, with subordinate amounts of marcasite, galena, native bismuth, pyrrhotite, chalcopyrite, sphalerite, covellite and chalcocite.

Figure 46. Open cut at Woolwonga mine. Note anticlinal structure and bedding-parallel quartz veins.

Gold occurs as small particles of free metal in quartz or as minute blebs in arsenopyrite. Gangue minerals are mostly quartz with minor siderite, K-feldspar and Mg-rich tourmaline (dravite).

Yam Creek

Yam Creek is the northernmost mine within the so called Priscilla Line of Reefs, which extends for 5 km to the southwest of Yam Creek and includes the *Princess Louise*, *Radfords Blow*, *Iron Blow* and *Sandy Creek* mines. Parts of this area were recently extensively explored by GBS.

The Yam Creek mine was operated between 1886–1904 (Blanchard 1937, Wygralak 1983). Most of the surface workings were concentrated on the smaller western lode. In 1901, Northern Territory Goldfields of Australia Ltd sank a shaft with a crosscut running from the 57 m level. Numerous shafts were later sunk to various depths, ranging between 20 m and 27 m. Blanchard (1937) reported the production of 238 kg of gold from ore grading 14.9 g/t Au.

Mineralisation is contained in two parallel, north-trending lodes, about 250 m apart. The lodes comprise discontinuous zones of bedding-parallel quartz veins, interbedded with slate and sandstone of the host Mount Bonnie Formation. Veins generally range in thickness between 0.1 and 0.3 m, and dip 65–75° west. There are also thicker quartz veins (up to 2.4 m), which probably represent saddle reefs. The oxidation zone extends to a depth of 20–30 m. Below this zone, the ore consists of quartz containing up to 10% pyrite and minor arsenopyrite.

Gold in iron-rich sedimentary rocks

These deposits are associated with iron-rich sedimentary rocks (also described as banded iron formation, ironstone or iron formation) in the Golden Dyke Dome, Howley Anticline and Moline Dam areas. The bulk of the mineralisation is stratabound and follows ironstone beds in the middle part of the Koolpin Formation. Gold-quartz veins, similar to those discussed in the preceding class of deposits, may also be present within some deposits. Matthaei *et al* (1995a, b) showed that the mineralisation at Cosmo Howley is contained within subvertical, bedding-concordant quartz veins and veins in fold hinges. In the Golden Dyke and Cosmo Howley areas, the hangingwall is carbonaceous shale of the upper Koolpin Formation.

Gold in these lodes is present as sub-microscopic particles in arsenopyrite and, to some extent, in pyrite, as it is for the gold-quartz veins. Some irregular grains of visible gold are also present. The oxidised ore is free milling.

These deposits have been described briefly by Crohn (1968) and Stuart-Smith (1985), and some detailed studies are also available (eg Nicholson 1978, 1980, Wilkinson 1982, Alexander *et al* 1990, Nicholson and Eupene 1990, Kavanagh and Vooys 1990). A brief summary of the important deposits is given here.

Cosmo Howley

The *Cosmopolitan Howley* (generally abbreviated to Cosmo Howley) mine is located 55 km northwest of Pine Creek township. It produced 1.05 t Au during 1879–1915, at an average grade of 22 g/t Au (Hossfeld 1942). This deposit was discovered in 1873 during construction of the Overland Telegraph Line and, along with the Big Howley mine, was worked until 1909. Between 1908 and 1915, gold was obtained through cyanidation of tailings. Exploration in the 1930s by Anglo-Queensland Mining Pty Ltd (later Mount Isa Mines Ltd) failed to justify mining operations. Diamond drilling in 1948 and 1963 by the Mines Branch of the Northern Territory Administration, in 1957–1959 by BMR, in 1975–1979 by BHP Ltd, and in 1982 by Geopeko Ltd intersected ore-grade material, but failed to establish a minable reserve.

In 1984, Dominion Mining Ltd started systematic drilling and defined a minable resource. Production commenced in 1987 and involved two pits that reached a depth of 120 m. The global resource to 270 m depth was defined as 10 Mt at 2.75 g/t Au and a total of 17.7 t Au was produced between 1987–1994 from 7.7 Mt of ore at 2.3 g/t Au (Matthaei *et al* 1995a). A remaining underground resource (*Cosmo Deeps*) of 2.62 Mt at 5.05 g/t Au was estimated by Northern Gold (1998). In 2008, this resource was upgraded by GBS to 8.74 Mt @ 4.55 g/t Au.

Mineralisation is hosted by the Koolpin Formation in the core of a regional anticline (**Figure 47**). The Koolpin Formation is divided into three informal members (Alexander *et al* 1990). The 'lower member' is 250 m thick and consists of carbonaceous mudstone and siltstone. The 100 m-thick 'middle member' comprises interbedded ironstone and carbonaceous mudstone. The 50–150 m-thick 'upper member' consists of carbonaceous mudstone. The Zamu Dolerite locally intruded the mine succession as sills, prior to folding.

The auriferous 'middle member' of the Koolpin Formation consists of five ironstone beds (named I1 to I5), each 5–20 m thick and separated by four intervals of mudstone (M1 to M4). The ironstones comprise laminae of iron-rich silicates up to 5 mm thick, alternating with sulfide-rich bands. They have assemblages of chlorite and actinolite, plus minor mica, quartz, garnet, graphite and fine pyrite, and contain 10–15% iron as silicates, sulfides and carbonates. Common features of the ironstone intervals are recrystallised chert nodules and bands.

The intervening mudstones comprise chlorite, quartz and muscovite with minor pyrite and rare garnet. Lenses containing 60% Mg-rich tourmaline (dravite) are present towards the base of the 'middle member'. Nicholson (1980) interpreted these lenses as metamorphosed boron-rich sedimentary rocks. Gold mineralisation at Cosmo Howley occurs in all ironstone horizons, but economic grades are confined to the I5 and M4 intervals (**Figure 47**).

The deposits are located on the major Howley Anticline, which plunges 50–75° toward 310°. This anticline has numerous internal parasitic folds and is asymmetric, dipping more steeply to the west. Faulting is intense, especially in the axial plane and the east limb; fault zones are 1–10 m wide and are subparallel to the axial plane of the fold. Other deposits on the crest of the Howley anticline include *Chinese Howley*, *Mottrams*, *Big Howley*, *Howley Ridge*, *Bridge Creek* (described separately above), *Western Arm* and *Mount Paqualin* (**Figures 48**, **49**).

Gold occurs mostly as sub-microscopic inclusions in arsenopyrite and pyrite. Free gold is rare. On a broad scale, mineralisation is stratabound, being confined to the ironstone–mudstone interval. However, it is also spatially related to discordant and concordant quartz veins and to quartz-filled fractures and faults (Matthaei *et al* 1995a). Higher grades usually occur in zones immediately adjacent to veins rather than within the veins themselves. Grades

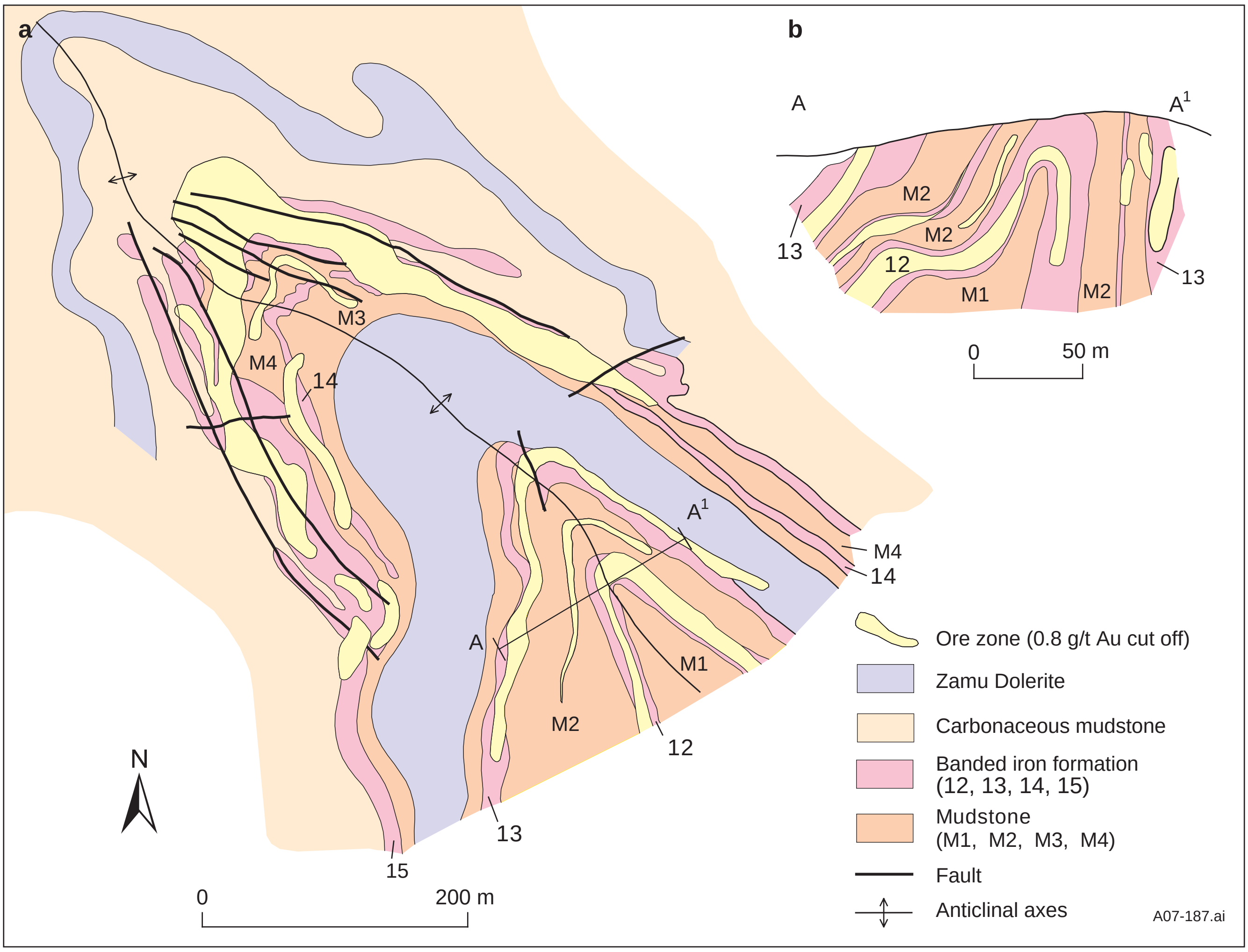

Figure 47. Geological (**a**) plan and (**b**) cross-section at Cosmo Howley mine (adapted from Dominion Mining Ltd Annual Report for 1998).

range from 3 g/t Au on the flank of the anticline, to 8 g/t Au in fold noses, and to over 20 g/t Au in oxidised portions of the veins and brittle fracture zones (Stuart-Smith 1985).

Cosmo Howley and other deposits located along the Howley anticline form the 24 km-long Howley Line of lodes. Recorded historical production from this line (excluding Cosmopolitan Howley) is about 1 t Au (Sullivan and Iten 1952). The deposits are located variously in the Koolpin Formation (Mount Paqualin), Gerowie Tuff (Chinese Howley) or Mount Bonnie Formation (Big Howley). These deposits are not associated with ironstone beds, but are structurally controlled gold-quartz veins.

Exploration by Northern Gold (2005) and GBS (Report to Canadian Stock Exchange, 3 December 2007) indicated that gold content along the Howley Anticline between Cosmo Deeps in the south and Mottrams in the North amounts to nearly 0.4 Moz of gold. Exploration by GBS was expected to increase this figure leading to the development of a single ‘big pit’ in this area.

Golden Dyke Dome area

This group of deposits occurs on the western limb of Golden Dyke Dome (Nicholson 1980). The area was first prospected in 1872 and a little coarse alluvial gold was discovered. By 1936, approximately 43 kg Au had been produced from shallow underground workings (Hossfeld 1936c, Crohn 1968).

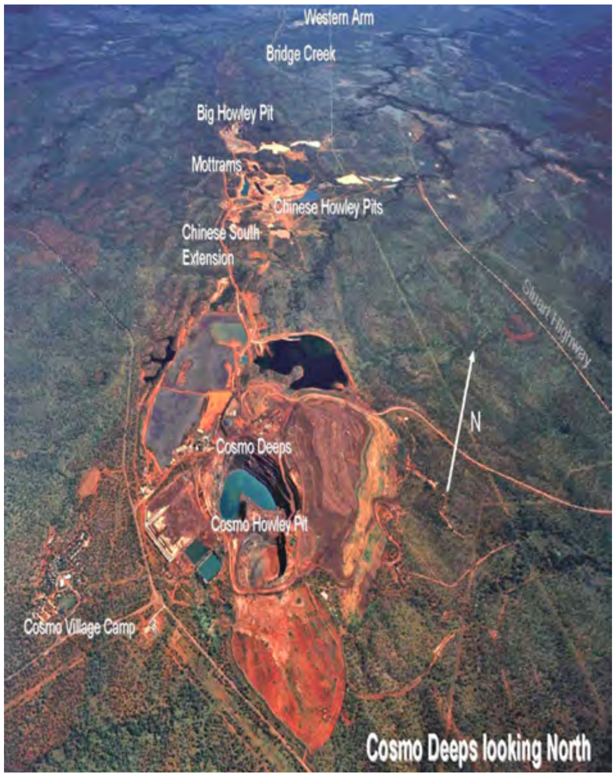

Figure 48. Gold deposits along Howley Anticline (photo courtesy of GBS Gold Australia Pty Ltd). Mount Paqualin deposit is located further north.

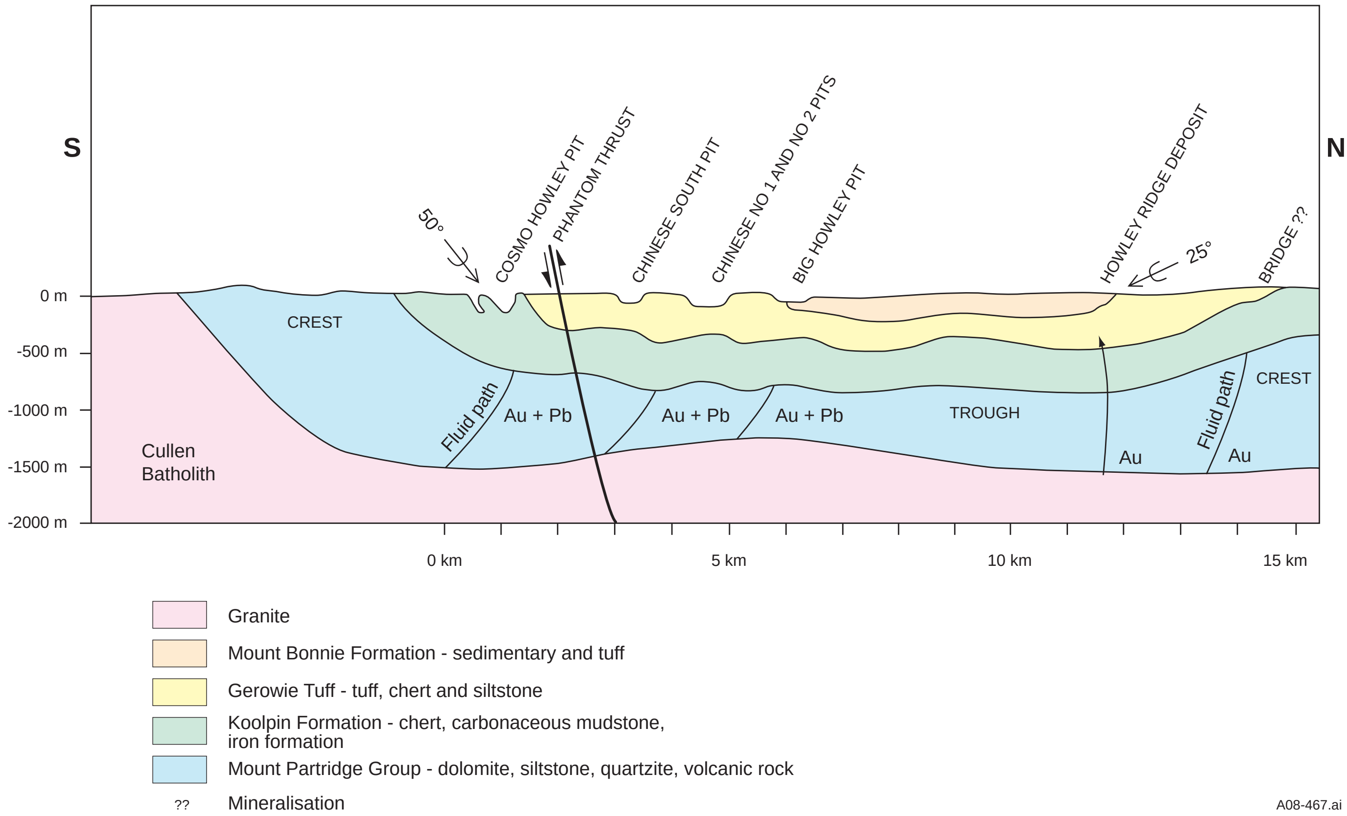

Figure 49. Gold deposits along the Howley Anticline between Cosmo Howley and Bridge Creek showing mineralising fluid paths.

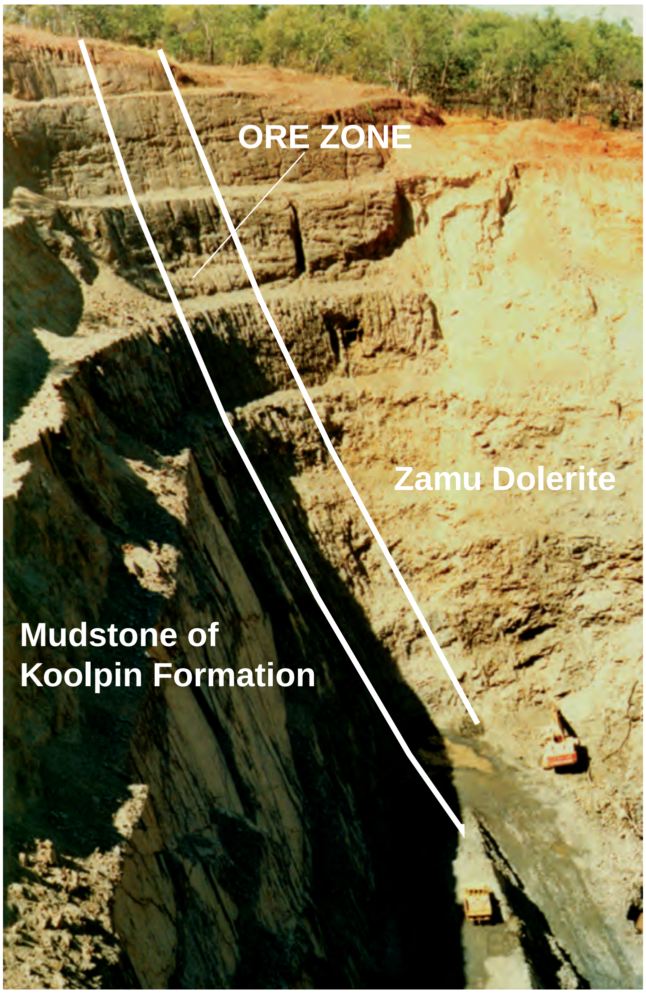

Figure 50. Open cut at Golden Dyke mine looking south.

Modern exploration in the 1980s led to open-cut operations at *Golden Dyke*, *Langley*, *Davis 2*, *Afghan Gully* and *Fisher Lode*. Other workings in the area, *Corbets* and *Good Shepherd*, were explored, but not mined.

Post-1980 production from the Golden Dyke, Davis 2, Langley, Afghan Gully and Fisher Lode open pits is 1.18 t Au. Golden Dyke was the main producer (0.1 Mt ore at 7.5 g/t Au) and the pit reached a depth of 150 m, well into the primary ore (**Figure 50**). The other pits stopped in the oxidised zone and are less than 30 m deep.

As at Cosmo Howley, mineralisation at Golden Dyke is associated with ironstone beds in the "middle member" of the Koolpin Formation, but quartz veining is rarely present. Five ironstone horizons (I1–I5) have been identified. Fisher Lode is within horizon I5; Langley, Golden Dyke and Davis 2 are in I4; and Corbets is in I2. The Afghan Gully lode is in a tourmalinite lens in quartz-carbonate stringers. The I3 horizon is also known as Buck Reef and can be traced around Golden Dyke Dome as a series of sugary-textured ferruginous quartz 'blows'. It has been explored by costeans, but gold values were generally low. Texturally these quartz blows are identical to the smaller chert pods at Cosmo Howley, and Nicholson (1978) considered that they represent a continuous bed.

The mineralogy of the ironstone units is essentially similar to that in the Cosmo Howley area (Nicholson 1978). At Golden Dyke, the mineralised lode is situated on the western limb of an anticline, where the host rocks strike 145° and dip 80° southwest. The lode is concordant and follows the ironstone horizon. The host rocks are composed of alternating 2–7 mm-thick, green ferroactinolite laminae and thinner green-brown laminae of chlorite, ferroactinolite and stilpnomelane.

Large (5 mm) euhedral crystals of arsenopyrite cut the laminae and are invariably present in the gold-rich ironstone. Associated minerals are pyrite and minor chalcopyrite, pyrrhotite, galena and sphalerite.

Moline goldfield

Thirteen gold deposits, hosted by iron-rich sedimentary rocks in the Mount Bonnie Formation, were discovered and developed within the Moline goldfield by Cyprus Gold Australia Corporation (later Moline Management Pty Ltd) between 1984 and 1991. Gold is also hosted in quartz veins in this goldfield (see Gold-quartz veins, lodes, sheeted veins, stockworks and saddle reefs, above).

Mineralisation in sedimentary rocks of the Mount Bonnie Formation is associated with laminated pyritic chert and pyritic-carbonaceous shale beds along crests of F_3 folds. The chert commonly contains sugary cherty nodules and tourmaline (Miller 1990). Gold is associated with Fe-As-Zn-Pb sulfides in zones up to 23 m wide.

The Moline Dam orebody is the largest example of this class. It was mined by open-cut methods between 1989–1991, producing 1.5 t of gold from 595 500 t of ore (D Bale, Moline Management, pers comm 1992). The following description is largely based on Miller (1990).

Bedding strikes 305° and dips 65–45° southwest, occupying the hinge zone of an overturned anticline. Mineralisation occurs in four subparallel lodes, individually up to 23 m wide, within a zone that is 1100 m long and 65 m wide. The lodes are banded and comprise pyrite±pyrrhotite, sphalerite, galena, arsenopyrite and bismuthinite within micro- and macro-shear zones produced by bedding plane slip during folding.

Gold occurs as 2–30 µm particles within, or between arsenopyrite, sphalerite and galena. This base metal association is also common in other stratabound deposits (eg *Tumbling Dice*, *Dingo* and *Simple Dreams*). Moline Dam lodes average 2700 ppm As, 10 ppm Ag, 1500 ppm Pb and 2400 ppm Zn. Wallrock alteration includes quartz, sericite, K-feldspar, albite, adularia, chlorite, tourmaline and carbonate.

The *Southern Hercules* (*School*) deposit is located 200 m southeast of the *Northern Hercules* pit in the same anticline as Moline Dam. Some 227 200 t of ore grading 3 g/t Au was mined between 1989 and 1990 (D Bale, pers comm 1992). The Mount Bonnie Formation at this site occupies the hinge area of an overturned anticline; bedding strikes northwest (305°) and dips 60° southwest.

Gold mineralisation at Southern Hercules is associated with two parallel, 330°-trending shear zones that dip 40–65° southwest. Localised thickening of the ore zones occurs where the main shear intersects cross-shears and massive quartz veins, to produce plunging, elliptical higher-grade shoots.

Polymetallic gold deposits

These deposits are contained within interbedded pyritic shale, dolomitic siltstone and tuff of the Mount Bonnie Formation and somewhat resemble the previously discussed Moline Dam deposits. However, in addition to gold, they also contain significant lead, zinc, copper and silver. Quartz veining is rare. Common sulfide minerals in primary ore are sphalerite, galena, arsenopyrite, pyrite, chalcopyrite, pyrrhotite and tetrahedrite. Zinc is the dominant element, followed by silver and gold. The *Mount Bonnie* and *Iron Blow* mines are examples of this type.

Mount Bonnie

This mine was initially worked in 1902 by Northern Territory Goldfields of Australia Ltd, who sank a 15 m shaft (Jensen *et al* 1916). During 1912–1916, the mine was developed via several vertical and inclined shafts and a 92 m-long adit, but it produced no ore. In 1917–18, three diamond holes were drilled and two intersected the mineralised lode at depth. No records of production for 1903–1916 are known.

In 1973, Horizon Exploration Ltd and Jingellic Minerals Pty Ltd undertook geological mapping and diamond drilling, which outlined a possible reserve of 0.48 Mt of ore grading 7.67% Zn, 0.4% Cu, 1.8% Pb, 186 g/t Ag and 1.5 g/t Au (Ivanac 1974). About 12 000 t of ore was mined from an open pit and transported to the Mount Wells Battery in 1979 (Rich *et al* 1984).

In 1975, Geopeko Ltd and BP Minerals Ltd carried out a detailed appraisal of base metal deposits in the Grove Hill area, including a considerable amount of drilling of the Mount Bonnie sulfide zone (Rich *et al* 1984).

During 1979–1980, a period of high gold and silver prices, it was decided to reinvestigate Mount Bonnie. Twenty diamond drillholes into oxidised ore, along with sampling of old workings, outlined a reserve of 0.1 Mt at 8 g/t Au and 230 g/t Ag (Rich *et al* 1984). The right to mine oxidised ore was acquired by Henry and Walker Group Ltd, and open pit mining commenced in 1983. A total of 110 000 t of oxidised ore grading 7 g/t Au and 230 g/t Ag was mined during 1983–1985 (Eupene and Nicholson 1990). Currently available resources are given at 0.65 Mt @ 1.7 g/t Au, 279 g/t Ag, 9% Zn, 2% Pb and 0.5% Cu (Northern Gold 2005).

The Mount Bonnie deposit lies on the eastern limb of the Margaret Syncline, at the same stratigraphic level as the Iron Blow deposit. The host rocks are interbedded shale, siltstone, greywacke, hornfels, carbonate rocks and minor pebble breccia of the lower Mount Bonnie Formation. The lode dips 40° west and is 15 m thick (**Figure 51**).

The original gossan could be traced 100 m along strike and consisted mainly of haematite and limonitic clay and minor duftite, cerussite, coinchalite, malachite, plumbojarosite and scorodite. The upper 70 m of the oxide zone was relatively enriched in gold, silver, lead, bismuth, arsenic, antimony, mercury and tin and had a distinctive, chalcocite-rich supergene zone (Rich *et al* 1984).

Iron Blow

The gossan at Iron Blow was discovered in 1873 and worked in 1886, when 100 t of ore was mined (McDonald 1901). During 1898–1906, Northern Territory Goldfields of Australia Ltd produced 15 000 t of oxide and sulfide ore from underground and surface workings (Eupene and Nicholson 1990).

In 1912, a diamond drillhole intersected low-grade ore at 23.3 m (Hossfeld 1937b). Geophysical surveys (Hossfeld 1937b, Rayner and Nye 1937) identified significant electromagnetic and self-potential anomalies over the known portion of the orebody and indicated an extension of the lode to the north.

From 1957 to 1974, the area was explored intensively by surface mapping, drilling and geophysical surveys by a number of exploration companies, as well as BMR and NTGS (Dunn 1961, Skattebol 1962, Rix 1964, Danielson 1970, Woyzbun 1976). A Geopeko Ltd–BP Minerals Ltd joint venture secured the option for the deposit in 1975 and carried out additional drilling (Goulevitch 1978). This outlined a sulfide resource of 0.98 Mt of ore grading 6.8% Zn, 0.9% Pb, 117 g/t Ag and 2.1 g/t Au (Eupene and Nicholson 1990).

In 1984, Henry and Walker Group Ltd mined the upper 40 m of the orebody, producing 10 000 t of oxide ore at 9 g/t Au and 250 g/t Ag, and 25 000 t of sulfide ore at 7 g/t Au and 360 g/t Ag. Northern Gold (1998) estimated a remaining inferred resource of 1.07 Mt grading 2.16 g/t Au.

Iron Blow occurs on the western limb of Margaret Syncline. The host rocks are interbedded siltstone, slaty shale (pyritic and carbonaceous), greywacke, hornfels, chert and minor conglomerate and carbonate rocks of the lower Mount Bonnie Formation.

The primary ore consists of a massive, medium- to coarse-grained sulfide-carbonate-silicate mineral assemblage with a distinct, weak, bedding-parallel mineral foliation. Laminations of sphalerite in carbonaceous slate were observed in drill core (DDH S/9, 139.45 m) and used as evidence for a syngenetic origin by Goulevitch (1980).

Uranium–gold deposits

Gold is associated with uranium deposits in the South Alligator Valley area and at the Jabiluka and Koongarra mines in the Alligator Rivers Region. Although considerable information is available regarding the uranium deposits, information about the associated gold is scarce.

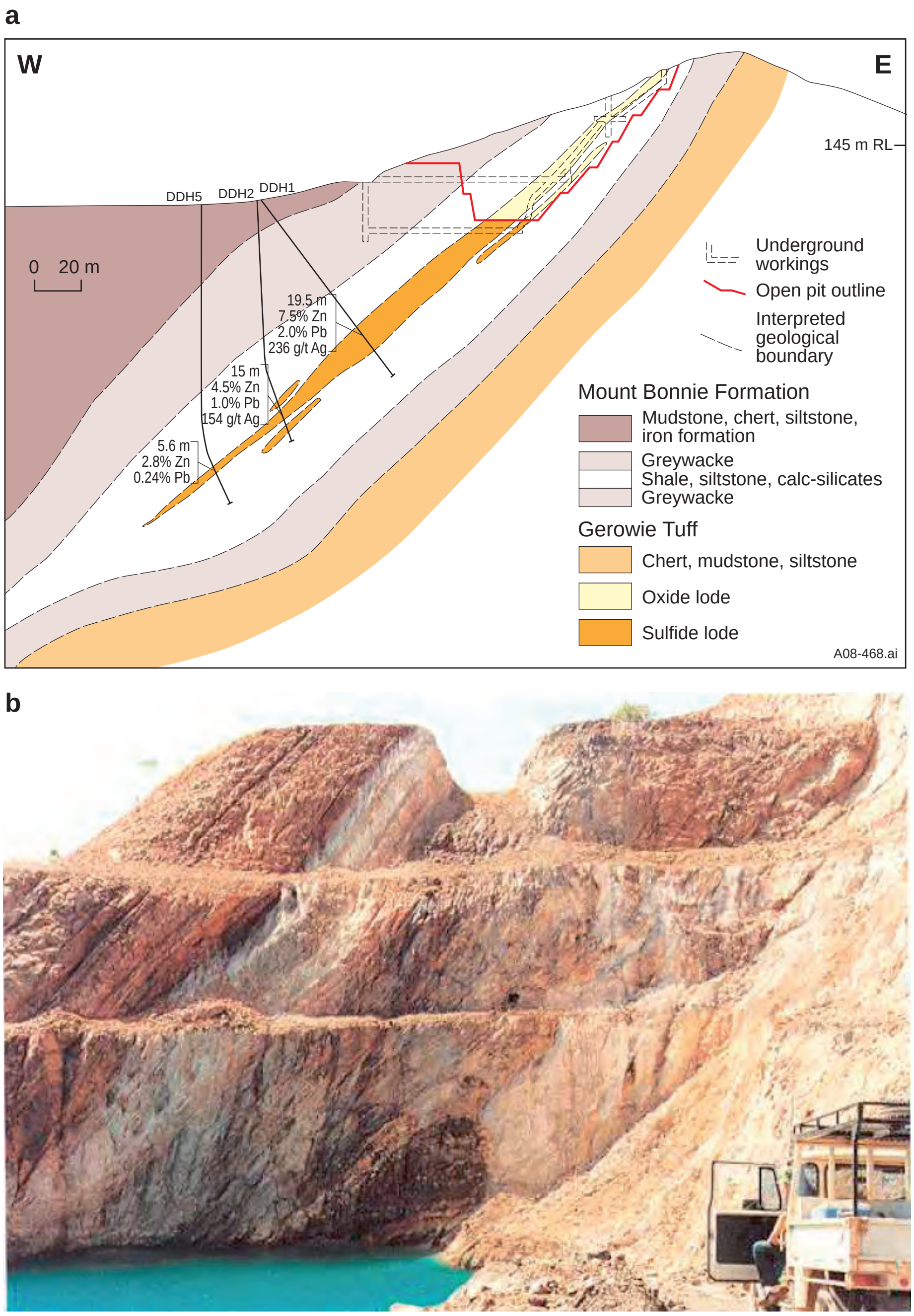

Figure 51. Mount Bonnie mine. (**a**) Generalised cross-section (modified after Eupene and Nicholson 1990). (**b**) Open cut looking north.

South Alligator Valley
Thirteen deposits were mined in this area by United Uranium NL between 1955 and 1964, producing some 875 t of U_3O_8 and 359 kg Au from 146 500 t of ore, grading 0.12–2.5% U_3O_8 (Fisher 1968). Ore was extracted from a number of small stopes to a depth of 90 m. These workings are located in a 600 m-long section of the Rockhole-Palette Fault. The mineralised lodes strike northwest (300°) and dip 70° southwest. They occur along reverse faults, of which carbonaceous shale and cherty ferruginous shale of the Koolpin Formation form the hangingwall, and quartz sandstone (Coronation Sandstone) and altered felsic volcanic rocks (Pul Pul Rhyolite) form the footwall.

Uranium mineralisation consists of stringers, pods and lenses of massive pitchblende or sooty fracture coatings in shoots that are 25 mm to 2 m thick (Taylor 1968). Other ore minerals include clausthalite (PbSe), eskebornite ($CuFeSe_2$), pyrite, marcasite, chalcocite, native gold and secondary uranium minerals (Ayres and Eadington 1975). Threadgold (1960) examined gold-bearing uranium ores from the *El Sherana*, *Palette* and *Rockhole* mines and noted that gold was present as minute (average 10 micron) inclusions within pitchblende, along shrinkage cracks filled with secondary minerals, and as minute inclusions (3–80 microns) within galena-clausthalite veinlets that cut pitchblende.

Mineralisation is contained in a major, northwest-trending, dextral strike-slip fault (Rockhole-Palette Fault), at or close to the unconformity between the El Sherana and South Alligator groups. In detail, the mineralisation is located in structures created by brittle dilational deformation (Valenta 1991).

Geochemical and fluid inclusion studies (Ayres and Eadington 1975, Wyborn *et al* 1990) indicate that uranium was originally leached from Palaeoproterozoic felsic volcanic rocks by highly oxidised groundwater. Brines descended through near-vertical faults into carbonaceous basement rocks, resulting in reduction of the oxidised fluids and the precipitation of uranium.

Jabiluka (North Ranger)
Jabiluka uranium-gold deposit, 20 km north of Jabiru, total uranium resource 15.44 Mt @ 0.48% U_3O_8 (CRA ASX Announcement 30/01/2009), and a gold resource of 1.1 Mt at 10.7 g/t Au (North Limited 1998).

This deposit is hosted by quartz-chlorite schist of the lower Cahill Formation in, or near zones of brecciation, shearing and faulting. Uraninite is the main ore mineral and minor coffinite, thucholite and brannerite are also present.

Gold mineralisation is confined to the western half of the orebody and is associated with graphitic horizons, and particularly with areas of strong uranium mineralisation. Most gold occurs within the main orebody, where values in excess of 500 g/t Au have been reported. Significant gold is also intersected within the hangingwall schist, but in this case it is not associated with significant uranium mineralisation. Gold occurs as inclusions (10–100 microns in size) or veins in uraninite, and is also associated with lead and nickel tellurides (Hills 1973).

Fluid inclusion studies are consistent with the involvement of two distinct fluids: a relatively low-salinity fluid (mean 23 wt% equivalent NaCl) with no detectable gases in the vapour phase, and a high salinity fluid (mean 35 wt% equivalent NaCl), with CH_4, and minor CO_2 and N_2. Fluid inclusion temperatures are in the range 100–280°C (Hancock *et al* 1990).

Theories on the genesis of Jabiluka include: absorption onto colluvial magnesian clays in palaeokarst cavities within the Cahill Formation (Ferguson *et al* 1980b); convection of magmatically-heated groundwater within the Kombolgie Formation and uranium precipitation occurring due to reduction in the underlying Cahill Formation (Gustafson and Curtis 1983); and mixing of two fluids of contrasting salinity and oxidation state (Hancock *et al* 1990).

Koongarra
Koongarra uranium deposit, 25 km south of Jabiru, was discovered by Noranda Australia Limited in 1970 and sold to Denison Mines Australia Limited in 1980. Total resources are 3.453 Mt of ore at 0.44% U_3O_8. Most uranium (94%) is contained in 1.831 Mt of high-grade ore averaging 0.795% U_3O_8 (Snelling 1990). The deposit is known to contain 3.11 t Au. Native gold is present in clusters of rounded grains (less than 5 microns) in uraninite. There are no further details about the nature of the gold mineralisation, but it may be similar to that at Jabiluka.

Western Arnhem Land
A number of mineral occurrences with anomalous uranium have been located in western Arnhem Land by Cameco Australia Pty Ltd. These include the *Flying Ghost, Banshee, Casper, Phantom* and *Stretch* prospects. These occurrences are spatially associated with elevated Au (up to 236.5 ppm), Pt (up to 49.6 ppm) and Pd (up to 8 ppm). Mineralisation is in the Gumarrirnbang Sandstone (Kombolgie Sub Group, P6 succession of Ahmad 2000), close to the contact with the conformably underlying Gilruth Volcanics. In the sample with the highest gold assays from the Casper Prospect (236.5 ppm), native gold is associated with goethite and lapidocrocite. In general, the uranium (±Au-PGE) mineralisation is associated with clays in zones of intense fracturing within the Gumarrirnbang Sandstone. Diamond drilling at the Flying Ghost prospect shows that mineralisation is located at the lower and upper contacts of the Gilruth Volcanics with the Gumarrirnbang Sandstone (Drever *et al* 1998).

Gold–platinum group element deposits

Coronation Hill in the South Alligator River Valley region is a well known example of this type of deposit. Other Au-PGE prospects are *Gold Ridge*, *Sargent North*, and a number of minor occurrences in the Rum Jungle area south of the Waterhouse Granite Complex and in the western Arnhem Land area. At Coronation Hill, mineralisation is in microfractures, veinlets and disseminations in quartz-feldspar porphyry, volcaniclastic siltstone, debris flow conglomerate, sedimentary breccia and diorite. At Gold Ridge it is associated with a shear zone within the Fenton Granite. At Sargent North, mineralisation is within haematite-quartz breccia.

Coronation Hill

The Au-PGE mineralisation at Coronation Hill was discovered in 1984 by BHP Minerals and lies beneath and to the east of the old uranium open cut of the same name. Since its discovery, several other minor Au-Pt-Pd ± U prospects have been identified by both the Coronation Hill Joint Venture Partners and BMR in the South Alligator Valley Mineral Field.

All of these prospects lie within or near the Rockhole-Palette Fault System. They are located close to the unconformity between the Coronation Sandstone (El Sherana Group) and pre-Nimbuwah Event basement rocks, and are surrounded by alteration haloes (sericite-chlorite-haematite), which may extend for over 1 km (Wyborn *et al* 1990).

The most well known and documented deposit in the region is Coronation Hill (**Figures 52**, **53**). This deposit contains an indicated resource of 6.69 Mt averaging 6.42 g/t Au, 0.3 g/t Pt and 1.01 g/t Pd (Minmet, December 2007). The stratigraphic setting of the deposit is not well understood. Carville *et al* (1990) and Wyborn *et al* (1990) described the host lithologies as quartz-feldspar porphyry (assigned to the Gerowie Tuff), chloritic volcaniclastic rocks (Shovel Billabong Andesite), quartz diorite (Zamu Dolerite) and sedimentary breccia (Coronation Sandstone). An alternative interpretation (Needham 1988) is that the quartz-feldspar porphyry and chloritic volcaniclastic rocks are part of the Coronation Sandstone that has been intruded by fractionated quartz-feldspar porphyry. This interpretation is supported by the similar geochemistry of samples from CHJV drill core and surface samples collected during geological mapping by the BMR (Ferenczi and Sweet 2005). Eupene (2003) prepared a 3D model of the deposit, based on the geological logs. He considered that the lowermost unit intersected in drillholes is the Koolpin Formation, which is represented by a dolostone. This is conformably overlain by chloritised volcaniclastic sedimentary rocks, possibly representing the Gerowie Tuff, which are overlain by a unit called 'Type C breccia', characterised by clasts of amygdaloidal basic volcanic rocks, quartz feldspar porphyry, quartz diorite and chloritised volcaniclastic sedimentary rocks. The 'Type C' breccia was considered by Eupene to correlate with breccia at the base of the Coronation Sandstone and is overlain by a sandstone unit (the capping sandstone) belonging to the Katherine River Group. Two types of debris flow breccias, probably postdating the capping sandstone were identified. These breccias have faulted contacts with other rock types. 'Type A' breccia is polymictic and contains clasts of porphyry, siltstone, quartz sandstone and volcaniclastic sedimentary rocks. The 'Type B' breccia is a monomictic and is dominated by clasts of porphyry with minor black shale, green siltstone and quartz. This succession has been

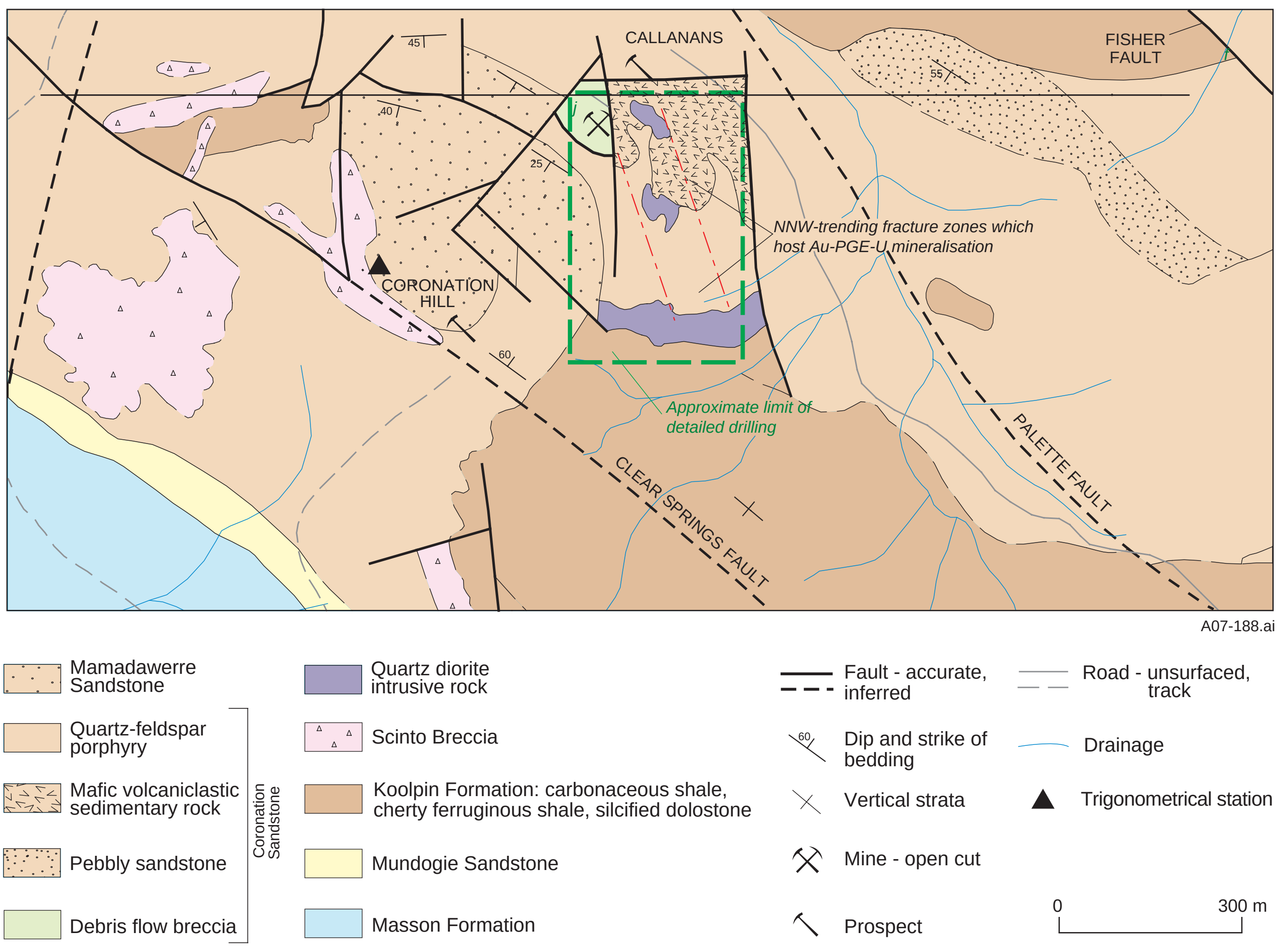

Figure 52. Geological setting of Coronation Hill deposit (modified from Wyborn *et al* 1990).

intruded by quartz feldspar porphyry and basic intrusive rocks, which are older than the 'Type C' breccia, because of the presence of porphyry clasts in the breccia (Ahmad and Hollis, in prep).

The Au-Pt-Pd mineralisation is structurally controlled by the proximity of the Coronation Sandstone–South Alligator Group unconformity and two pre-mineralisation fault systems: east–west-trending reverse faults have a vertical displacement of 300–400 m and dip 60–70° south; west-northwest-trending vertical faults and related shears postdate the east–west reverse faults and have an east-block-up sense of movement. Bedding dips steeply (50–60°) to the southwest.

The deposit, as defined to date, has a strike length of about 250 m and is 50–100 m wide. Drillholes have intersected mineralisation at depths in excess of 600 m, but only the top 250 m has been extensively drilled. Mineralisation comprises several narrow (average width 10 m) tabular bodies, which are sub parallel to north-northwest-trending faults. Mineralisation is present along microfractures, microveinlets, as quartz-carbonate-haematite veinlets and as disseminations within the alteration matrix of the host rocks.

The gold is microscopic (3.5–332 µm) and is associated with selenium ± replacive pyrite. Sulfides are very rare and include pyrite and trace amounts of marcasite, pyrrhotite, sphalerite, chalcopyrite and galena. The Au and Pt-group mineral phases show a distinct selenide association.

Mernagh *et al* (1994) identified two styles of mineralisation at Coronation Hill:

- U-Au-PGE found at, or below the Kombolgie unconformity, in a sub-vertical zone containing sporadic lenses and disseminations. This is generally restricted to conglomerates containing carbonaceous clasts, and to chloritic alteration zones in quartz feldspar porphyry. Sometimes, visible gold grains occur in association with disseminated and patchy pitchblende.
- Au-PGE, which occurs in irregular quartz-calcite-chlorite veins or breccias in the quartz feldspar porphyry, quartz diorite and volcaniclastic rocks. This style is confined to units below the Kombolgie unconformity, but otherwise shows no control by lithology.

Needham and Stuart-Smith (1987) considered the deposit to be of epigenetic sandstone type. Fluid inclusions, stable isotope studies and chemical modelling indicate that the ore constituents were transported in descending, oxidised, low-pH calcium-rich brines at a temperature of around 140°C. They were precipitated (except U) as a result of a decrease in fO_2 and an increase in pH due to reaction with feldspathic rocks. Uranium was precipitated due to the reaction of oxidised descending fluids with reduced methane-bearing fluids (Mernagh *et al* 1994, Mernagh and Wyborn 1994).

Gold Ridge

The Gold Ridge prospect is located about 23 km southwest of Hayes Creek Inn on Tipperary pastoral lease. Gold mineralisation was discovered and drilled by Mount Isa Mines Ltd between 1991 and 1992 (McGeough 1992). A small inferred resource of 32 000 t averaging 4.5 g/t Au, 0.3 g/t Pt and 0.5 g/t Pd to a vertical depth of 36 m is present. Some mining has taken place via a shallow open cut, but there are no records of production.

The prospect lies in a roof pendant of Wildman Siltstone within the Fenton Granite. On the surface, a northwest-trending quartz breccia-filled fault zone that dips 50–55° to the northeast can be discontinuously traced over 500 m. Some 30 percussion holes have been

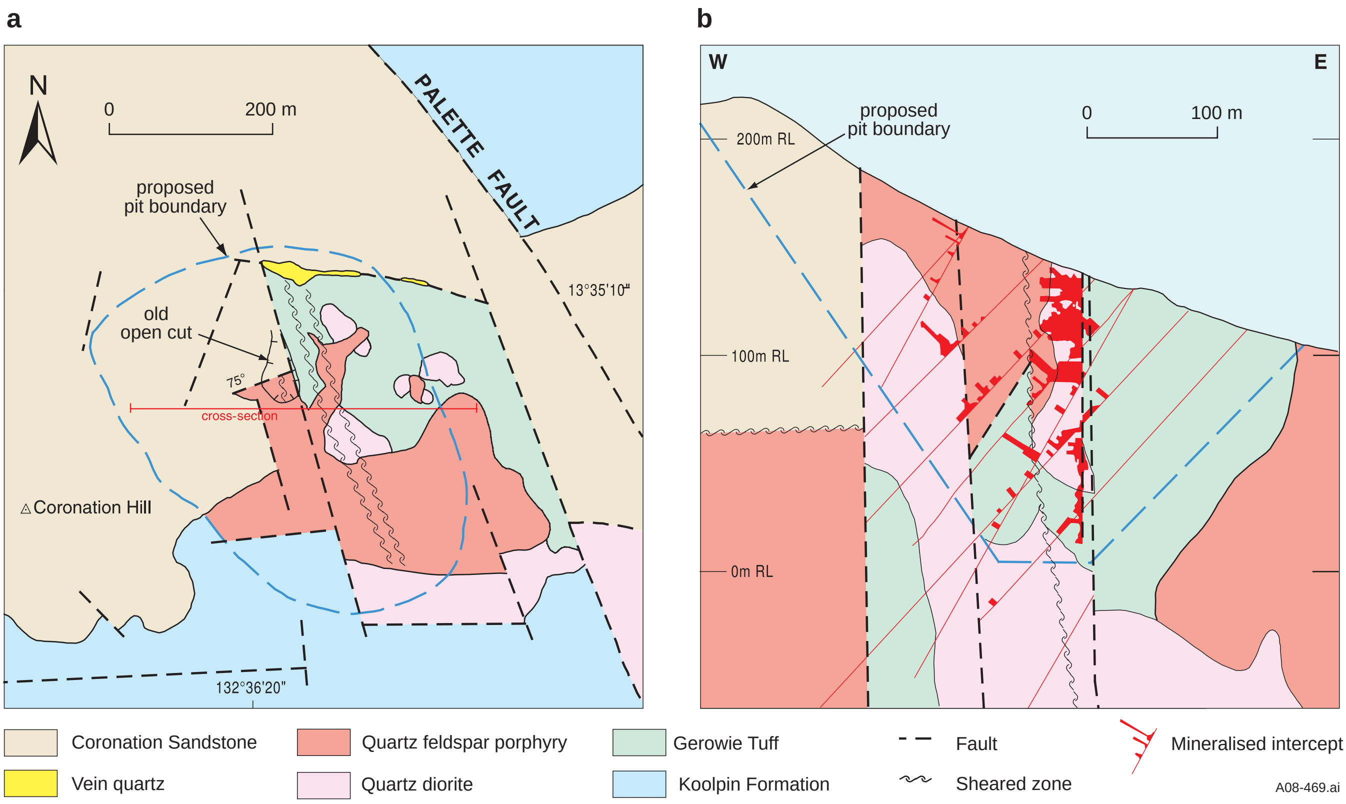

Figure 53. Geological (**a**) plan and (**b**) cross-section of Coronation Hill deposit (modified after Carville *et al* 1990).

drilled and 12 costeans excavated in this vicinity. Au-Pt-Pd mineralisation is largely confined to a fine-grained, dark brown to black, graphitic (± pyrite) mylonite unit above the vein quartz breccia zone. Significant Au-Pt-Pd mineralisation is present over a strike length of 150 m and to a vertical depth of 55 m. Diamond drilling, carried out by NTGS in 2004 to obtained core samples of the mineralised lode, was unsuccessful, due to high hole deviation and drilling difficulties (Ahmad and Hollis, in prep).

Rum Jungle area

A number of Au-Pt-Pd prospects were located in the late 1990s in the Coomalie Dolostone in the area surrounding the Waterhouse Granite Complex. Au-PGE mineralisation has been intersected in drillholes at the *Sargents North*, *Kylie* and *Hardtop* prospects. At Sargents North, a potential shallow resource of 20–30 000 t @ 3–4 g/t Au with associated PGE was suggested (Williams 1999a). This prospect is located in a 45° east-dipping succession of tremolite chlorite schist assigned to the Coomalie Dolostone. At the Hardtop prospect, the best reported intersections were 4 m @ 2.2 ppm Au, 0.6 ppm Pt and 0.3 ppm Pd (Williams 1999b). At Kylie, the original Uranerz drill core was re-assayed by Nicron Resources Ltd (Williams 1996) for Au-PGE and the best intersection in drillhole KY78/03 was 2 m @ 1.29 ppm Au, 0.58 ppm Pt and 0.78 ppm Pd. No primary Pt-Pd minerals have been described from these prospects. Mineralisation is close to the unconformity with the overlying Tolmer Group, and haematite quartz breccia of the Geolsec Formation is developed at the contact. In 2004, diamond drilling by NTGS intersected the mineralised lode in a highly weathered gossanised zone that assayed at 360 ppb Au and 36 ppb Pd (Ahmad and Hollis, in prep).

Other primary gold deposits

Sundance

This unique gold deposit (possibly related to palaeokarst processes) is located 2.5 km east of Batchelor.

Pancontinental Mining Ltd discovered free gold in 1978 in a gossanous rock at this locality while exploring for uranium (Pancontinental 1986; Simpson 1993, 1994). Analyses ranged up to 55 g/t Au. In 1979–1980, Pancontinental Mining conducted a program of costeaning, mapping, drilling, and ground magnetic and radiometric surveys, which revealed that mineralisation was spread over a large area, but did not persist at depth. In 1986, a geological resource of 200 000 t @ 4 g/t Au was estimated. This was refined to a drilling-delineated 14 000 t of proven and indicated ore averaging 8.16 g/t Au. Mining in 1986, 1993 and 1994 produced a total of 36 000 t of ore averaging 8.5 g/t. The ore was treated in 1986 at the Mount Bonnie plant and in 1993–94 at the Dominion Mining Ltd plant at Cosmo Howley. The mined ore comprised mostly clusters of boulders of dark brown, silicified haematite-quartz breccia. Larger and deeply buried boulders contain massive pyrite. Free gold can be observed in some gossanous specimens. The largest orebody has a surface diameter of 25 m and a thickness of 8 m. It narrows with depth to form a pipe composed of the same material. Assays revealed that it also contains up to 2 % tin (Simpson 1994).

Mineralisation is located at the contact between the Coomalie Dolostone and overlying Whites Formation. Rafts of sandstone, belonging to the Geolsec Formation, are present immediately to the north of the No 1 pit.

Mineralisation is in a mushroom-shaped orebody with a large aerial extent, but does not continue below a depth of about 20 m. Ore occurs mostly as small to large lumps and boulders, up to 5 m in size, of haematite quartz breccia, comprising angular to irregular quartz clasts in a matrix of partly porous, silicified iron oxide-rich breccia, including gossanous quartz vein fragments. Other ore types are sub-gossanous clayey haematite, siliceous breccia with clasts of chalcedonic and flinty silica, and light, porous, almost pumice-like gossanous rock. Minor pyrite is enclosed by vein quartz and within hard shells of silica and iron oxides.

A diamond hole drilled through the auriferous gossan averaged 45.2 g/t Au between 7.1 and 9.5 m, and then passed through a zone of massive auriferous pyrite with intervals of talc and magnesite. This pyritic zone assayed 12.1 g/t over a length of 11.5 m. Apparently, the high-grade ore has resulted from the oxidation and enrichment of auriferous, massive sulfide stock. A talc alteration halo surrounds the sulfide stock. Drill core analysis indicated up to 930 ppm Sn in the primary ore and 4850 ppm Sn in the secondary ore (Simpson 1994).

Placer deposits

Alluvial and eluvial deposits are associated with most of the hard-rock gold lodes and have been mined at a number of places, for which there are few records. Significant workings occur at the *Howley*, *Fountain Head*, *Yam Creek*, *Sandy Creek*, *Margaret Diggings*, *Union Extended*, *Pine Creek* (*Silver Coin*) and *Union Reefs* areas.

Howley alluvials

The Howley alluvials (*Chinese Howley*, *South Howley*) extend over an area of 110 km^2 in the vicinity of the Howley Anticline. Auriferous gravels are generally confined to creek beds and are covered by 1–4 m of silt. The gravels are 2 m thick in the upper reaches of the creek, thinning to 1 m downslope.

Good grades of gold are present throughout, with richer grades (0.25–0.6 g/m^3) near the base of the gravels, which are thought to be the result of mudflows during the Pleistocene (Metana Minerals 1989). In the first half of 1989, mining produced 95.64 kg Au (Mines and Energy, Northern Territory, records).

Fountain Head alluvials

The Fountain Head alluvials are located 140 km southeast of Darwin, adjacent to the *Fountain Head* gold deposit. It was one of the largest alluvial deposits in the PCO, containing 1.74 Mt of auriferous gravels at an average grade of 0.2 g/t Au. These gravels are generally covered by 1 m of soil and silt. They occur in the main drainage system and in secondary drainage depressions over an area of 8 km^2. They consist of coarse subangular clasts of vein quartz, siltstone and greywacke of the Mount Bonnie and Burrell Creek formations.

Gold mainly occurs as thin flakes up to 0.5 mm, randomly distributed in the matrix of the gravels. These gold flakes have high silver contents (up to 38%), which may indicate minimal transport from the source area (Ahmad *et al* 1993). During 1989, 85.39 kg Au was produced from this mine (Mines and Energy, Northern Territory, records).

Wandie alluvials
The Wandie field is located 50 km north of Katherine and was discovered in 1895 (Balfour 1978a, b). It was worked until 1905 and produced 300 kg Au (Walpole 1962), although this figure is uncertain, due to understatement and language difficulties with Chinese miners.

Most production was from the *Wandie King*, *Police Camp*, *Welcome Stranger* and *Boulder* (*Lake Wandie*) leases. Numerous shafts were also sunk on the narrow (0.2–1 m) northwest-trending quartz veins within phyllite and greywacke of the Burrell Creek Formation. The average grade of primary ore was 63 g/t Au (Bagas 1983).

A modern phase of mining commenced in 1987 after the establishment of reserves adjacent to the old Wandie King and *Wandie Belle* leases. Strip mining of Wandie was completed by April 1992. The operation produced 296 kg Au from the Wandie Belle, Wandie King, Boulder, *Eastern Extension* and *Gilmortona* workings (Mines and Energy, Northern Territory, records).

Most gold was extracted from a 1.6 m-thick gravel bed that was covered by 2 m of soil (Thomas 1966). Grades averaged 0.3–0.4 g/m^3, but reached 1 g/m^3 in some pockets (K Padget, pers comm 1992). The gold occurs as fine flakes and nuggets within pebble- to cobble-sized lag gravels of subangular vein quartz and weathered phyllite.

The source of the gold appears to be pyritic quartz veins from the Burrell Creek Formation. These veins are generally conformable with bedding, are associated with anticlinal structures, and contain erratic grades of up to 15.7 g/t Au (Denwer 1989a, b).

Ore genesis

Considerable information is available on the genesis of vein quartz-hosted gold deposits within the Pine Creek Orogen, including a wealth of data on fluid inclusions, stable isotopes, wall rock alteration and paragenesis (eg Sheppard 1992, Ahmad *et al* 1993, Wygralak 1996, Matthaei *et al* 1995a, b, Şener 2004). A summary reproduced from Ahmad and Hollis (in prep) is provided below.

Wall rock alteration
Wall rock alteration effects are generally minor and are confined to a fringe of altered rock along the edge of the vein. The main wall rock alteration minerals are sericite, quartz, chlorite, minor carbonate and pyrite. Study of the veining sequence indicates that at least three stages of veining are present in most deposits (**Figure 54**). Later quartz veins (stage 2), which are mostly barren, but can contain base metal sulfides, cut early gold-bearing stage 1 veins. Stage 3 quartz veins are generally devoid of any mineralisation and usually form euhedral crystals in vuggy cavities. Late carbonate veins in some deposits cut all stages of quartz veins.

In BIF-hosted deposits, chlorite is the dominant alteration mineral and much of it formed at the expense of amphibole. Early, possibly retrograde chlorite is light green, weakly pleochroic, occurs as fibrous aggregates and is often veined by a darker green chlorite composed of radiating fibres. Late chlorite is probably of hydrothermal origin. Sericite is the next most common alteration mineral and seems to have been formed later than the early chlorite (Ahmad *et al* 1993). The Mount Todd and Toms Gully deposits do not have large alteration haloes, suggesting that mineralisation in these deposits was introduced while the rocks were in thermal and chemical equilibrium with the hydrothermal fluids (Şener 2004). The only significant deposit, which does not match the alteration types discussed above is Maud Creek, which shows sericite-carbonate-fuchsite-graphite alteration within the gold orebody (Morrison and Treacy 1998).

In stratabound polymetallic deposits, the predominant alteration processes are silicification, chloritisation and sericitisation. The most evident form of alteration is silicification of the carbonate beds and this includes a quartz-carbonate-talc-tremolite-actinolite assemblage, within and adjacent to the massive sulfide ore zones. Chloritisation of the wallrocks is often both pervasive and intense, producing a massive, fine-grained chlorite rock and chlorite veins adjacent to the massive sulfide zones. Other effects include partial and selective alteration of primary minerals, such as the replacement of carbonates, biotite and pyroxenes by chlorite. Sericitic alteration is represented by the presence

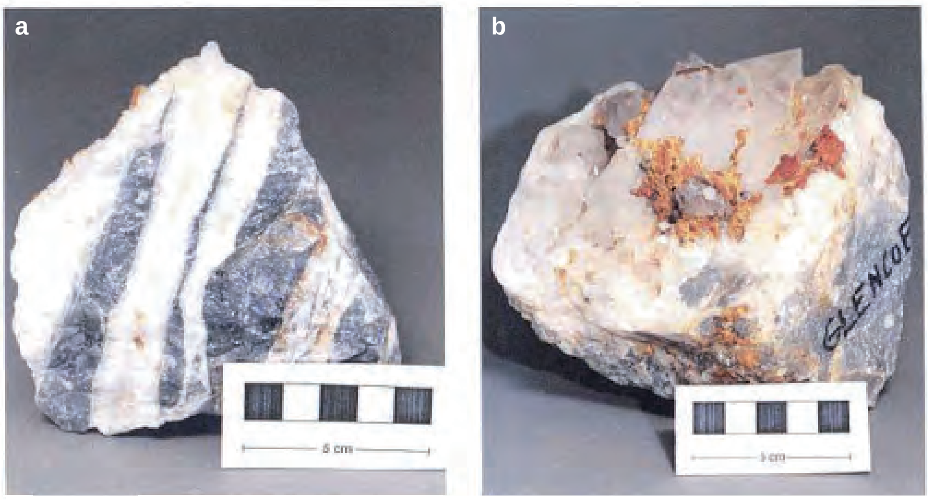

Figure 54. Stages of quartz veining in Pine Creek Orogen deposits. (**a**) Stage I blue-grey quartz cut by stage II veins (Pine Creek goldfield). (**b**) Crystals of stage III quartz (Glencoe mine).

of randomly orientated flakes of phlogopite and muscovite, which often form spots and bands in altered wall rocks. Minor amounts of microcline are also often present.

Fluid Inclusions

Ahmad *et al* (1993) and Wygralak (1996) carried out a regional study of a number gold deposits from the PCO. Sheppard (1992) studied the fluid inclusions at the Toms Gully deposit, whereas Ho (1993, 1994) and Ho and Shepherd (1993) studied the characteristics of fluid inclusion at the West Arm deposit. Four distinct fluid inclusion types (**Figure 55**) were recognised on a regional scale by Wygralak (1996).

Fluid inclusion studies on Au-quartz veins, Sn-quartz veins, Sn-sulfide veins, Sn-Ta-pegmatites, Pb-Zn-Ag veins and Au-quartz veins in stratiform Au deposits show the following four types of inclusions: H_2O + CO_2 + CH_4-bearing, low-salinity Type A inclusions; H_2O + ca 20 vol%, vapour-bearing Type B inclusions; H_2O + <15 vol%, vapour-bearing Type C inclusions with variable salinities; and H_2O + NaCl + vapour-bearing Type D inclusions. Inclusion types C and D are paragenetically late and are not related to the main ore-forming stages (Wygralak 1996). However, for the West Arm deposit, these high-salinity, low-temperature, low to nil CO_2-bearing inclusions have been considered to be contemporaneous with the gold mineralisation event and may have evolved from the type 1 and 2 fluids at 240–320°C and ca 1 kbar (Ho 1993, 1994, Şener 2004).

Filling temperatures on these inclusion types are regionally consistent and there is no significant inter- or intra-deposit variation. Type A inclusions were trapped on the H_2O-CO_2 solvus mostly within the 250–350°C mode. Pressure-corrected (600–1600 bar) temperatures on Type B inclusions also fall within this narrow range. Salinity modes on Type A inclusions are mostly within a narrow range of 3–5%. Type B inclusions have higher salinities, which vary in the range 1–27% and average about 10%. The P-T and salinity ranges of these deposits are comparable with those of the mesothermal deposits.

Types A and B inclusions occur together, but whereas the latter are devoid of CO_2 and CH_4, in the former, these species are abundant.

Both CH_4 and CO_2 are abundant in fluid inclusions from low- to medium-grade metamorphic environments (Swanenberg 1980, Roedder 1984). These metamorphic

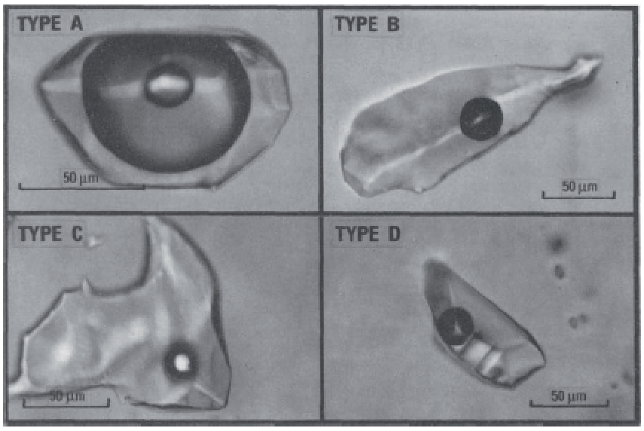

Figure 55. Types of fluid inclusions in auriferous quartz veins from Pine Creek Orogen.

fluids also contain higher concentrations of calcium and magnesium (Crawford *et al* 1979). Almost all the gold occurrences in the PCO are located within contact aureoles and a large proportion of CO_2, CH_4, $CaCl_2$ and $MgCl_2$ in the fluid inclusions could be of contact-metamorphic origin.

Type B inclusions lack both CO_2[10] and CH_4, and are also more saline. Theoretically, it is possible to derive fluids trapped in Type B inclusions from those trapped in Type A inclusions by CO_2 loss, due to a drop in pressure, or an increase in salinity, or both (Roedder 1984).

Another possibility requires separate sources for Type A and Type B fluids. In this model, low-salinity Type A fluid is generated by contact metamorphism and may be present as a single H_2O-CO_2-CH_4 phase above the solvus. The higher-salinity H_2O-CO_2-free Type B fluid of magmatic origin may have arrived later and mixed with the Type A fluid, causing CO_2 + CH_4 effervescence due to phase separation.

The studied mineral occurrences are spatially closely associated with granite intrusives and a genetic link is likely.

Sulfur isotopes

Measurements of $\delta^{34}S$ from a number of PCO gold deposits are summarised in Ahmad *et al* (1993). Pyrite and arsenopyrite from the Toms Gully mine gave a very restricted $\delta^{34}S$ range of 9.2 to 10.3‰ PDB (average 9.7‰). Stage I pyrite from other deposits (Enterprise, Kohinoor, Fountain Head, Maid of Erin, Union Reefs, Zapopan, Woolwonga and Faded Lily) gave a range of 3.9–8‰ (average 5.47‰) and there is no apparent inter-deposit variation in the $\delta^{34}S$ values. Two galena samples (Stage III) returned $\delta^{34}S$ values of 2 and 2.6‰, and four sphalerite samples gave values of 5.8, 4.7, 6.8 and 5.6‰. Sphalerite and galena (Stage III) co-exist in one sample and a $\delta^{34}S$ temperature for this sample was calculated at 244°C, which is in general agreement with the fluid inclusion temperatures on Stage II veins.

The $\delta^{34}S$ values of pyrite, arsenopyrite and marcasite were determined on samples from the Golden Dyke and Cosmo Howley mines. Two marcasite samples gave values of -0.3 and +0.5‰. Pyrite 1 (fine disseminate) and Pyrite 2 (coarse, thin stringers) gave $\delta^{34}S$ values ranging from +1.5 to +3‰ (average 2.2‰). Arsenopyrite values are distinctly heavier and ranged between +4.4 and +5.7‰. Twenty-eight samples of pyrite, pyrrhotite, chalcopyrite and sphalerite from the Mount Bonnie mine averaged 2.0 ± 1.3‰.

The $\delta^{34}S$ values of quartz vein-type gold deposits fall within the magmatic range. The Toms Gully and Northern Hercules deposits show relatively higher values, which may have resulted from incorporation of sedimentary sulfides. Stratiform gold and polymetallic deposits also have a narrow range of $\delta^{34}S$ values, which fall within the magmatic range. Previous studies on these deposits (eg Nicholson 1980, Goulevitch 1980) have suggested a synsedimentary exhalative origin. Considering that sulfate was present in the seawater and that the deposits are contained within a predominantly sedimentary succession, the $\delta^{34}S$ values support a magmatic sulfur source for these deposits.

[10] Up to 2 mole% CO_2 is soluble in NaCl solutions at temperatures and pressures as low as 25°C and 5 bar (Collins 1979) and will not be visible as a separate phase.

Hydrogen and oxygen isotopes

Ahmad *et al* (1993) and Wygralak (1996) provided data on $\delta^{18}O$ determinations on vein quartz and δD on fluid inclusion water. $\delta^{18}O$ values of water in equilibrium with vein quartz were calculated using homogenisation temperatures and experimentally determined quartz-H_2O fractionation factors.

The $\delta^{18}O$ H_2O values of the hydrothermal fluids show a narrow spread of 3–12‰ SMOW and are regionally similar. This is compatible with either magmatic or metamorphic waters, or a mixture of these components.

The δD values for magmatic waters range from -50 to -85‰ SMOW (Taylor 1979). δD values for fluid inclusions in auriferous vein quartz from the PCO range from -57 to -19‰. These values are heavier than the magmatic water and are within the metamorphic waters range. Such a range of values may be due to the formation of CH_4 by reaction of hydrothermal solutions with carbonaceous material, or due to the mixing of isotopically lighter waters with heavier waters, eg magmatic and metamorphic waters.

$\delta^{13}C$ of fluid inclusion CO_2

$\delta^{13}C$ measurements on fluid inclusion CO_2 were provided by Ahmad *et al* (1993) and range from +1 to -32‰ PDB. The distinctly negative values of most samples suggest the incorporation of organically derived carbon.

Pb isotopes

Lead isotope measurements on pyrite and arsenopyrite in the Toms Gully deposit are consistent with derivation from mixed granitic and country rock sources (Sheppard 1992). In contrast, Matthäi *et al* (1995a) showed, from $^{207}Pb/^{204}Pb$ ratios of sulfides at Cosmo Howley, that the lead was not derived from potential magmatic sources and that Th/U ratios were consistent with the derivation of lead from the country rock. This was confirmed by Partington and McNaughton (1997) who evaluated the lead isotope signature of a variety of gold deposits and granitoids in the PCO. They concluded that the dominant source of lead in the deposits is probably either Palaeoproterozoic and/or Archaean basement rocks.

Age of mineralisation

Although there is a strong spatial association of Cullen Event granites, thermal metamorphism and gold mineralisation, there are insignificant data on the actual geochronology of the gold veins. Matthäi *et al* (1995a) conducted a lead isotope study of arsenopyrite from the Cosmo Howley deposit and determined a $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ isochron age of 1820 ± 110 Ma. There is a large uncertainty, but the mean age is indistinguishable from the SHRIMP U-Pb zircon age of the nearby McMinns Bluff Granite. An apparently better-defined age of 1810 ± 10 Ma was obtained by SHRIMP U-Pb methods on a mineral separate of monazite and xenotime, associated with gold mineralisation at the Goodall deposit (Compston and Matthäi 1994). However, there are doubts as to whether or not the monazite and xenotime are related to the ore-stage minerals or gold (Şener 2004).

The $^{40}Ar/^{39}Ar$ system has been used as geochronometer for gold mineralisation events in the Tanami Region (Wygralak and Mernagh 2001, Wygralak *et al* 2005). However, it is an indirect method that relies on the analysis of alteration minerals, eg sericite, muscovite, feldspar etc. These minerals are susceptible to isotopic overprinting and resetting by subsequent hydrothermal or metamorphic events.

Şener (2004) carried out SHRIMP U-Pb geochronological studies on monazite and xenotime from the Union Reefs, Goodall and Mount Todd deposits. After the exclusion of several grains due to unacceptably high common lead, xenotime from Union Reefs yielded a mean age of 1698 ± 18 Ma. The significance of this age is uncertain, as it does not coincide with any known event in the PCO. Monazite from within auriferous quartz veins from the Mount Todd deposit also contained a large population with unacceptably high common Pb contents. Selected analyses yielded a mean age of 1854 ± 16 Ma. This is interpreted as representing an earlier generation of monazite, which was incorporated into the veins from the wallrock by mechanical processes (Şener 2004). Xenotime from the Mount Todd deposit yielded a mean age of 1819 ± 8 Ma, which is considered to be the age of gold mineralisation at that deposit. The prevailing age range coincides with the intrusion of Cullen Batholith granites. Monazite associated with gold veins from the Goodall deposit has yielded a mean age of 1727 ± 11 Ma after the exclusion of several analyses. Although Şener (2004) considered it to be a reliable age for gold vein formation at the Goodall deposit, this age is younger that the overlying El Sherana/Edith River/Katherine River groups, which have no auriferous veins. It is also about 100 My younger than the intruding granites; the significance of this age remains ambiguous.

Genesis of Pine Creek Orogen gold deposits

A variety of genetic models, ranging from exhalative syngenetic (for BIF-hosted deposits) to magmatic to hydrothermal have been proposed for the formation of the PCO gold deposits. Data on fluid inclusions, stable isotopes and lead isotopes suggest a mixed metamorphic/magmatic source. Geochronological data on gold vein systems are diverse and mostly inconclusive.

Partington and McNaughton (1997) provided observations constraining the geological timing of the PCO gold deposits. Gold veins crosscut the Zamu Dolerite and are therefore younger than the Nimbuwah Event. At Cosmo Howley, contact-metamorphic garnet, andalusite and cordierite grains are cut or fragmented in places by gold-bearing veins, providing evidence of a post-peak contact-metamorphic timing for the gold mineralisation (Matthäi *et al* 1995a). At the Enterprise deposit, cordierite porphyroblasts are commonly replaced by a sericite-biotite-quartz assemblage, which is the dominant hydrothermal alteration assemblage at this deposit (Cannard and Pease 1990). Fragmentation and the incorporation of contact metamorphic assemblages into the veins during incremental growth also provide strong evidence for a post-contact-metamorphic timing for gold mineralisation at this deposit (Matthäi *et al* 1995a).

Most geological models for gold deposits in the PCO take into consideration the spatial relationships to granitoid intrusions and suggest a mixed contact-metamorphic and magmatic source for the auriferous hydrothermal fluids, which were liberated during the emplacement of the granitoids (Stuart-Smith *et al* 1993, Ahmad *et al* 1993, Wygralak 1996, Wall 1989, Bajwah 1994, Matthäi *et al* 1995a,b, Partington and McNaughton 1997).

On the basis of monazite and xenotime geochronology, Şener (2004) argued that the gold deposits formed after the youngest phase of granitoid intrusion and peak contact-metamorphism, several tens of millions of years after granitoid magmatism. However, as discussed above, the data presented by this author is inconclusive. Partington and McNaughton (1997) considered that the presence of high-heat-producing granites is a prerequisite for the formation of PCO gold deposits. The heat from the granite intrusions and a prolonged cooling history, coupled with pre-existing duplex thrust-fold structures allowed regional-scale long-lived hydrothermal systems to channel fluids, both from granites and the surrounding rocks.

Gold deposits hosted within the iron-rich sedimentary rocks are considered by some authors (Nicholson 1978, Wilkinson 1982, Nicholson and Eupene 1984) to have been derived by sedimentary exhalative processes. Matthaei *et al* (1995a, b) suggested a model, in which magmatic fluid interacted with a CH_4+CO_2-bearing metamorphic fluid generated within the hangingwall carbonaceous slate, causing the precipitation of gold. They implied that mineralisation was caused by the mixing of magmatic and metamorphic fluids and that the reaction of these fluids with carbonaceous matter at a temperature range of 550–620°C caused ore mineral precipitation. Such temperatures are substantially higher than the 250–350°C range reported from other gold deposits in the PCO (Wygralak 1996). M Ahmad (NTGS, unpublished data) carried out fluid inclusion studies on some mineralised quartz veins in the Cosmo Howley and Golden Dyke mines and also obtained a temperature range of 250–350°C.

The polymetallic gold deposits have been considered to be of sedimentary syngenetic origin, with ore fluids derived from the devitrification of the underlying tuffaceous sedimentary rocks (Goulevitch 1980, Nicholson and Eupene 1990). However, sulfur isotope data are similar to the other gold deposits of the PCO and suggest a magmatic sulfur source (Ahmad *et al* 1993).

The above observations could be incorporated into a model (**Figure 56**) involving contact metamorphic and magmatic fluids. During stage I, granitic intrusion of the Cullen Batholith caused contact metamorphism followed by the release of oxidised, moderately saline, gold-bearing fluid; at the same time, devolatilisation reactions in surrounding rocks produced reduced, low-salinity, $CO_2 \pm CH_4$-bearing contact metamorphic fluids. The magmatic fluid was partly reduced while ascending through the graphitic sedimentary rocks of the Koolpin Formation and some gold was precipitated. In other deposits, mixing fluids caused the reduction of oxidised auriferous fluid and the final precipitation of gold in favourable structures. During stage stage II, the margins of the intrusion became solid due to loss of heat and this limited the escape of volatiles. The gradual pressure build up of the entrapped volatiles eventually exceeded the mechanical strength of the rocks and the solidified crust was ruptured, liberating late residual fluids that were carrying base metals (Ahmad *et al* 1993, Wygralak 1996).

An alternative explanation is that the gold mineralisation event occurred several tens of million years after the intrusion of granites (Partington and McNaughton (1997). In high-heat-producing granites, like those in the PCO, the decay of radioactive elements provides a permanent heat engine lasting for hundred of millions of years after the crystallisation of the magma. This long-lasting thermal anomaly may create paragenetically and chronologically complicated pulses of hydrothermal activity. This may explain the subsequent resetting, the spread of Rb-Sr, Ar-Ar data and the alteration/precipitation of monazite and xenotime, yielding anomalously younger U-Pb ages, as discussed above.

Gold prospectivity

Historically, the Pine Creek Orogen has been the most prospective region of the Northern Territory. It has a long record of discovery over the last two decades and at the turn of the nineteenth century. Favoured models of ore genesis on the various deposits, which take into consideration various geological factors (eg regional and contact metamorphism, granite type, structure and host lithology), are used to portray the prospectivity of the region in **Figure 57**.

Most gold deposits are located in rocks that are regionally metamorphosed to lower-greenschist facies. Higher-grade metamorphic rocks in the Litchfield Province and Nimbuwah Domain have relatively few recorded gold occurrences, with the exception of uranium-gold deposits

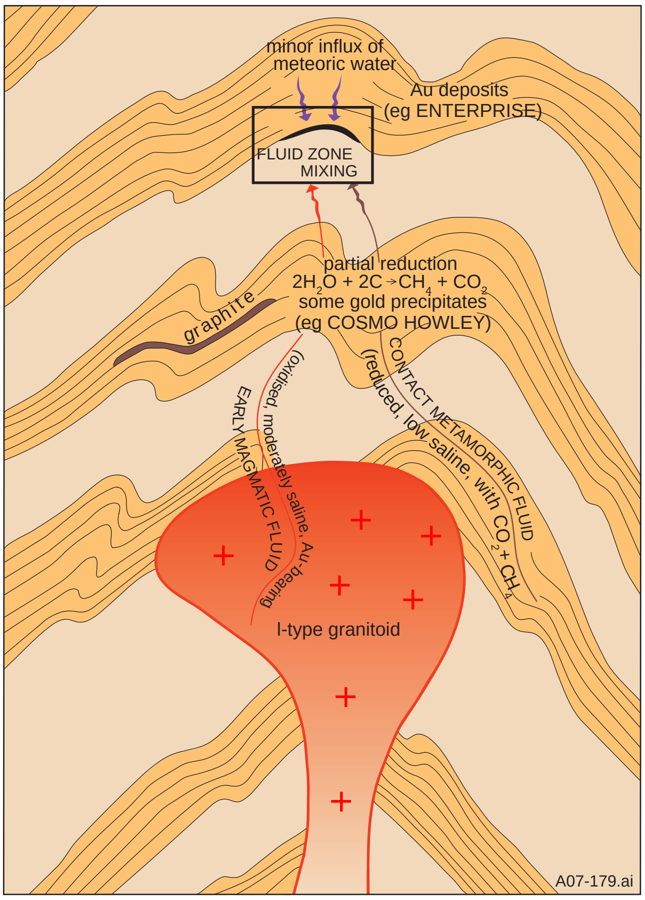

Figure 56. Model for genesis of gold deposits in Pine Creek Orogen. See text for more detailed explanation.

such as Jabiluka. Another feature is an association with I-type granites and their contact metamorphic aureoles. It is significant that all the major gold deposits lie within the five-km aureole zone of I-type granite plutons. A further feature is the presence of structural conduits for the transport of ore fluids (major lineaments, shear zones, anticlines). With two exceptions (Bonrook and Specky Creek), there are no known gold deposits hosted within the granite bodies and therefore, granites are considered to have low prospectivity.

The most prospective region of the PCO is a 100 km-wide northwest-trending belt between the South Alligator Valley and the Stuart Highway, ie, between the Pine Creek Shear Zone and the South Alligator Fault Zone. To the north and south, Phanerozoic strata cover this belt.

Palaeoproterozoic formations close to the unconformity with the basal McArthur Basin succession are considered to have potential for gold-uranium-type deposits and these are largely located in the Nimbuwah Domain in the South Alligator valley region. Only minor gold occurrences are currently known in the Litchfield Province. However, given that the Litchfield Province succession is very poorly exposed and is interpreted to contain equivalents of the same successions as the Central Domain, the Litchfield Province is considered to have unrealised potential for gold.

In summary, the Central Domain of the PCO is currently considered to have high prospectivity for gold. Only a few out of 369 known gold occurrences within the PCO are situated outside this area.

TENNANT REGION

Traces of gold were found near Tennant Creek in 1874, but no significant mining or prospecting took place until 1932, when the importance of the field was realised and two small batteries were constructed near the site of the present town. The lack of gold in quartz veins and absence of easily recoverable alluvial gold discouraged early prospectors. Later, it was realised that gold is associated with ironstone bodies and not quartz veins. Since these early gold discoveries, the district has been the focus of a considerable amount of mineral (mainly gold) exploration, particularly from the 1970s onward.

Since 1932, the Tennant Creek mineral field has produced 130.2 t Au, 345 000 t Cu, 14 000 t Bi, 220 t Se and 56 t Ag from over a hundred small- to medium-sized mines. To the south, in the Davenport Province, there are several minor gold occurrences in quartz veins and stringers that have contributed 75 kg Au.

The bulk of historical gold production was in the period 1960–1980, during which the Tennant Creek mines produced about 64 t Au. Most production was derived from 12 main deposits, with Warrego, Nobles Nob and Juno providing over 96 t Au (**Table 5**).

The geology and mineralisation of the Tennant Creek goldfield have been the subjects of many investigations by research organisations (CSIRO, BMR, NTGS and Australian universities) over the last fifty years. Much of the information provided below is summarised from these previous studies.

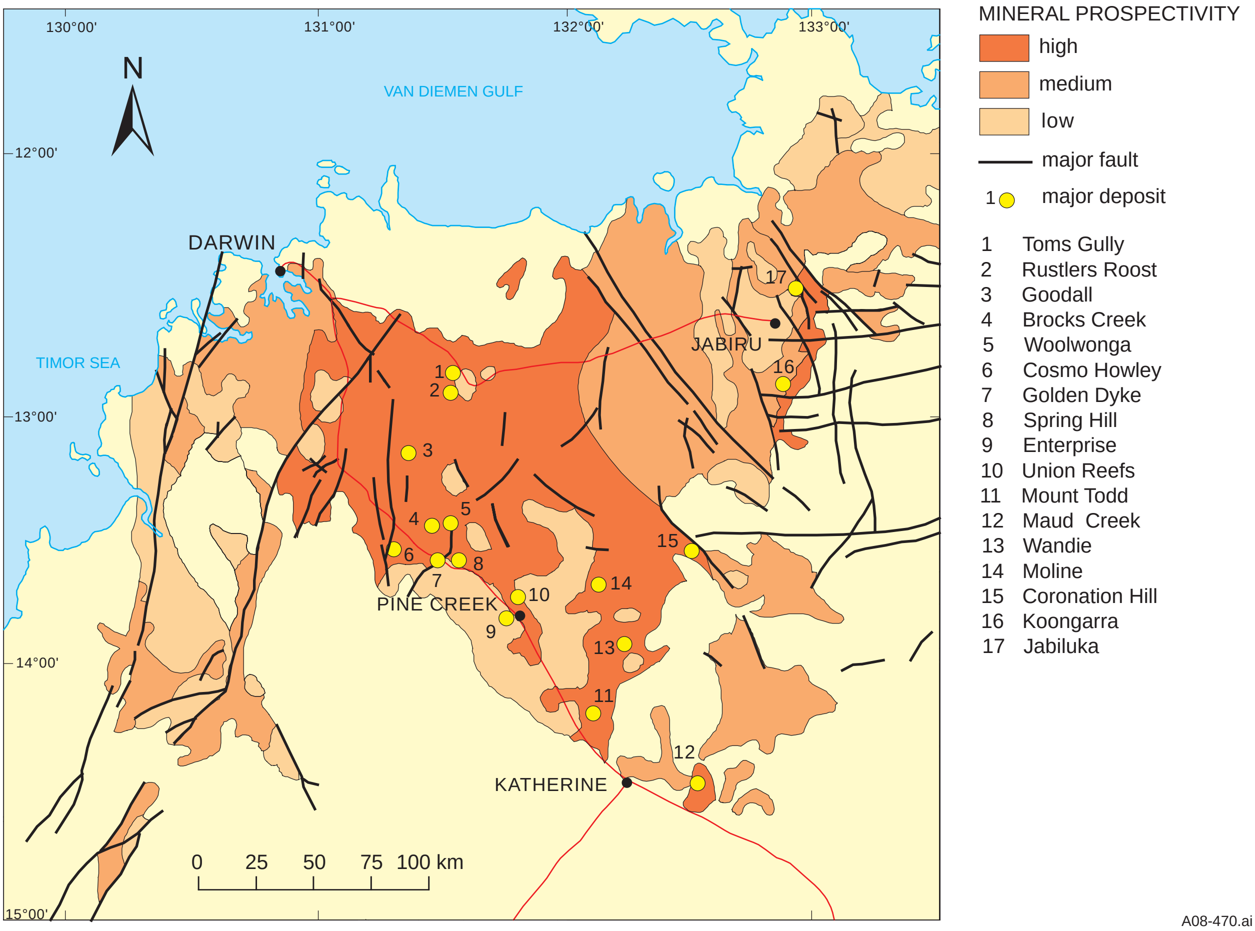

Figure 57. Gold prospectivity of Pine Creek Orogen.

In the Tennant Creek orebodies, the Cu/Au ratios vary widely; some deposits are essentially copper free (Nobles Nob, White Devil), whereas others contain ore-grade copper (Warrego, Gecko). The deposits are closely associated with ellipsoidal pipe-like ironstone bodies.

Au±Cu±Bi mineralisation occurs in both discordant ironstone pods and in hydrothermally altered metasedimentary rocks, adjacent to and below the ironstones. Mineralogical zonation of both ore and gangue minerals is characteristic. Primary gold is concentrated towards the base, or in the footwall of the ironstones and is associated with massive magnetite-chlorite±muscovite/sericite. Bismuth is partly within, and above the gold zone in magnetite-chlorite±muscovite/sericite-talc gangue. Copper is found within talc-magnetite-dolomite gangue above the gold zone, or in the massive magnetite±quartz body.

Regional geology

The Tennant Region comprises three separate provinces: the Tomkinson (previously Ashburton) Province in the north, the central Warramunga Province (previously called Tennant Creek Block by Le Messurier *et al* 1990), and the Davenport Province in the south (**Figures 8**, **58**). Cambrian sedimentary rocks of the Georgina and Wiso basins flank the region to the east and west, respectively. The Tomkinson Province mainly contains Palaeoproterozoic platform sedimentary rocks that are stratigraphically equivalent to the McArthur Basin. This province contains no significant gold occurrences and is therefore not discussed below, but note that this lack of discoveries may partly reflect a lack of exploration. The Warramunga Province contains the Au±Cu±Bi orebodies that are characteristic of the Tennant Region. A number of small W, Au, Cu, Ag-Pb and U occurrences occur in the Davenport Province (Ferenczi and Ahmad 1996) within metasedimentary and metavolcanic rocks that were deposited in the range 1840–1730 Ma.

Mine	Ore (Mt)	Ore Grades	Metal produced
Warrego	4.75	8.0 g/t Au 2.0 % Cu 0.3 % Bi	41 280 kg Au 91 500 t Cu ca 12 000 t Bi ca 5 500 kg Ag
Nobles Nob	2.14	17.0 g/t Au	34 580 kg Au ca 1 730 kg Ag
Juno	0.45	57.0 g/t Au 7.0 g/t Ag 0.4 % Cu 0.6 % Bi	26 130 kg Au 2 752 kg Ag 1 429 t Cu 2 293 t Bi
White Devil	1.30	15.2 g/t Au	19 800 kg Au
Peko	3.16	3.5 g/t Au 14.0 g/t Ag 4.0 % Cu 0.2 % Bi	7 481 kg Au 44 163 kg Ag 118 884 t Cu 7 350 t Bi
Orlando	0.32	11.0 g/t Au 3.5 g/t Ag 1.8 % Cu 0.1 % Bi	3 772 kg Au 1 223 kg Ag 4 852 t Cu 4.7 t Bi
Eldorado	0.21	20.0 g/t Au	3 800 kg Au
Argo	0.29	8.6 g/t Au	2 050 kg Au
Gecko	3.0	1.2 g/t Au 4.0 % Cu	3 450 kg Au 122 700 t Cu
Golden Forty	0.15	12.0 g/t Au	1 762 kg Au
TC8	0.08	18.0 g/t Au	1 420 kg Au
Ivanhoe	0.32	3.0 g/t Au 12.0 g/t Ag 3.0 % Cu	847 kg Au 3 872 kg Ag 8 950 t Cu
Chariot	0.13	8.9 g/t Au	1 101 kg Au

Table 5. Gold production from major deposits in Tennant Region.

Warramunga Province

The geology, stratigraphy, structure and tectonic evolution of this area have been detailed in several previous studies (eg Mendum and Tonkin 1971, 1976, Stolz and Morrison 1994, Compston 1995, Donnellan *et al* 1994, 1995). An outline of the stratigraphy and a generalised interpretative geological map are shown in **Figure 59**.

The Warramunga Province comprises a deformed, lower greenschist-facies flysch succession (Warramunga Formation) intruded by syn-orogenic granite and granodiorite, as well as by stratabound felsic porphyry. This succession is overlain by silicic volcanic and volcaniclastic rocks (Flynn Subgroup) and is intruded by late orogenic granite, porphyry and lamprophyre.

The Warramunga Formation comprises greywacke, siltstone and shale with interbedded felsic volcanic rocks and was deposited at about 1862 Ma. Crustal melting resulted in the formation of dry, I-type granodioritic melts and granitic differentiates (‘Tennant Creek Supersuite’ of Wyborn *et al* 1997), which intruded the Warramunga Formation and lower parts of the Flynn Subgroup between 1860 and 1840 Ma, during and subsequent to the 1850–1845 Ma Tennant Event. These early granitoids show no anomalous enrichment in incompatible elements (eg Th, U, Rb, Ce, Sr) or relatively fractionated phases, which suggests that they are an unlikely source for the Au-Cu-Bi-bearing fluids (Stolz and Morrison 1994).

Deformation of the Warramunga Formation produced tight upright folds with a pervasive, subvertical, east–west slaty cleavage accompanied by lower greenschist-facies metamorphism. Deposition of the volcano-sedimentary Flynn Subgroup more or less coincided with the plutonic events. The volcanic rocks are characterised by potassium-rich rhyolitic to rhyodacitic lava, felsic tuff and ignimbrites, probably derived from the underlying consanguineous plutons (Donnellan *et al* 1995).

Progressive dextral shearing resulted in large-scale, east-trending open folds, as defined by the stratabound porphyries. Disharmonic folds, angular folds (box, chevron and kink) and plunging anticlines with a weak subvertical crenulation cleavage developed within the Warramunga Formation. Northwest-trending open folds of disharmonic style (concentric to angular) were generated within the Flynn Subgroup.

The youngest igneous events in the Tennant Region were the intrusion of the Warrego and Gosse River East granites (dated respectively at 1677 ± 4 Ma and 1712 ± 5 Ma; Compston 1995), as well as lamprophyre dykes and sills (ca 1685 Ma). These events suggest significant melting in the lower to middle crust at around 1700 Ma (Compston and McDougall 1994).

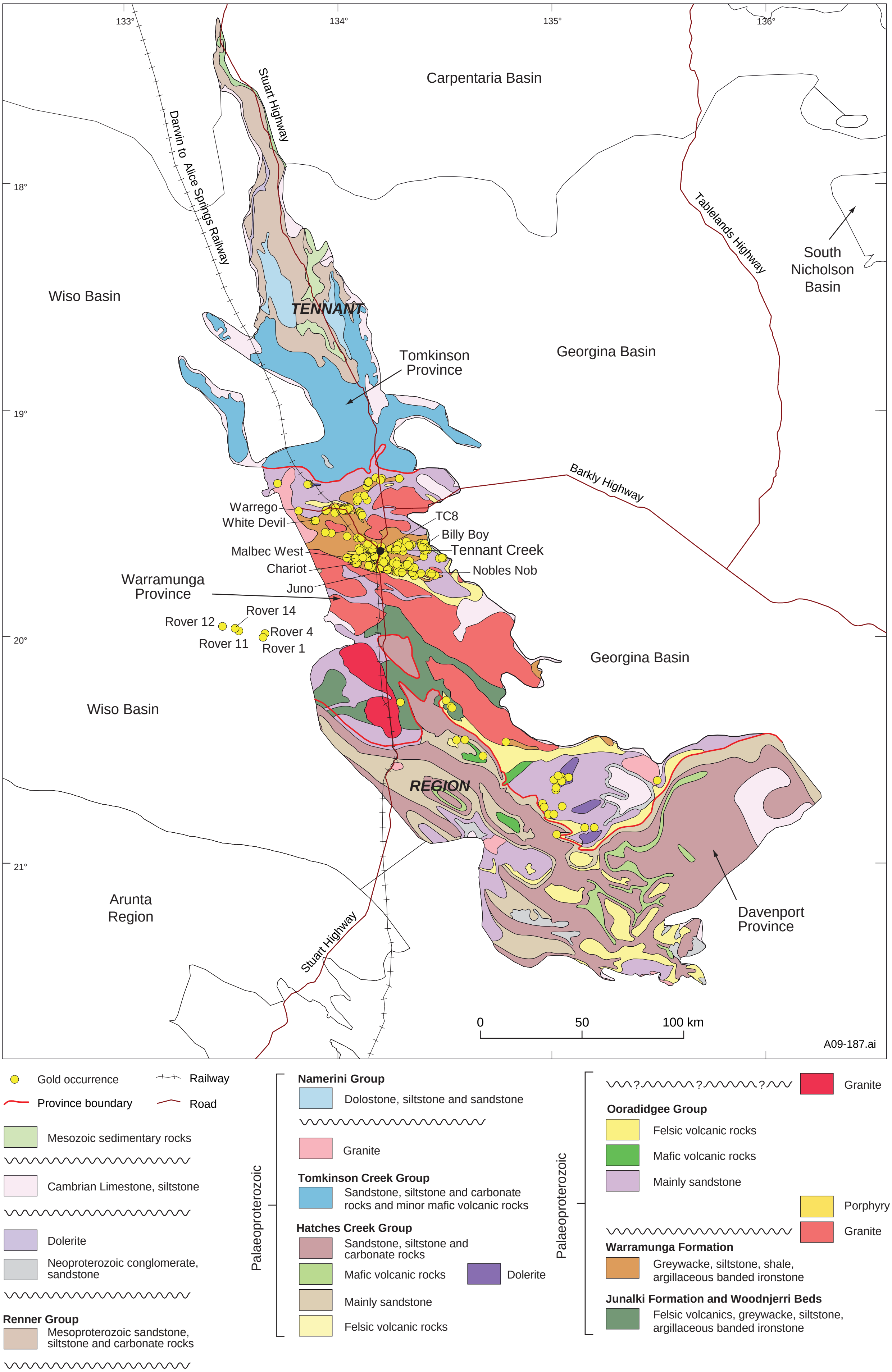

Figure 58. Regional subdivisions and geology of Tennant Inlier.

Davenport Province

The Hatches Creek Group, comprising sandstone, conglomerate, siltstone, shale and carbonate rocks, with interbedded volcanic and pyroclastic rocks, conformably overlies the Flynn Subgroup. Its three constituent subgroups (Ooradidgee, Wauchope and Hanlon subgroups) were deposited in a large, subsiding, intracratonic transtensional basin. The Ooradidgee Subgroup is characterised by fluvial to deltaic sedimentation accompanied by subaerial felsic and mafic volcanism (1830–1815 Ma) and by penecontemporaneous subvolcanic intrusive activity (Blake *et al* 1987). The felsic igneous rocks were named the Treasure Suite by Wyborn *et al* (1997) and are I-type granodiorites. It is a fractionated suite similar to the Cullen Supersuite in the Pine Creek Orogen and may be responsible for gold mineralisation in the Tennant Region.

Deformation of the Hatches Creek Group involved two events, and was accompanied by lower-greenschist facies metamorphism. The first episode produced large upright concentric, northwest-trending folds, accompanied by reverse faulting. The second episode produced upright, concentric north- to northeast-trending folds, northeast-striking thrust faults and northwest-trending strike-slip faults (Blake *et al* 1987). Interference of the two fold sets is evident, locally producing domes and saddles (Stewart 1987). Post-tectonic granites, often containing anomalously high tin and tungsten values, were emplaced as steep-sided plutons into the Hatches Creek Group at about 1710 Ma (Page 1995) along with minor dykes of lamprophyre. This igneous association has been termed the Devils Suite by Wyborn *et al* (1997) and is a highly fractionated I-type granodiorite suite that includes the Elkedra, Devils Marbles and Warrego granites.

Gold deposits–Warramunga Province

The ironstone bodies are irregular, flattened, ellipsoidal and pipe shaped, and range in mass from a few tonnes to over 15 Mt (Le Messurier *et al* 1990). Over 700 ironstone bodies have been recorded throughout the field, but fewer

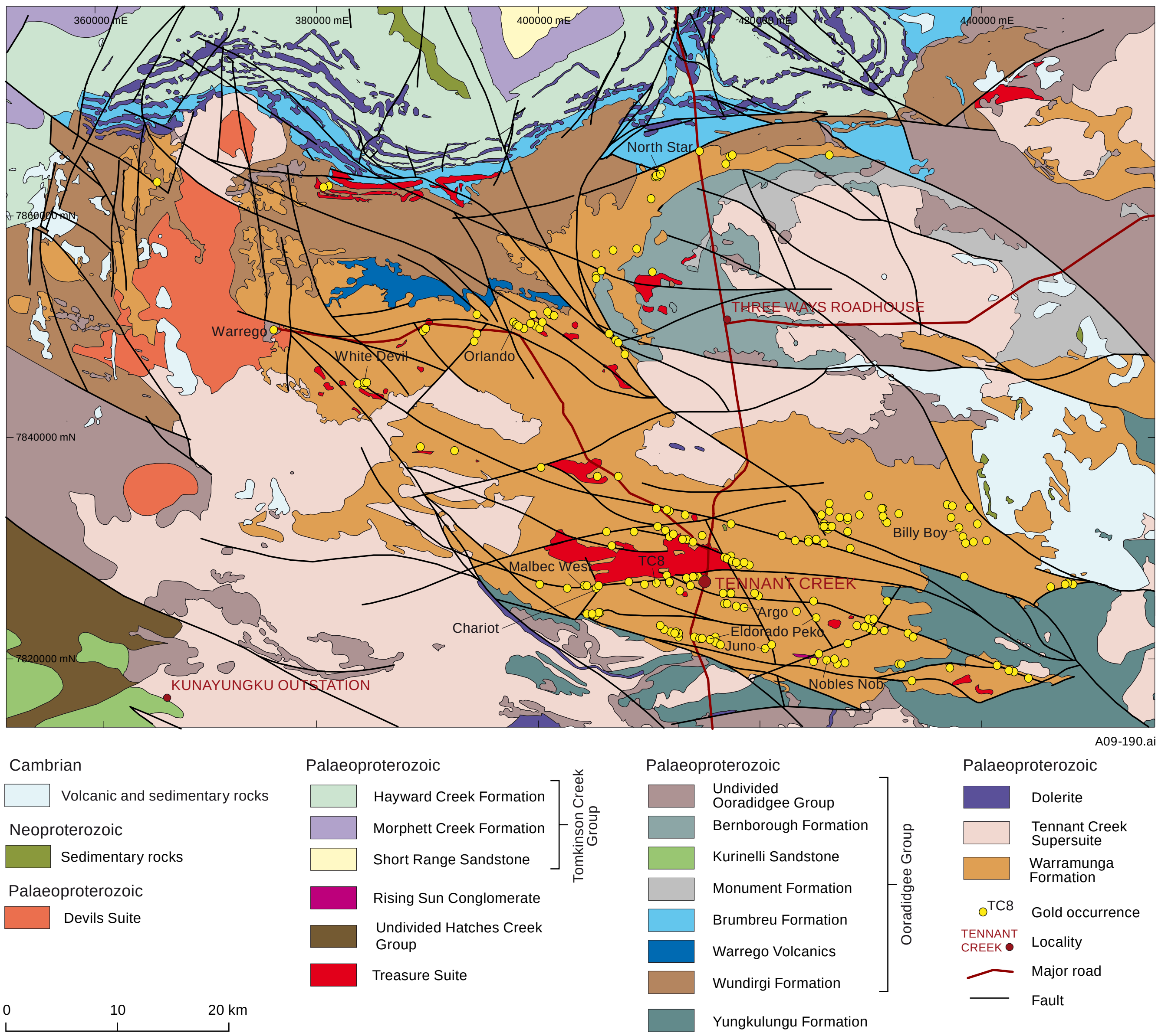

Figure 59. Regional interpreted geology and gold deposits of Warramunga Province, Tennant Region, based on Donnellan *et al* (1999).

than 200 are known to contain significant mineralisation, and only 25 have produced more than 100 kg Au.

Figure 60 illustrates the surface expression of an ironstone body and ironstone in the open pit at the Eldorado mine. Most ironstone bodies are discordant to bedding, with only a few being near-concordant. In the oxidised zone, which commonly extends to 100 m below the surface, the ironstone consists mostly of haematite, with minor remnant magnetite, goethite, quartz, sericite and clay minerals. Hypogene ironstone consists of magnetite, quartz, and chlorite, with minor amounts of pyrite, talc, dolomite, muscovite and calcite (Wedekind *et al* 1989).

Several significant 'lines of lodes' can be traced discontinuously along east-trending orientations subparallel to the Mary-Lane Shear Zone, particularly in the southern part of the field.

A close relationship between mineralised ironstone and 'haematite shale' beds is present along the line of lodes from Mount Samuel to Rising Sun in the southern part of the field. In the subsurface, the ironstones at Nobles Nob, Juno and TC8 are located on, and partially replace the haematite shale beds. However, there are numerous deposits that are not associated with haematite shale or porphyry intrusions, which suggests that neither is critical for ironstone formation. In general, most ironstones are hosted within argillaceous mudstone and shale, which are typically more strongly cleaved and fractured than the coarser sandstone units, a factor that appears to make them more susceptible to replacement by chlorite and magnetite. Other local lithological controls may include preferential ironstone replacement along contacts between sedimentary rocks and quartz porphyry intrusions (eg Warrego and

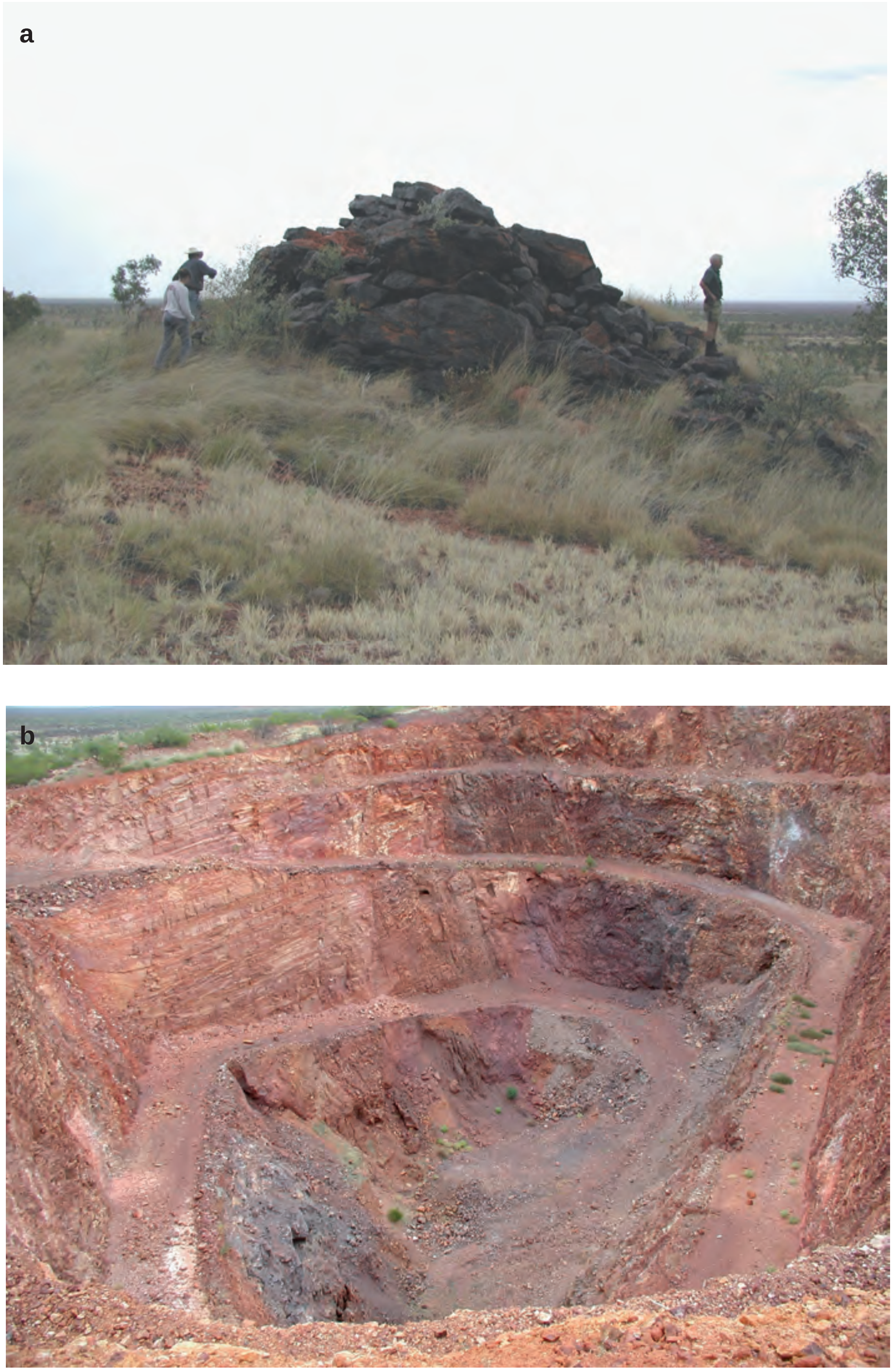

Figure 60. Eldorado mine, Tennant Region. (**a**) Surface expression of ironstone body and (**b**) ironstone (darker tone) within open pit.

Jubilee), or within intraformational, sedimentary slump breccias (eg Gecko and Peko).

There are three significant trends of ironstone-bearing shear zones, first recognised by Crohn and Oldershaw (1965). The east–west (090–100°) trend is dominant, and coincides with bedding and a penetrative S_1 cleavage. The southeast (130°) and east northeast (070°) trends are possibly second-order shears related to the D_1 event, and are responsible for the irregular en echelon pattern of ironstones developed due to shear–bedding or shear–S_1 intersection.

Most major shear zones are barren; however, many deposits (eg White Devil, Black Angel, Argo, Lone Star) are located in smaller, east-trending, brittle-ductile shear zones and faults. Numerous gold-bearing ironstones are also located at positions of pitch reversal within faulted anticlines and drag folds. These tight, parasitic F_1 anticlinal folds are often doubly plunging (ca 20–40°), due to the shearing component that accompanied D_1. Several other subsurface deposits are hosted within anticlinal structures (eg Juno, White Devil, Gecko, Peko and Argo), which highlights these structures as favoured loci for ironstone replacement.

Of the 17 mined gold deposits, only six have significant copper and bismuth contents. These latter deposits also produced silver, and minor selenium was obtained from Warrego, Juno and Gecko. Au-Cu-Bi mineralisation is found within the ironstone pods and altered metasedimentary rocks, above, adjacent to and below the ironstones. Studies (eg Large 1975, Skirrow 1993, 2000) on the deposits have shown that ore zonation patterns may be well developed in the pod-like ironstones (**Figure 61**) and almost absent in the pipe-like ironstones.

Primary gold is concentrated towards the base, or in the footwall of the ironstone in a magnetite-chlorite±muscovite/sericite gangue. In many smaller oxidised deposits, gold ore was located along the brecciated ironstone–sediment contact. Gold is typically fine grained and ranges from a few microns to 1 mm. Bismuth mineralisation in the primary zone consists of bismuthinite and minor sulfides (wittchenite, emplectite, aikinite), and occasionally, seleniferous bismuth

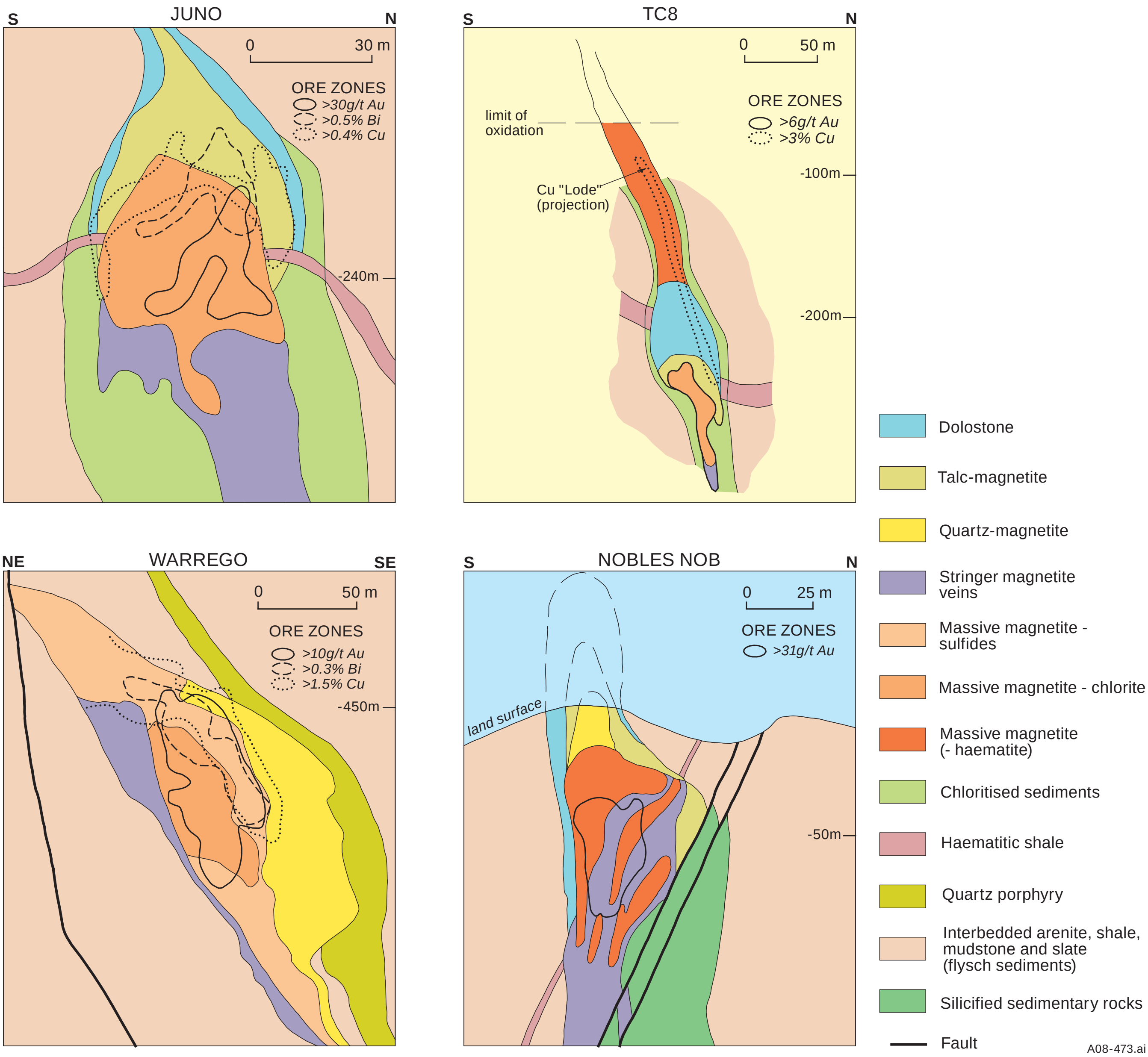

Figure 61. Zoning pattern in ironstone bodies at Juno, TC8, Warrego and Nobles Nob mines, Tennant Region.

sulfosalts (junoite, wittite, guanajuatite), often partially within or above the gold zone in a magnetite-chlorite-muscovite/sericite±talc gangue. Bismutite ($[BiO]_2CO_3$) and bismite (Bi_2O_3) are commonly encountered in the oxidised zone of bismuth-bearing deposits.

Copper mineralisation in the primary zone consists of chalcopyrite, which commonly replaces and infills fractures in massive magnetite and early-formed pyrite. In other cases, chalcopyrite is intergrown with magnetite and quartz, suggesting co-precipitation of these three minerals (Large 1974). Veinlets of chalcopyrite may also be present within the alteration pipe below the ironstone pod. Bornite occurs as a minor phase, although a bornite-rich copper lode within a talc-dolomite zone has been delineated at TC8 (Giants Reef Mining 1993). Other sulfides, which may be present in minor to trace amounts, include galena, sphalerite, cobaltite, molybdenite, tetrahedrite and enargite.

Many of the subsurface Au-Cu-Bi deposits are characterised by intensive chloritisation and varying degrees of dolomite-talc alteration and sericitisation. Minor tourmalinisation has been described at Peko (Whittle 1966), and iron-silicate (stilpnomelane-minnesotaite-greenalite) alteration at West Peko (Skirrow 1993). Large (1991) showed that the alteration zones may exhibit a distinct vertical and lateral distribution away from the massive magnetite-chlorite core, in the form of an outer envelope of quartz-magnetite+haematite (eg Warrego, White Devil, Gecko) or talc and/or carbonate (eg Juno, TC8, Argo).

Gold deposits in ironstone bodies

In the following section, major ironstone-hosted gold deposits are described. Details of smaller deposits are given in **Appendix 1**.

Nobles Nob

Nobles Nob is located 13 km southeast of Tennant Creek and was discovered in 1933. Production commenced in 1939, when payable gold was struck at a depth of 16.5 m. During 1939–1943, about 3582 t of ore was mined to produce 80.5 kg Au. Australian Development Ltd (ADL) acquired the leases in 1948 and mined the deposit, using underground (1949–1967) and open-cut (1968–1985) methods, to produce 34.5 t Au from 2.14 Mt of ore.

The host succession consists of tightly folded greywacke, siltstone and shale of the Warramunga Formation. The main ironstone body (No 1 lens) is predominantly hosted within drag-folded and brecciated shale, including a destructively silicified haematitic shale unit. Bedding trends easterly and dips steeply (60–80°) south, occupying the southern limb of a major F_2 anticline. A well developed cleavage (S_1) trends east–west and dips steeply (70–80°) north. The North Wall fault zone has truncated the main ironstone lens, which is also offset to the east by numerous north-trending vertical faults (Reveleigh 1977). The quartz-haematite lode strikes east–west and plunges 20° east. It is lenticular in both plan and cross-section (**Figure 61**), with maximum dimensions of 190 m strike length, 40 m width and 80 m depth. The lode appears to be localised at the intersection of bedding and cleavage (Yates and Robinson 1990). Gold mineralisation is concentrated in the central zone of the pod (30–82 m depth) within brecciated quartz-haematite (with magnetite increasing below 55 m) and stringer veins in altered sericite-chlorite-haematite shale. Supergene enrichment produced grades in excess of 1550 g/t Au between the 30 and 60 m levels. The supergene gold is quite pure (fineness of 960) and is generally very fine grained (<0.2 mm), except in some rich sections where it formed elongate masses several centimetres in length. Bismutite and bismite are closely associated with gold in the upper parts, which contained up to 10% Bi in places. Bismuthinite, with minor pyrite, chalcopyrite and enargite, are present below the zone of oxidation.

Warrego

The Warrego mine is situated about 45 km northwest of Tennant Creek and has been the most productive mine in the Tennant Creek goldfield to date, producing some 38 t Au, 91 500 t Cu, ca 12 000 t Bi and ca 5.5 t Ag from 4.95 Mt of ore. This subsurface deposit was first identified as a 2200 nT magnetic anomaly during an airborne magnetic survey flown by BMR in 1956. The first lode intersection was made in 1962 and full-scale production commenced in 1973 (Wedekind and Love 1990). Underground operations ceased in late 1989 and retreatment of the tailings (4.98 Mt at 1 g/t Au) was undertaken between 1994 and 1998, producing a further 3280 kg Au.

The hangingwall succession consists of a 30–50 m-thick quartz porphyry sill that has intruded chloritic slates (**Figure 61**). The footwall succession east of the ‘Footwall Fault’ consists of interbedded chlorite-muscovite schist, metaquartzite and spotted chloritic slate. Contact-metamorphosed and potassic-altered greywacke and shale are present west of the ‘Footwall Fault’. The ca 1677 Ma Warrego Granite outcrops some 800 m west of the deposit (Wedekind and Love 1990). Most of the sedimentary rocks and the local cleavage trend northwest, and appear to have been rotated some 90° by intrusion of the Warrego Granite (Wedekind 1990).

The Warrego deposit consists of two major and several smaller lenses of ironstone (magnetite-chlorite-quartz), which strike northwest, dip 70° northeast and plunge 47° southeast. These lenses strike parallel to bedding, but have steeper dips, more or less coinciding with the cleavage. The main pipe (No 1 orebody) extends from 140–790 m below the surface and is up to 75 m wide. Gold mineralisation is concentrated in high-grade (average 20 g/t Au) en echelon pods, composed of magnetite, chlorite and muscovite in the footwall of the ironstone lens. There is a distinct vertical and lateral zonation of ore and gangue minerals away from the gold-rich pod into bismuth-rich and then copper-rich zones (**Figure 61**). Gold grains (commonly 0.5–1 mm) and bismuth minerals (bismuthinite-guanajuatite) are intergrown with randomly oriented laths of chlorite and muscovite, and chalcopyrite typically infills fractures within massive magnetite. Gold is also present in the copper ore zones as minute (1–3 µm) inclusions within fractured chalcopyrite and pyrite grains.

White Devil

The White Devil deposit is located 35 km northwest of Tennant Creek. The deposit was first worked, along with the neighbouring Black Angel, throughout 1937–1941, to produce 4.2 kg Au from 379 t of ore. In 1986, Australian Development Ltd (later Poseidon Gold Ltd) acquired the leases from Peko-Wallsend Ltd and commenced open pit and later underground mining to produce 19.84 t from 1.3 Mt of ore. The remaining total reserves and resources (as of June 1998) stand at 180 000 t @ 9.3 g/t Au and 200 000 t @ 10.5 g/t Au, respectively. The following brief description is largely summarised from Edwards *et al* (1990), Nguyen *et al* (1989) and Huston and Cozens (1994).

The host succession of tightly folded greywacke and shale is intruded by post-D_1 quartz-feldspar porphyry dykes, which also crosscut the ironstone lode and which have undergone chloritic and sericitic alteration related to the introduction of Au±Cu±Bi-bearing fluids. During D_1 deformation, the host succession was metamorphosed to lower greenschist facies and folded into an upright, 50° west-plunging anticline with a pervasive cleavage. The lodes were emplaced along a chloritic shear zone that developed along the axis of the anticline during early D_2 deformation.

Two styles of Au±Cu±Bi orebodies are present: (1) thin, shear-related mineralisation (Main Zone and Pinter B orebodies) with ore grades of 17 g/t Au, 0.5–0.8% Cu and 0.15% Bi; and (2) pod-like ironstone-hosted mineralisation (Deeps Zone and Pinter C orebodies), with ore grades of 22 g/t Au, 0.1% Cu and 0.25% Bi.

The 'Main Zone' is characterised by 0.5–7 m-wide ore zones, consisting of gold, chalcopyrite, pyrite, bismuthinite and marcasite. The ore is hosted by highly chloritic sedimentary rocks with magnetite stringers in the hangingwall and adjacent brecciated ironstones. The 'Deeps Zone' consists of gold, bismuthinite and bismuth sulfosalts, with minor chalcopyrite and pyrite, within chlorite-magnetite-altered sedimentary breccia, fractured chlorite-magnetite ironstone and stringer zones beneath and adjacent to the elliptical ironstones, which may reach 50 m in width. Within deeper parts of the orebody a mineralogical and chemical zonation is evident, which progresses from a gold-rich footwall, through a bismuth-rich section, to a copper-rich hangingwall.

Pervasive chloritisation with minor amounts of talc alteration extends 15–20 m into the adjacent sedimentary rocks. Dolomite alteration has been intersected in the lower portions of the Pinter and Deeps Zone orebodies. Gold in both ore types is generally fine grained. The fineness for White Devil bullion for 1991–1992 was 933.

TC8

The TC8 deposit is 4.5 km west of Tennant Creek. The target was identified in 1970 by Western Nuclear during a low-level aeromagnetic survey and was drilled in 1972 by a joint venture comprising Western Nuclear, Aquitaine Australia Minerals and Geopeko. The deposit was mined in 1986–1988 by Norseman Gold Mines using underground methods to produce 1420 kg Au from 80 000 t of ore. A separate copper lode (**Figure 61**) containing an inferred resource of 104 000 t @ 5% Cu, 0.3 g/t Au and 34 g/t Ag exists above and northward of the exhausted gold pod. Mine tailings have a reported grade of 0.7 g/t Au, 0.3% Bi and 0.5% Cu (Giants Reef Mining 1993).

The host succession consists of folded chloritic slate, siltstone and greywacke, and a 5–10 m-thick haematitic shale bed. Cleavage (S_1), strikes east–west and dips 70° north. The ironstone body is about 160 m long, 10–25 m wide and extends to a depth of 375 m (Hills 1990). The body occupies a cleavage-parallel shear zone that intersects the haematitic shale unit some 200 m below the surface (**Figure 61**). The gold mineralisation is located within the sericite-chlorite-magnetite stringer zone, within and below a discrete chlorite-magnetite pod approximately 50 x 6–12 x 50 m in size. Gold grains up to 0.25 mm occur, intergrown with bismuthinite and chalcopyrite (**Figure 62**). Copper mineralisation consists of bornite and chalcopyrite, with minor wittchenite and covellite, and traces of gold within a dolomite-magnetite-quartz-talc gangue that forms the hangingwall envelope of the gold pod.

Juno

The Juno deposit is located about 8 km southeast of Tennant Creek and has produced some 26.13 t Au, 1440 t Cu, 2295 t

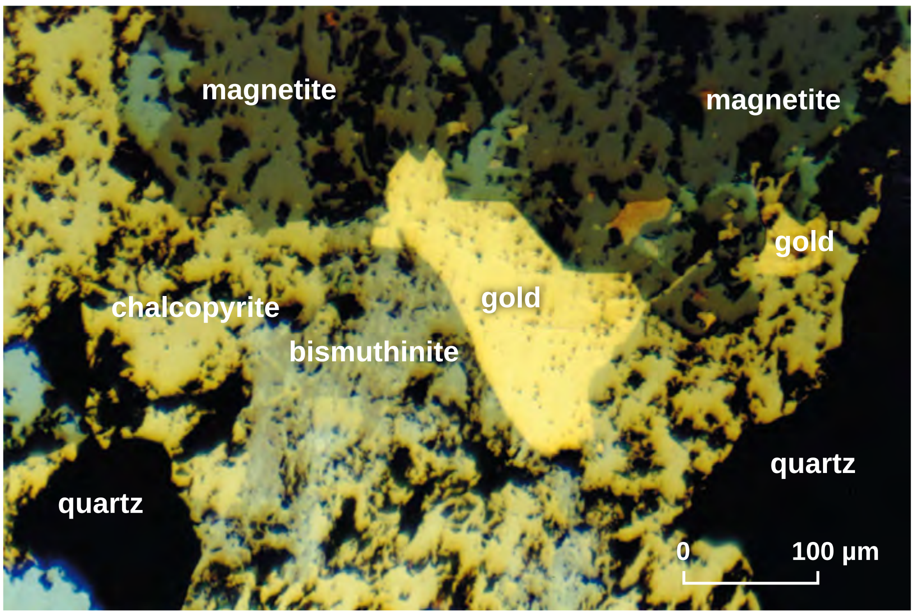

Figure 62. Coarse gold in magnetite from TC8 deposit intergrown with chalcopyrite and bismuthinite.

Bi and 2.752 t Ag from 455 000 t of ore. This subsurface deposit was first identified as a discrete magnetic anomaly from an airborne magnetic survey flown by BMR in 1937 (Daly 1957). The first lode intersection, however, was not made until 1965, and full-scale production commenced shortly after, in 1967 (Large 1975). Mining operations ceased in 1977.

Two east–west-trending orebodies were mined at Juno. The eastern No 1 orebody has a strike length of 150 m, is up to 15 m wide and dips 85° north. Most of the ore was extracted from the relatively compact western No 2 orebody, which is 75 m long and up to 30 m wide. The orebodies occupy the hinge area of an east–west anticline and developed where shears intersected a haematitic shale bed (5–7 m thick), some 230 m below the surface. Bedding dips nearly vertically, and a distinct axial plane cleavage (S_1) dips 80° north, parallel to the elongation of the orebodies.

The Juno No 2 orebody has a distinct mineral zonation within and around the ironstone pod. The core of the ironstone consists of 80% magnetite and 20% chlorite, and is enclosed above by a talc-magnetite zone with minor pyrite. An outer dolomite-rich envelope contains haematite, quartz and magnetite, and separates the talc-magnetite zone from stratigraphically higher chloritised metasedimentary rocks. A magnetite-chlorite stringer pipe extending some 350 m below the ironstone body has been intersected in drillholes.

Assay data indicate that Au, Bi, and Cu occur in distinct overlapping zones (**Figure 61**). Gold generally occurs as minute grains (10–30 microns) dispersed within the magnetite-chlorite pod. Larger gains (up to 1 mm) are present within subhorizontal chlorite-filled cracks or magnetite shrinkage cracks. Overlapping and above the gold zone are bismuth sulfosalts (junoite, wittite, emplectite and bismuthinite-aikinite series), concentrated in an umbrella shaped zone partly within the magnetite-chlorite pod and extending into the talc-magnetite zone at its apex. Chalcopyrite is concentrated along the outer contact between the magnetite-chlorite and magnetite-talc zones. Pyrite is also concentrated in the copper zone and persists further into the magnetite-talc zone.

Chariot and Malbec West mines

These deposits are located 10 km northwest of Tennant Creek. They were discovered in 1998 by Giant Reefs Mining NL as a result of exploration using a detailed ground gravity survey, targeting deeper ironstones, which may or may not have a magnetic signature. The Chariot mine (**Figure 63**) had an initial resource of 0.11 Mt @ 20.2 g/t Au (Giants Reef Mining Ltd, ASX Announcement, 30 April 2005). Malbec West was a smaller deposit with an initial resource of 52 000 t @ 11.5 g/t Au. Between 2003–2005, the two mines produced 0.127 Mt of ore grading 8.88 g/t Au for 35 390 oz of gold (MODAT).

Billy Boy

Billy Boy deposit is located 27 km east of Tennant Creek and was discovered in 1998 by Giants Reef Mining Ltd. Mineralisation consists of steeply dipping shoots of high-grade gold-copper ore (**Figure 64**) hosted by haematite-chlorite-clay breccia (**Figure 65**). The indicated resource in the high-grade zone is 8122 t @ 19.6 g/t Au, 5.1 % Cu and 0.8 % Bi (Giants Reef Mining 2000). Extensive drilling has revealed that the high-grade area occupies only a very small part of the larger mineralised host unit, which extents over 300 m of length and is open at both ends and at depth (*ibid*).

Rover field

The Rover field is located 75 km southwest of Tennant Creek, and comprises a series of Tennant Creek-style gold-copper prospects that occur beneath 70–200 m of Cambrian sedimentary rocks of the Wiso Basin (**Figure 66**). The Rover field was first explored by Geopeko during the 1970s to early 1980s, targeting a number of significant magnetic anomalies in the underlying basement. A low-level aeromagnetic survey was conducted by Geopeko in 1974 and covered much of the field. Diamond drill testing of the Rover 1 and various other selected magnetic targets intersected a number of significant copper, gold, cobalt, bismuth, lead and zinc prospects, associated with strong chlorite-dolomite-ironstone alteration that was considered to closely resemble the mineralisation mined at Tennant Creek. This program was terminated in 1982, when the field became Aboriginal freehold land.

In 2005, Adelaide Resources Ltd commenced a renewed phase of exploration in the field and drilling of airborne magnetic anomalies produced encouraging copper and gold intersections from a number of prospects. Drilling of the Rover 1 prospect by Westgold Resources Ltd returned high-grade intersections, including 65 m @ 11.0 g/t Au, 32 m @ 20.8 g/t Au and 13 m @ 48.8 g/t Au, with copper grades typically in the range 0.5–2.0% Cu, and with associated cobalt, bismuth and silver (Westgold Resources Ltd, ASX announcements, 4 June and 29 August 2008). Mineralisation is associated with a strongly altered and mineralised ironstone-chlorite unit within well developed sub-vertical ironstone formations. Early interpretation of the drilling by Westgold Resources have suggested that high-grade gold and copper mineralisation is structurally controlled and intimately associated with 'open space' brittle veins to micro-veinlet arrays, shearing and disseminations (Westgold Resources Ltd, ASX Announcement, 4 June 2008). The mineralisation is interpreted to be within the Warramunga Formation.

In 2008, Westgold Resources also defined a JORC-compliant lead-zinc-silver resource from the Explorer 108 prospect of 8.7 Mt at 5.6% Pb+Zn, 20 g/t Ag and 0.3 g/t Au (Westgold Resources Ltd, ASX announcement, 19 March 2008). Numerous magnetic and gravity anomalies in the Rover field remain untested and the field has the potential to contain numerous Tennant Creek-style deposits.

Gold-quartz vein deposits

There are only three known gold-quartz vein deposits in the Tennant Creek Goldfield. The *Last Hope* mine has produced 12.9 kg Au from bedding-parallel quartz veins, located at the contact between metasedimentary rocks of the Wundirgi Formation and a dolerite sill (Ivanac 1954). The *Bull Pup* mine has produced 1.7 kg Au from quartz veins in faulted sandstone of the Wundirgi Formation (Tapp 1967). At the

Dolomite mine (also known as *Pinnacles Extended*), about 7.5 kg Au has been extracted from quartz and dolomite veins in a fractured felsic porphyry intrusive.

Placer deposits

Small-scale eluvial and alluvial mining has been undertaken adjacent to gold-quartz vein deposits at Last Hope, Bull Pup and Dolomite. Gold nuggets up to 32 oz have been recovered from the eluvials at Last Hope (also known as *Moonlight Rockhole*), which produced 16.7kg Au in 1936–1938 (Balfour 1989).

The amount of eluvial gold derived from ironstone Au±Cu±Bi deposits is small. According to Balfour (1989) and Mines and Energy, Northern Territory, records, some of the placer gold production includes *Mascot* (8.2 kg), *Lady Pearl/Mary Ann* (684 g), *Little Ben* (93 g), *Mary Lane* (75 g) and *Havelock* (47 g).

Gold deposits–Davenport Province

Official production records indicate that only 25 kg of gold was produced between 1926 and 1995 from the Davenport Province. However, discussions with local miners and prospectors suggest that 75 kg is a more realistic figure. Most gold has been derived from small-scale eluvial and hard-rock mining of gold-quartz veins in the Kurinelli area. Over the last twenty years, significant amounts of nugget gold have been recovered using metal detectors.

Gold is present in quartz veins occupying bedding-parallel faults or shears within sediment–dolerite contact zones, or within sedimentary and volcanic rocks of the Ooradidgee Subgroup. The tabular veins are typically 0.5–1.5 m wide and 10–100 m long. Stockwork development is also common. Gossanous boxworks after pyrite and brecciation are often present in irregular high-grade (>10 g/t Au) zones. The origin of the auriferous veins is uncertain, but it appears that they were derived from fractionated granitic intrusives at depth.

Kurinelli area

The Kurinelli goldfield, located 85 km east of Wauchope, was discovered during an expedition in 1898 (Davidson 1905). Mining activity has been sporadic; most of the hard-rock ore has been obtained from the Kurinelli mine, whereas eluvial/alluvial gold has been recovered from numerous locations within a 40 km^2 area centred on Kurinelli Bore (AMG GR NT048285).

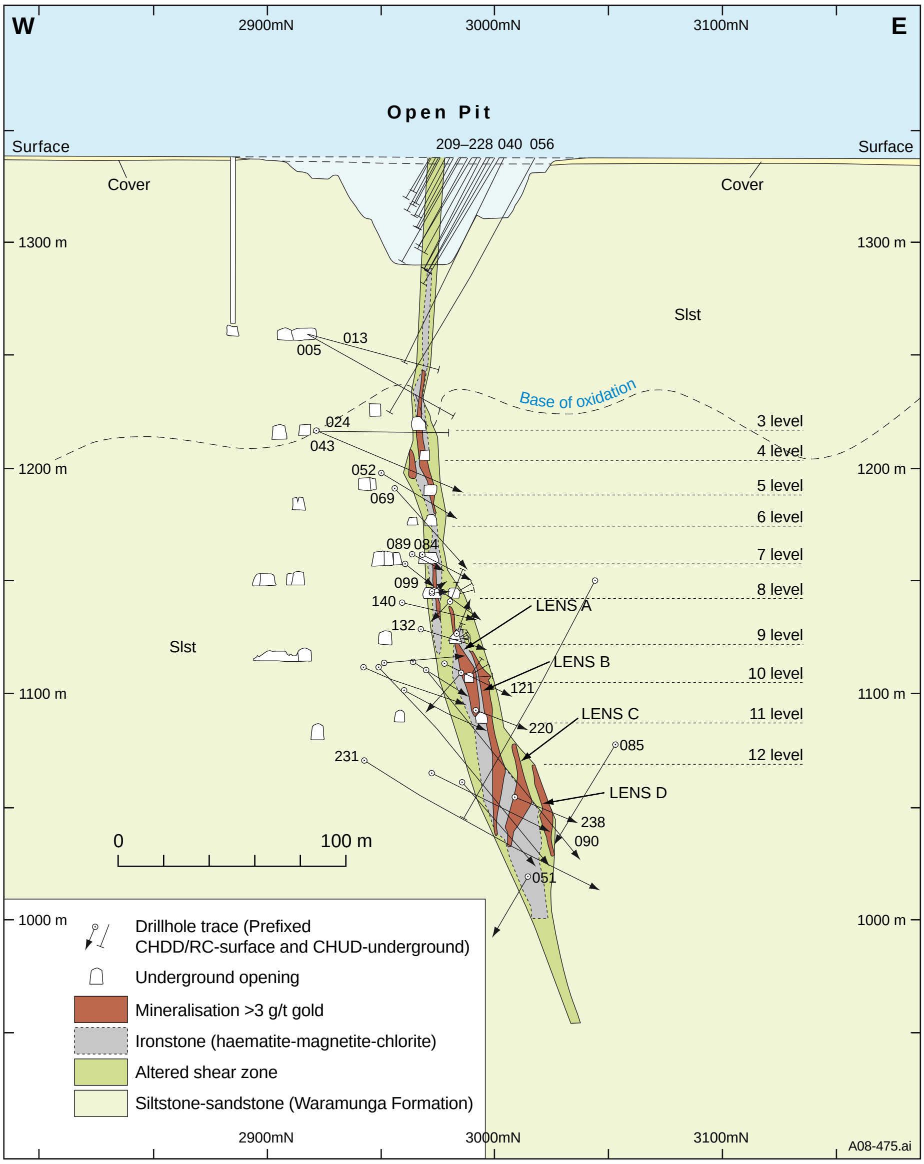

Figure 63. Cross-section of Chariot deposit (from Giants Reef Mining Ltd, ASX Announcement, 30 April 2005).

Gold is generally located in northeasterly-trending, quartz-filled shear zones within dolerite/gabbro and sandstone (Rooneys Formation), or at the dolerite–sediment contact. Quartz veins, emplaced subparallel to bedding, are 0.2–2 m wide and can be traced for up to 200 m along strike. Mineralisation is erratic and occurs as fine- to coarse-grained native gold, in places associated with chalcopyrite and pyrite (Ewens 1975).

At the Crystal mine, three shafts have been sunk into dolerite-hosted, en echelon quartz veins that form a discontinuous line over a strike length of 400 m. The veins trend northeast and dip 50° to the southeast, parallel to bedding in rafts of altered volcanolithic sandstone (Taragan Sandstone) that are enclosed within the dolerite/gabbro sills. There are no official records of production from this deposit, but local prospectors have obtained about 31.1 kg of gold using metal detectors (R Hall, pers comm 1996). Gold-rich sections (up to 34 g/t Au) are found in the narrow, iron oxide-bearing quartz veins (Ryan 1961).

Several other small scattered occurrences have been worked intermittently by prospectors since 1926, when William Garnett discovered the *Power of Wealth* mine (Balfour 1978a, b). Gold is present in bedding-parallel quartz veins, which are 1–3 m wide and up to 200 m long. The veins are hosted by a variety of rock types, including quartz sandstone and shale of the Kurinelli Sandstone

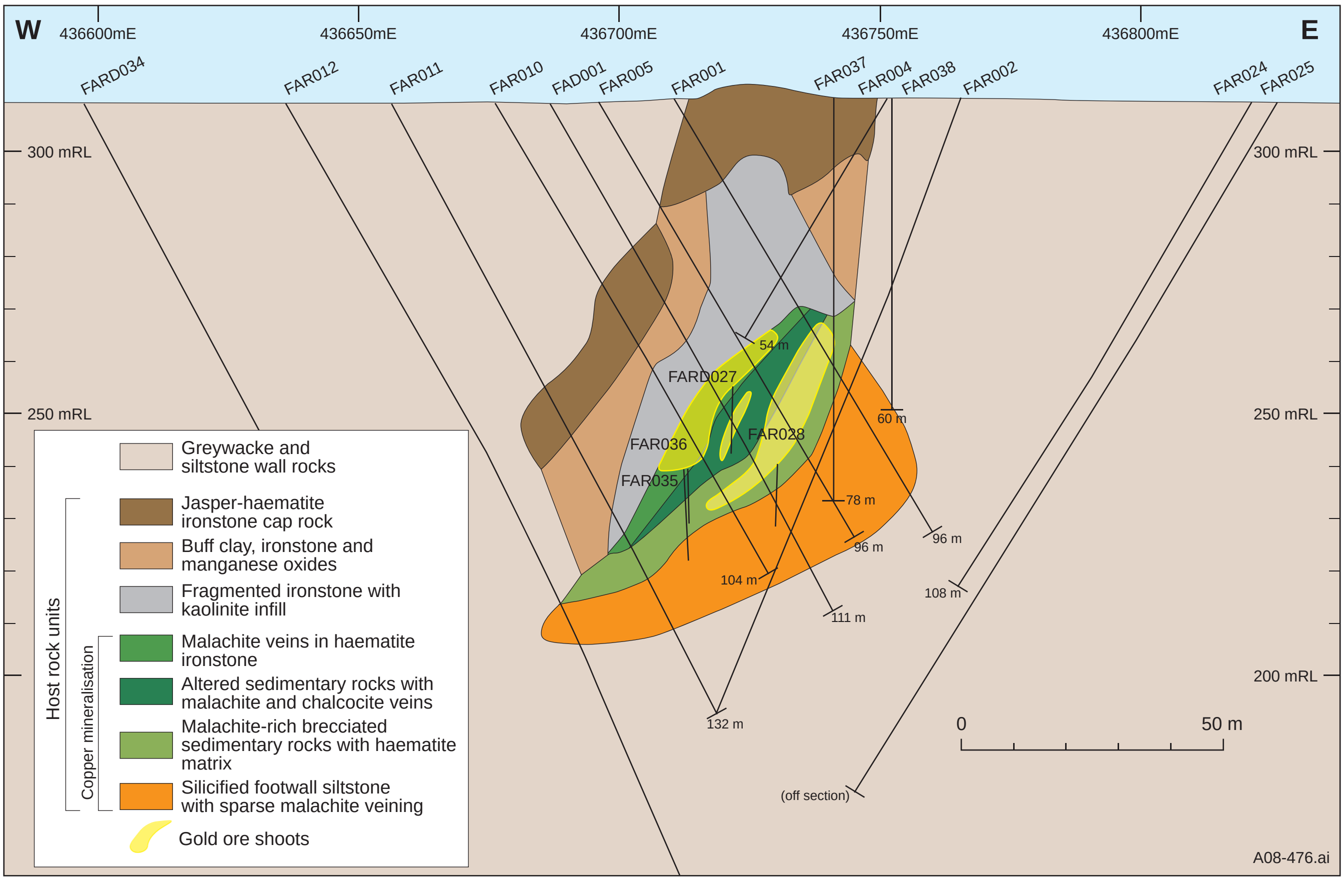

Figure 64. Cross-section of Billy Boy deposit (Giants Reef Mining 1999).

Figure 65. Quartz-haematite breccia from Billy Boy deposit (courtesy of Emmerson Resources 2007).

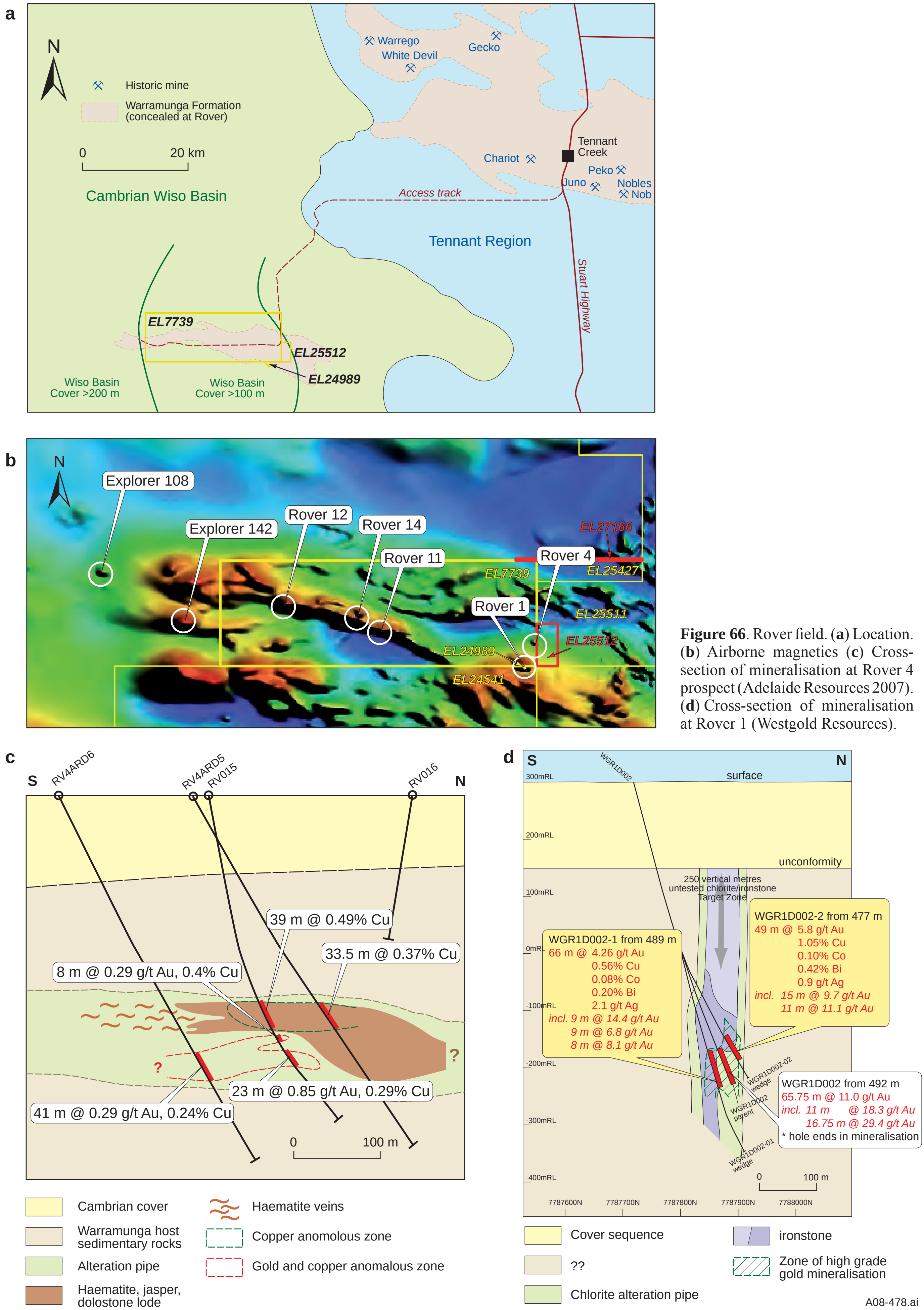

Figure 66. Rover field. (**a**) Location. (**b**) Airborne magnetics (**c**) Cross-section of mineralisation at Rover 4 prospect (Adelaide Resources 2007). (**d**) Cross-section of mineralisation at Rover 1 (Westgold Resources).

(*Great Davenport*, *Power of Wealth*, *Aztec*, *Priesters*), acid volcanics of the Epenarra Volcanics (*Millars*) and Junalki Formation (*Opengidgi*), basalt of the Edmirringee Volcanics (*Kurundi*), sandstone of the Taragan Sandstone (*Cairns*), granophyre (*Davidsons*), and quartz-feldspar porphyry (*Davidsons*).

The more recent exploration of these prospects has been mainly by costeaning and chip sampling (Cullen 1987, Shields and Boyer 1987, Sanderson 1987) ; this has returned results unfavourable for mining. Only the Great Davenport, Power of Wealth and Cairns prospects have been evaluated by diamond drilling.

Soil sampling conducted by Arafura Resources NL during 2006–2007 defined a coherent, 2 km-long northeast-trending zone of elevated gold results with values as high as 2.51 g/t Au (Arafura Resources Ltd ASX announcement 28 November 2007).

Ore genesis

Ironstone-hosted gold deposits

The Tennant Creek-style gold deposits are inextricably associated with ironstone bodies hosted within the Warramunga Formation, particularly in the vicinity of thin beds of argillaceous banded iron formation and haematite-rich shale. Therefore, an understanding of the relationship between gold deposition and the ironstone bodies is of fundamental importance. The regional distribution of the ironstones indicates that they are concentrated along linear shear zones.

Early investigations undertaken on small surface mines recognised that the iron oxides acted as a chemical trap for later gold-bearing fluids (Woolnough 1934, 1936, Owen 1940).

The first mineral paragenetic studies concluded that the mineralisation involved a two-stage process involving magnetite (±quartz-chlorite-pyrite) pod formation, followed by the precipitation of Au-Bi-Cu minerals (Pontifex 1964, Whittle 1966). Most studies have supported the two-stage model (Wright 1965, Meade 1986, Edwards 1987, Huston *et al* 1993), although some workers have proposed a one-stage mineralisation phase (Large 1974, Reveleigh 1977).

There have been at least seven different theories of ore genesis proposed by various authors:

- Iron oxides and Au-Cu-Bi metals are magmatic in origin and were derived from granitic and porphyry intrusive rocks (Woolnough 1936, Owen 1940, Ivanac 1954, Crohn and Oldershaw 1965).
- Ore-forming metalliferous brines were derived from the dewatering and remobilisation of flysch sedimentary rocks during diagenesis (Elliston 1966).
- Basic intrusives (gabbro and dolerite) were the source of the mineralising fluids (Pontifex 1964, Whittle 1966, Dunnet and Harding 1967).
- Metal-rich hydrothermal fluids were derived from blind intrusions, which also produced the lamprophyre dykes (Reveleigh 1977).
- Mineralising fluids were derived from connate water released from argillaceous sedimentary rocks in the vicinity of granite and porphyry intrusive rocks (Large 1974, 1975).
- Mineralised ironstones represent remobilised, sediment-hosted massive oxide deposits, which were originally formed at or close to the sea floor from metal-rich solutions (Norris 1980, Main *et al* 1990, Goulevitch in Giants Reef Mining 1993).
- Mineralisation is the result of a two-stage process involving early ironstone formation from connate brines, followed by the introduction of hydrothermal, sulfur-bearing Au-(Cu-Bi) fluids (Wedekind *et al* 1989, Nguyen *et al* 1989, Wall and Valenta 1990, Skirrow and Walshe 1993).

Fluid inclusions in quartz from barren and mineralised ironstone suggest essentially two different kinds of fluids (Khin Zaw *et al* 1994a, b). The quartz in mineralised ironstone has inclusions that homogenised at a higher temperature (>300°C) and salinity values that are generally higher than 30 wt% equivalent NaCl. There is also an abundance of vapour-rich inclusions that contain N_2 gas. Quartz from unmineralised ironstone has fluid inclusions that indicate a lower temperature and salinity and are vapour rich. Nguyen *et al* (1989) and Skirrow and Walshe (1993) found that the oxide-stage fluids were relatively higher in temperature and salinity compared to the sulfide-stage fluids.

Fluid inclusion work on samples from gold occurrences in the Kurinelli area have revealed the presence of at least three fluids (Wygralak and Mernagh 2008a). About 80% of inclusions consist of Type D aqueous inclusions, which represent two fluids. The first fluid homogenises over a broad temperature range of 140–340°C and has high salinities in the range 18–22 wt% NaCl eq. The second fluid homogenises in the narrow temperature range of 420–440°C and has a low to moderate salinity of 2–20 wt% NaCl eq. Inclusions representing this fluid coexist with CO_2-bearing Type A inclusions, which form the remaining 20% of all inclusions. Type A inclusions homogenise over a narrow temperature range of 400–440°C to liquid, vapour or by fading meniscus indicating boiling conditions.

Gold-bearing veins in the Davenport Province do not contain micas, thus preventing dating by the $^{40}Ar/^{39}Ar$ method. Muscovite selvages on W-Sn quartz veins in this area yield $^{40}Ar/^{39}Ar$ ages of ca 1720 Ma (Fraser *et al* 2006).

Oxygen-hydrogen isotope studies, undertaken on several deposits (Large and Wedekind 1988, Horvath 1988, Wedekind 1990, Skirrow 1993), suggest that the 'barren' ironstones probably formed from formational waters, whereas a second fluid source, either metamorphic or magmatic, was responsible for the economic mineralisation (Wedekind 1990, Skirrow 1993).

Carbon-oxygen isotope studies on carbonates from Juno (Large 1974), and White Devil and Argo (Huston 1991) indicate large variations in carbon and oxygen isotope ratios, but a positive trend is seen in late-stage calcite from Argo, which may indicate mixing of multiple $\delta^{13}C$ and $\delta^{18}O$ sources. Huston (1991) suggested that mixing probably involved a magma-derived fluid enriched in $\delta^{13}C$ and depleted in $\delta^{18}O$, with a metamorphic fluid depleted in $\delta^{13}C$ and enriched in $\delta^{18}O$.

Sulfur isotope data from various deposits show a significant variation in the values of $\delta^{34}S$, but strong modes are apparent at Gecko and Argo (between -1 and 1‰), Warrego (2–3‰) and at White Devil (2.5–4.5‰). This is compatible with a magmatic source for at least some of the sulfur in these deposits (Ferenczi 1996). The variation of $\delta^{34}S$ values in the deposits can be explained by the mixing of connate SO_4 and magmatic H_2S, or by fractionation during either the reduction of SO_4 or oxidation of H_2S in ore fluids.

Lead isotope analyses show a significant difference in the $^{208}Pb/^{204}Pb$ signature of Au-bearing ironstones compared with haematite shales, which suggests that magnetite-haematite shales are not the local source of the mineralisation for the economic deposits (Gulson *et al* 1987).

Black (1977) dated muscovite from Juno, Warrego, Golden Forty and Nobles Nob, using Rb-Sr methods, that suggest a mineralisation age of about 1810 Ma. More recent $^{40}Ar/^{39}Ar$ analyses of hydrothermal muscovite from Peko, Argo, Nobles Nob and Juno suggest a minimum age for the mineralisation of 1830–1825 Ma (Compston and McDougall 1994). Lead-isotope dating of samples from Juno, Argo, Gecko and Peko gave model ages of 1834–1819 Ma (Warren *et al* 1995). Significant igneous activity in the goldfield at about this time is recorded in the felsic volcanic rocks within the Flynn Subgroup (ca 1845–1830 Ma) and felsic porphyry intrusive rocks (1838 ± 9 Ma: Compston 1995).

In summary, field relations, fluid inclusions and stable isotopes suggest a two-stage model (**Figure 67**). During the first stage the ironstones formed from moderately saline connate brines during deformation and metamorphism of the Warramunga Formation. The iron oxides precipitated in dilatant zones and replaced highly strained and chemically reactive shale units to form massive pods and pipes. These ironstone bodies can be irregular in shape, but there is a tendency to be elongated in the down-dip direction of the cleavage, more or less perpendicular to the F_1 fold axes.

Later Au-Cu-Bi and related alteration phases infill fractures and locally replace parts of the ironstone (**Figure 67**). The ore-forming fluids were mesothermal and predominantly metamorphic in character. District variations in ore fluid chemistry and ore types could be due to local geological conditions (eg presence of carbonaceous shale or distance from ‘syn-ore’ magmatic intrusive rocks), which influenced the degree of mixing between deeper, magma-derived ore fluids and regional connate brines.

The ironstones play both a chemical and mechanical role in the ore deposition process, by fracturing in a brittle style, which subsequently allowed extensive redox reactions between the relatively oxidising sulfide-bearing ore fluids and the reducing ironstone bodies.

Gold-quartz veins

Little work has been carried out on the origin of quartz vein deposits in the southern part of the Tennant Region. In many respects, these are similar to the quartz vein deposits in the Pine Creek Orogen and it appears that they are most likely related to fractionated granitic intrusives at depth.

Gold prospectivity

The Warramunga Province of the Tennant Region remains one of the most prospective gold provinces of the Northern Territory. For about three decades to 1980, it was the only major gold producer and although by 1990, the historically known gold reserves had largely been depleted, the gold potential of this province is still considered high and the area continues to attract exploration interest. Previous exploration programs generally relied on the magnetic signatures of the hosts to the orebodies. Thus, airborne magnetic surveys, flown by BMR in 1956 and 1960 on a 1600 m line spacing, were directly responsible for the discovery of the Orlando, Ivanhoe, Warrego and Juno orebodies (Australian Development 1989). Further airborne surveys were carried out in the 1970s and generated over 100 new targets, all of which were drilled to some extent. Australian Development (1989) identified the following three factors that have complicated the search for gold deposits in the area:

- The magnetic anomaly attributed to an ironstone host may be masked by disseminated magnetite in the surrounding sedimentary rocks.
- Not all ironstones are gold bearing. Out of 650 known ironstone bodies, only 130 have been mined for gold. Most outcropping ironstones do not extend below the zone of oxidation and have little magnetic expression.
- economic gold mineralisation usually occurs in relatively small pods within a large ironstone body.

The lithologic, stratigraphic, igneous and metamorphic similarity of the Tennant Region with the Pine Creek Orogen and Tanami Region indicate that significant potential may still exist for structurally controlled, non-magnetic gold deposits within the region. Although there is still some potential for the discovery of small, “blind” high-grade ironstone-hosted Au±Cu±Bi deposits, other styles of mesothermal Au mineralisation, such as veins in fractured porphyry intrusions, or carbonaceous shale located within or near major fault/shear zones, could be targeted. Haematite-rich, non-magnetic ironstones such as at Nobles Nob provide a potential target over areas where the Warramunga Formation is present under shallow, surficial sedimentary rocks. Further potential also exists for “fossil” epithermal Au deposits within fractured and silicified Palaeoproterozoic felsic volcanic eruptive centres in both the Warramunga (Flynn Subgroup) and Davenport (Ooradidgee Subgroup) provinces.

A major focus of future exploration for ironstone-hosted gold-copper mineralisation in the Warramunga Province is likely to be at depth beneath Cambrian sedimentary rocks of the Wiso and Georgina basins, which are up to a few hundred metres in thickness. The geophysical response of ironstone-hosted mineralisation allows targeting through significant cover, such as in the Rover field.

The mineral potential of the Tennant Region is summarised graphically in **Figure 5**. As most currently known deposits are located within the Warramunga Formation, the outcrop extent of this unit is considered to have high gold potential, especially where it extends underneath thin basinal covers to the northeast. The overlying Flynn Subgroup and Hatches

Creek Group are considered to have moderate potential. Younger Proterozoic strata (Tomkinson Creek, Hanlon and Wauchope subgroups) are considered to have less potential for the discovery of gold deposits.

TANAMI REGION

The Tanami Region contains important occurrences of gold and in the past two decades has emerged as a highly prospective gold province of national and possibly global importance. The Tanami Region contains several promising and untested geochemical gold anomalies, and is still being extensively explored. Its potential for gold is considered to be very high and significant future discoveries can be expected. Currently known mineralisation is concentrated in three goldfields: The Granites, Dead Bullock Soak (DBS) and Tanami.

The historic 'The Granites' goldfield is located close to the Northern Territory–Western Australia border and is largely within an area under Aboriginal Land Trusts.

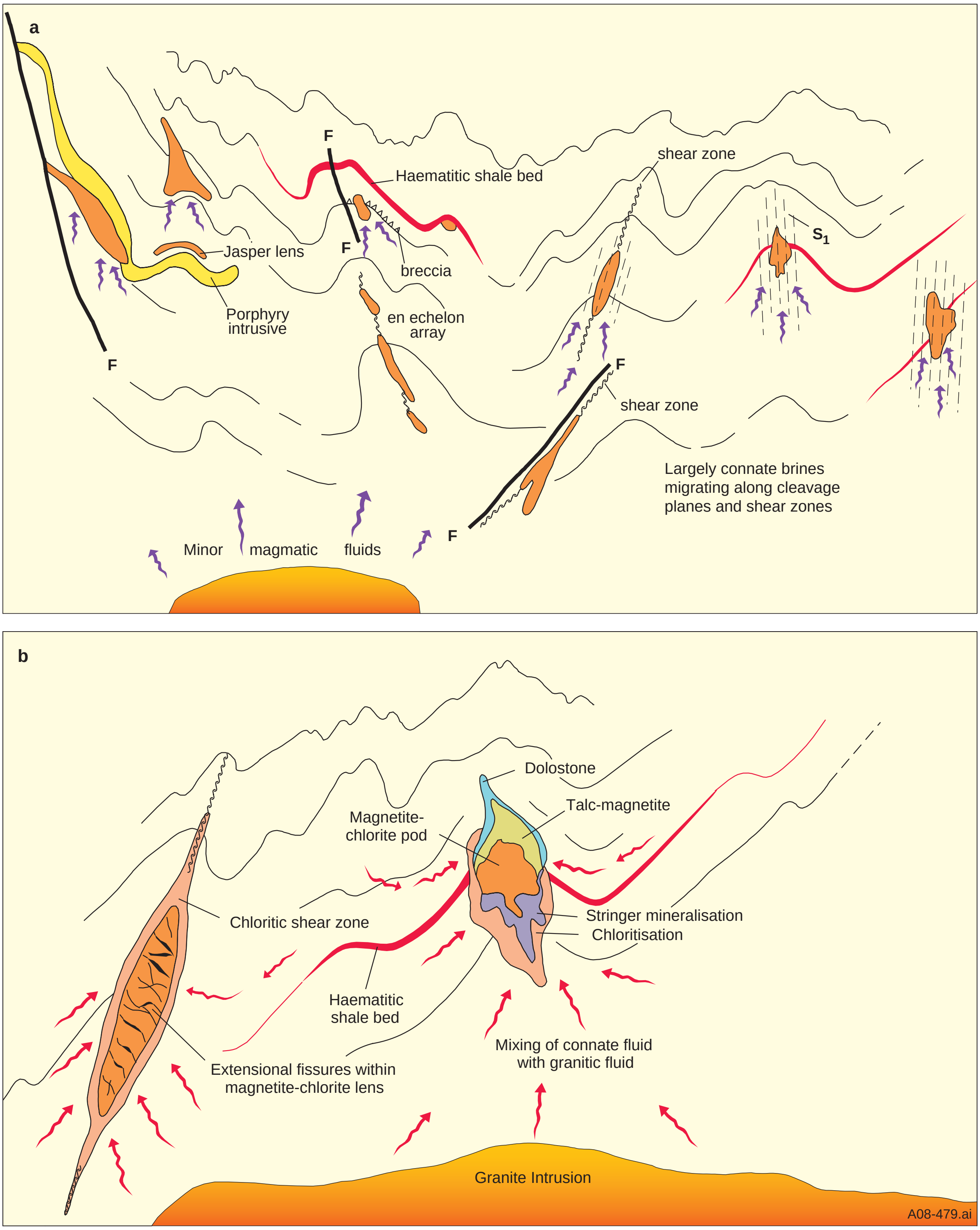

Figure 67. Generalised ore genesis model for Tennant Creek deposits. (**a**) Oxide stage: During diagenesis and early deformation, iron oxides were remobilised from sedimentary rocks and magmatic intrusive rocks, then concentrated in structural and stratigraphic traps to form massive pods and pipe-like bodies. (**b**) Sulfide stage: Development of extension fissures in ironstones within ductile, chloritic shear zones. Au-Cu-Bi-bearing-fluids, derived from granites, precipitate within fractured ironstones and adjacent altered metasedimentary rocks.

Alan Davidson discovered gold at this site in 1900 (Davidson 1905). Minor production continued until about 1910, after, which the field was neglected for 15 years (Hossfeld 1940a, b). Attempts were made to reopen the field in 1925 and 1927, but it was not until 1932, when J Escreete and party discovered alluvial gold, that the field received further attention. They commenced dry-blowing the alluvials focusing on the Burdekin Duck lease. Subsequently, an area that extended for 8 km along the line of lodes was pegged. The Northern Territory Administrator's report for 1932 states that two small batteries were installed by Chapman Gold Mines NL and about 70 t of ore had been raised from the Burdekin Duck mine. Chapman Gold Mines NL continued activities at the Quorn, Shoe, Longbottom, Ivy and Bullakitchie leases. The total production from 1933–1939 was stated to be 62 kg Au from 5000 t of ore (Hossfeld 1940b). Production continued until 1961, by which time a total of 470 kg Au had been produced, over half of this during 1945–1951 (Crohn 1961b). Water shortages, harsh living conditions and adverse reports by visiting geologists and mining engineers caused the field to be further neglected.

Brown (1909) visited the Tanami mine and provided notes on the geology. Talbot (1910) identified sandstone and conglomerate in the Gardiner Range, unconformably overlying the metamorphic rocks that contained the gold reefs. In the following year, Gee (1911) described the Tanami mine workings and noted the prospecting activities being undertaken at The Granites. Jensen (1915) described the geology in the vicinity of the gold workings at the Tanami mine. Ellis (1927a, b) carried out further geological investigations at the Tanami mine. Terry (1930) explored the country from Gardiner Range to The Granites. Hossfeld (1940a, b) provided detailed descriptions of the mining operations.

During 1939–1940, the Mines Branch of the Northern Territory Administration drilled eight holes at Tanami and core is still available for five of these. The depths ranged between 36 and 103 m (Hughes 1940). Between 1938 and 1948, Anglo Queensland Mining Company put down 20 diamond drillholes. In addition, Consolidated Zinc Pty Ltd carried out a reconnaissance survey of the Tanami Region (Phillips 1959) and BMR conducted airborne geophysical surveys in the early 1960s (Bureau of Mineral Resources 1965).

It was the deregulation of gold prices, combined with improvements in mining and metallurgical techniques during the late 1970s that boosted an extensive search in the region. In 1975, prospectors S Griffith and F Glastonbury introduced North Flinders Mines Ltd to The Granites goldfield, but the grant of tenement applications was delayed for eight years. After protracted negotiations with the Aboriginal landowners, four exploration licences were eventually granted in 1983. By June 1985, a total of 57 diamond drillholes and 75 reverse circulation holes were completed at Bullakitchie and Shoe, indicating *in situ* reserves totalling 1.9 Mt at 8.0 g/t Au (Mayer 1990). Production commenced at these deposits in July 1986.

In June 1985, North Flinders Mines announced a discovery in the Dead Bullock Soak (DBS) area, 35 km west of The Granites mine, of a deposit containing 0.6 Mt at 3.3 g/t Au. By June 1997, the resource inventory had increased to 18.54 Mt at 5.5 g/t Au. Open-cut mining commenced in November 1991 and ore from DBS was trucked to the processing plant at The Granites mine.

In 1985, Harlock Pty Ltd commenced exploration at the Tanami leases, 50 km northwest of DBS. This involved costeaning and diamond and percussion drilling that outlined proved and probable reserves totalling 0.8 Mt at 3 g/t Au (Nicholson 1990). In 1987, a 350 000 tpa CIL treatment plant started production. In 1988, control of the operations was transferred to the Tanami Joint Venture (TJV) comprising Zapopan NL, Kumagi Gumi Co Ltd and Kintaro Metals Pty Ltd. The TVJ carried out additional exploration and further evaluated the open pit resources. In 1991, the total resource was estimated at 4.02 Mt at 2.24 g/t Au.

Zapopan NL acquired the TJV in 1991 and continued mining until March 1994. From June 1987 to March 1994, the total production was stated to be 26.45 t Au. In 1995, Zapopan tenements and the plant were transferred to the Central Desert Joint Venture (CDJV), comprising Acacia Resources Ltd and Otter Gold Mines Ltd.

Exploration by the CDJV in an area to the southwest of Tanami mine commenced in 1990. By 1994, a resource of 3.45 Mt at 3.2 g/t Au had been identified at the Jims Find, Dogbolter and Redback Rise deposits. Mining commenced late in 1995 and produced 11.766 t Au from 3.87 Mt of ore to 31 December 1998.

During the 1990s, Normandy NFM Ltd conducted extensive exploration, which in 1999, resulted in the discovery of the Groundrush deposit. This deposit was discovered within seven weeks of the first sampling being undertaken. Subsequent exploration in 2001 below the existing pits in The Granites area led to the discovery of additional resources, particularly at Callie. Newmont Australia Ltd (Newmont) currently owns all mining operations within the Tanami Region.

It is estimated that by the end of 2007, the Tanami Region had produced 5.5 Moz Au. Newmont announced that as of 31 December 2008, their Tanami operations had total open pit, underground and stockpile proven reserves of 4 Mt @ 4.73 g/t Au for 660 000 oz gold at 96% recovery. The statement also includes a total proven plus probable resource of 11.5 Mt @ 3.66 g/t Au for 1.48 Moz Au (Newmont 2008).

Regional geology

The Tanami Region forms part of the Palaeoproterozoic orogenic domains of the NAC. To the south, it has a transitional relationship with the Aileron Province of the Arunta Region. The boundary between the provinces is poorly defined, as the Killi Killi Formation and Lander Rock Formation continue as equivalent stratigraphic units across the boundary. The southern margin of the Tanami Region is marked by a sharp increase in metamorphic grade associated with east-trending structures, whereas the eastern boundary is defined by the easternmost presence of the Dead Bullock Formation within the stratigraphy. Seismic data (Goleby *et al* 2009) suggests that a suture may exist in the underlying crust beneath the Tanami–Arunta transition, although any suture must predate deposition of the Tanami Group. To the north, the Tanami Region is unconformably overlain by the Palaeoproterozoic Birrindudu Basin and the Palaeozoic Wiso Basin.

The detailed geology of the Tanami Region is described by Crispe *et al* (2007) and Vandenberg and Crispe (in prep) and the following discussion is based on these publications. **Figure 68** shows the distribution of geologic units and regional faults.

The oldest rocks in the region are high-grade metasedimentary rocks and leucogranites of Neoarchaean age (2514 ± 3 Ma) that occur within the Billabong Complex. Archaean rocks have a very limited area of outcrop in the Tanami, although Nd isotope data and detrital zircon populations suggest a more extensive distribution at depth (Page *et al* 1995).

The most extensive Palaeoproterozoic unit is the 1838 ± 6 Ma (Cross *et al* 2005) Tanami Group, which is subdivided into the basal Dead Bullock and overlying Killi Killi formations. Graphitic units and banded iron formation of the Callie Member of the Dead Bullock Formation host most lode-gold deposits in the Tanami Region (Huston *et al* 2007). The Killi Killi Formation, which consists of turbiditic siliciclastic rocks, also hosts gold, but is less extensively mineralised. Dolerite sills, some of which have peperitic

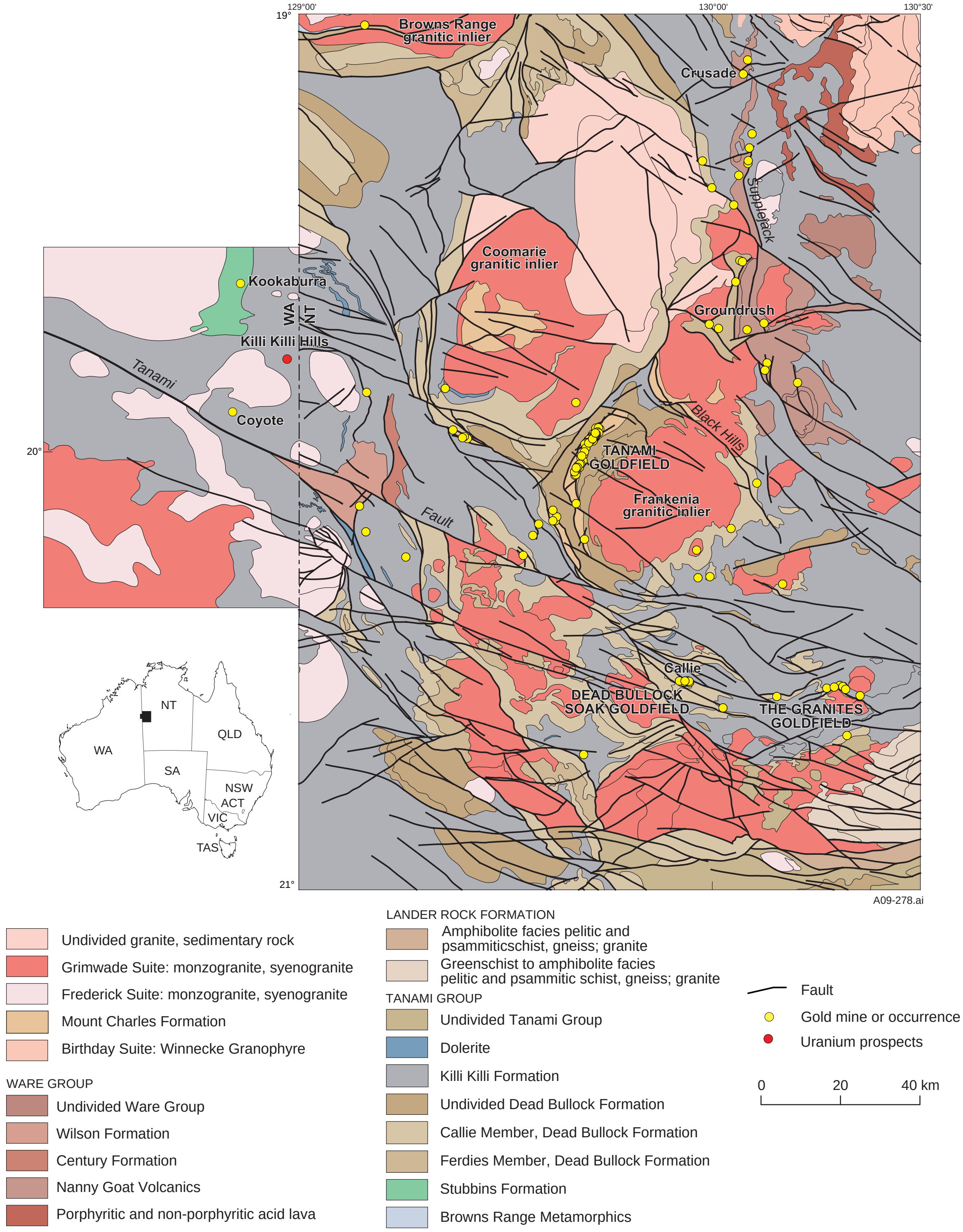

Figure 68. Regional interpreted geology and gold deposits in Tanami Region.

contacts with the enclosing sedimentary rocks, intrude the Tanami Group. Although the poor exposure precludes definitive statements, the Dead Bullock Formation seems to be restricted to the eastern and central part of the Tanami Region, barely extending over the border into Western Australia (**Figure 68**). This suggests that the Tanami basin was deepest in the eastern and central parts, a hypothesis supported by provenance data from the coarser-grained Killi Killi Formation, indicating that it was sourced from the Kimberley region to the west (Cross and Crispe 2007).

The close association of many deposits and prospects with carbonaceous and Fe-rich units in the Tanami Group suggests that the original architecture of the Tanami basin influenced the later lode-gold mineral system. Either the unusual composition of these fine-grained rocks localised gold deposition, or structures that developed during basin formation were reactivated during later lode-gold events.

The Tanami Group is unconformably overlain by the Ware Group, which is dominated by sandstone and felsic volcanic rocks, and which was deposited in the interval 1830–1805 Ma (Crispe *et al* 2007).

The Tanami Region also contains intrusive granitic rocks dominated by the Frankenia, Coomarie and Browns Range domes (**Figure 68**). These domes have a low, but variable magnetic intensity, consistent with multiple intrusive phases. Interpretation of magnetic and gravity data (Slater 2000a, b, Meixner et al 2004, Meixner and Lane 2005) led to the inference that more than half of the Tanami basement is possibly composed of granite. However, more recent seismic data indicates the extent of granite may be much more restricted and, although some bodies are aerially extensive, they are relatively thin (<2 km; Goleby et al 2006, 2009).

Most felsic magmatic rocks in the Tanami region have interpreted U-Pb zircon ages between 1825 Ma and 1791 Ma (Smith 2001). Most of the granitic bodies intruded the Tanami and Ware groups and their emplacement was coincident with protracted regional deformation (see below). The Mount Charles Formation was deposited before local granitic intrusion, as it is cut by felsic dykes (**Figure 69**) and was affected by contact metamorphism related to the emplacement of the Grimwade Suite Granite (Tunks 1996). No felsic intrusive rocks exist in the Pargee Sandstone and Birrindudu Group rocks.

Green (in Vandenberg and Crispe in prep) proposed that the granites in the Tanami region were derived from partial melting of late Archaean gneiss with minor assimilation of Tanami Group sedimentary rocks. He divided the granites of the Tanami region into three suites, using geochemical, petrographical and geophysical similarities, together with the classification criteria of White *et al* (2001).

The Birthday Suite is restricted to the northeastern Tanami Region and includes the formally named Winnecke Granophyre (Blake *et al* 1975) and volcanic rocks of the Mount Winnecke Formation. It correlates with a highly magnetic domain and comprises intimately related intrusive and extrusive rocks with an interpreted igneous crystallisation age of ca 1820 Ma. The Birthday Suite is an alkali-calcic type and represents the most alkali-rich granites in the Tanami Region. *The Frederick Suite* includes the magnetic parts of the Browns Range and Coomarie domes, as well as other discrete plutons with high magnetic responses, except for the Birthday Suite. Frederic Suite granites have interpreted igneous crystallisation ages ranging from 1815 to 1790 Ma and contain abundant older inherited zircons (Smith 2001). The suite is dominantly peraluminous and is defined as calc-alkaline. *The Grimwade Suite* is weakly to non-magnetic. It is widely distributed and includes the Slatey Creek, The Granites and Lewis granites of Blake *et al* (1979), and parts of the Browns Range and Frankenia dome granites, as well as granite south of the Dead Bullock Soak and The Granites goldfields. The Grimwade Suite extends southeast into the adjacent Aileron Province and has interpreted crystallisation ages in the range 1820–1790 Ma (Smith 2001). It is generally peraluminous and is defined as calc-alkaline.

The Tanami Region has a complex deformational history. Its Archaean basement, which is exposed in the Billabong Complex in MOUNT SOLITAIRE, has a gneissic foliation predating deposition of the Tanami Group (Vandenberg *et al* in prep). The first tectonostratigraphic event to affect the sedimentary rocks of the Tanami Group is the Tanami Event (D_1) dated 1830–1825 Ma (Huston *et al*

Figure 69. Felsic dyke cutting Mount Charles Formation in Tanami goldfield (west wall of Hurricane-Repulse pit).

2007), which produced tight to isoclinal folds in the Tanami Group. Between 1825 and 1790 Ma, the Tanami Region experienced two periods of compressional deformation (D_2 and D_3), the development of a post-D_3 rift filled with turbiditic sedimentary rocks and basalt of the Mount Charles Formation, the intrusion of the Grimwade and Frederick magmatic suites, and south-directed (D_4) and phases of northwest- and west-southwest-directed (D_5) shortening (Crispe *et al* 2007, Vandenberg *et al* in prep). Most of the lode-gold deposits in the Tanami Region are associated with D_5 shear zones and fault systems (Huston *et al* 2007). Structural relations indicate an age of 1800–1790 Ma for this deformational event. Numerous late thrust faults, oblique-slip faults and normal faults cut all earlier structures and are collectively designed D_{6+}. These structures often contain quartz-calcite infills postdating gold mineralisation. It is possible that some or all of these events are related to progressive deformation.

The metamorphic grade of metasedimentary rocks in the Tanami Group is mostly greenschist facies. Across most of the Tanami Region, pelitic rocks are fine-grained phyllites, with mineral assemblages including quartz-sericite and quartz-biotite-muscovite. The metamorphic grade of the Tanami and Ware groups is lowest in the northeast, where they are metamorphosed to lower-greenschist facies. The Mount Charles Formation at the Tanami goldfield is less metamorphosed than Tanami and Ware groups.

Localised contact metamorphism (**Figure 70**) has resulted in the growth of andalusite and less common garnet (almandine) porphyroblasts around some granitic intrusions, typically overgrowing the D_1 fabric (Scrimgeour and Sandiford 1993, Scott 1993, Valenta and Wall 1996, Vandenberg 2002). In the vicinity of The Granites goldfield, mid-amphibolite-facies contact metamorphism reached peak conditions of 600°C and 2.5 kbar (Scrimgeour and Sandiford 1993). The effects of contact metamorphism extend only a few metres to hundreds of metres from intrusive margins into the surrounding country rock indicating high-level intrusions.

Figure 70. Contact metamorphism at The Granites goldfield. (**a**) Andalusite schist. (**b**) Almandine schist at Quorn deposit.

The timing of regional metamorphism in the Tanami Region is poorly constrained. Structural criteria indicate that regional greenschist-facies metamorphism was associated with the 1830–1825 Ma Tanami Event. Higher-grade (up to mid-amphibolite-facies) metamorphism, related to later granite (and mafic) intrusions, occurred at 1815–1800 Ma.

Gold deposits

There are 121 currently known gold occurrences in the Tanami Region. These can be generally referred to five distinct deposit types:

- Au-quartz veins in carbonaceous siltstone. These contain very minor sulfides and are generally discordant to bedding. Mineralisation is in subparallel, sheeted quartz veins within a structural corridor. The Callie deposit is currently the only known example of this type of mineralisation.
- Au-sulfide (arsenopyrite, pyrite and pyrrhotite)±quartz±carbonate veins in banded iron formation and chert, eg West Bullakitchi, Shoe, Quorn, Villa, Triumph Hill. These veins follow a particular stratigraphic horizon of iron-rich, cherty metasedimentary rocks within the Dead Bullock Formation. Deposits are present in The Granites and Dead Bullock Soak goldfields, and have large tonnages and higher grades than those in the Tanami goldfield. In most aspects, they are similar to the BIF-hosted deposits of the Pine Creek Orogen, discussed above.
- Au-carbonate-sulfide±quartz veins. These are unique to the East Bullakitchie deposit and occur as concordant and discordant veins within metamorphosed sedimentary rock, which probably had a carbonate precursor.
- Au-quartz-carbonate veins in basalt of the Mount Charles Formation. The veins are present as breccia fills, veins and stockworks within lower greenschist-facies basalt, greywacke, siltstone and shale. The basalt is vesicular, has pillow structures and has undergone propylitic alteration. These deposits occur in clusters in the Tanami goldfield and have lower tonnages and grades.
- Au-quartz veins in dolerite, eg Groundrush.

Most of the gold deposits in the Tanami Region are grouped in three goldfields: Tanami, The Granites and Dead Bullock Soak (**Figure 68**). These are described below. Deposits not fitting into these goldfields are discussed separately.

Dead Bullock Soak (DBS) goldfield

The DBS goldfield comprises eight deposits (**Figure 71, 72**). Most of these have been mined out, with the exception of the Callie deposit, which is currently being mined by underground methods and contains the total remaining resources and reserves of this goldfield.

Mineralisation is hosted by the Dead Bullock Formation, comprising siltstone, shale, BIF and chert units that are conformably overlain by greywacke and siltstone of the Killi Killi Formation. In the local mine stratigraphy, the Dead Bullock Formation is informally divided into the 'Blake beds' and 'Davidson beds'. The Killi Killi Formation is referred as the 'Madigan beds'. These units have been informally subdivided into a number of subunits by Normandy NFM geologists (**Table 6**).

The lowermost unit, the '*Callie formation*', hosts the Callie deposit and comprises quartz-chlorite-sericite schist with minor graphitic and rare chert intervals. The 'Callie formation' consists of seven sub-units. The basal '*Lower Blake beds*' comprise massive, bedded quartz-sericite-chlorite-biotite metasiltstone, locally with carbonate. The '*Callie laminated beds*' comprise fine quartz-sericite-chlorite-biotite metasiltstone with a distinct, fine pale banding, representing original carbonaceous laminations. The overlying '*Magpie schist*' consists of finely interbedded, black carbonaceous metasiltstone with pale quartz-sericite-chlorite-biotite metasiltstone. A dolerite sill the '*End it all dolerite*' separates it from the overlying '*Callie boudin chert*'. The latter comprises sulfide-bearing carbonaceous schist containing distinctive ovoid chert or quartz nodules with pyrite, pyrrhotite and arsenopyrite. The overlying '*Pip schist'* comprises banded siltstone with elongate quartz-biotite spotting. The '*Upper Blake beds*' contain interbedded siltstone and carbonaceous siltstone with minor chert nodules.

The 'Orac formation' consists of two chert sub-units ('*Lower* and *Middle orac chert*') interbedded with chlorite schist ('*Middle* and *Upper orac schist*'). The latter contains extensive quartz veins.

The '*Schist hill formation*' is separated from the 'Orac formation' by the '*Coora dolerite*' sill and consists of several predominantly siltstone sub-units. The '*Dead bullock member*' consists of fine-grained quartz-chlorite-muscovite phyllite, characterised by abundant muscovite and pale ovoids interpreted as cordierite. The overlying '*Schist hill iron member*' ('SHIM'), consists of interbedded amphibole (actinolite, cummingtonite) rock, chlorite-rich phyllite and chert. All rocks of the 'SHIM' contain varying proportions of magnetite and some can be classified as BIF. Deeper portions of the 'SHIM' also contain significant carbonate. The SHIM is the host lithology of the Triumph Hill, Dead Bullock Soak Ridge, Colliwobble Ridge and Sleepy Hollow deposits. The overlying *'Colgate schist*' comprises fine carbonaceous shale containing scattered nodules and thin chert. The *'Manganiferous chert*' comprises phyllitic, chlorite-rich sedimentary rocks interbedded with chert. Some intervals contain abundant, disseminated manganiferous garnet. The poorly exposed '*Seldom seen schist*' represents carbonaceous phyllite similar to that of the 'colgate Schist'.

The '*Coora dolerite*' sill predates most deformation and was emplaced along the contact between the 'Schist hill formation' and 'Orac formation'. The '*End it all dolerite*' is present in the Callie area. Lamprophyric dykes, which represent minor late-stage intrusives, are biotite-rich and usually occur in swarms. They largely postdate gold mineralisation. Some dykes are composed almost entirely of biotite and are classified as glimmerite (Tate 1995).

The structure in the DBS area is dominated by a west-northwest-trending, steeply easterly plunging anticline, which is isoclinally folded and overturned to the south (**Figure 71**). The Callie and Villa deposits lie on the axis of this fold, whereas the Triumph Hill and Dead Bullock Soak Ridge deposits are immediately adjacent to it. Superimposed on this structure is a northwest-trending system of folds and faults.

Prograde metamorphism reached greenschist facies and was followed by a retrograde phase, which produced a ubiquitous quartz-sericite-chlorite assemblage (Smith *et al* 1998). Retrogression was followed by a heating event of either metamorphic or hydrothermal origin. Morrison (1993) postulated that this heating event was driven by an igneous intrusion, which focused fluids into the S_5 foliation within the structural corridor and which introduced mineralisation.

Callie

Callie was discovered in 1991 and open-cut mining commenced in 1995, producing 1.2 Moz gold. A decline was then driven from the pit and currently the deposit is being mined by underground methods. On 31 December 2009, the probable resource included 10.4 Mt @ 4.43 g/t Au for 46.07 t Au; the inferred resource included 10.7 Mt @ 5.52 g/t Au for 59.06 t Au (Newmont Mining Corporation Announcement to Canadian Stock Exchange, 27/01/2009). Drilling indicates that significant mineralisation extends below 1000 m.

In comparison to other deposits, the mineralisation at Callie is hosted in the lower part of the Dead Bullock Formation within the 'Lower Blake beds' and 'Callie laminated beds'. The strata is folded along east-plunging

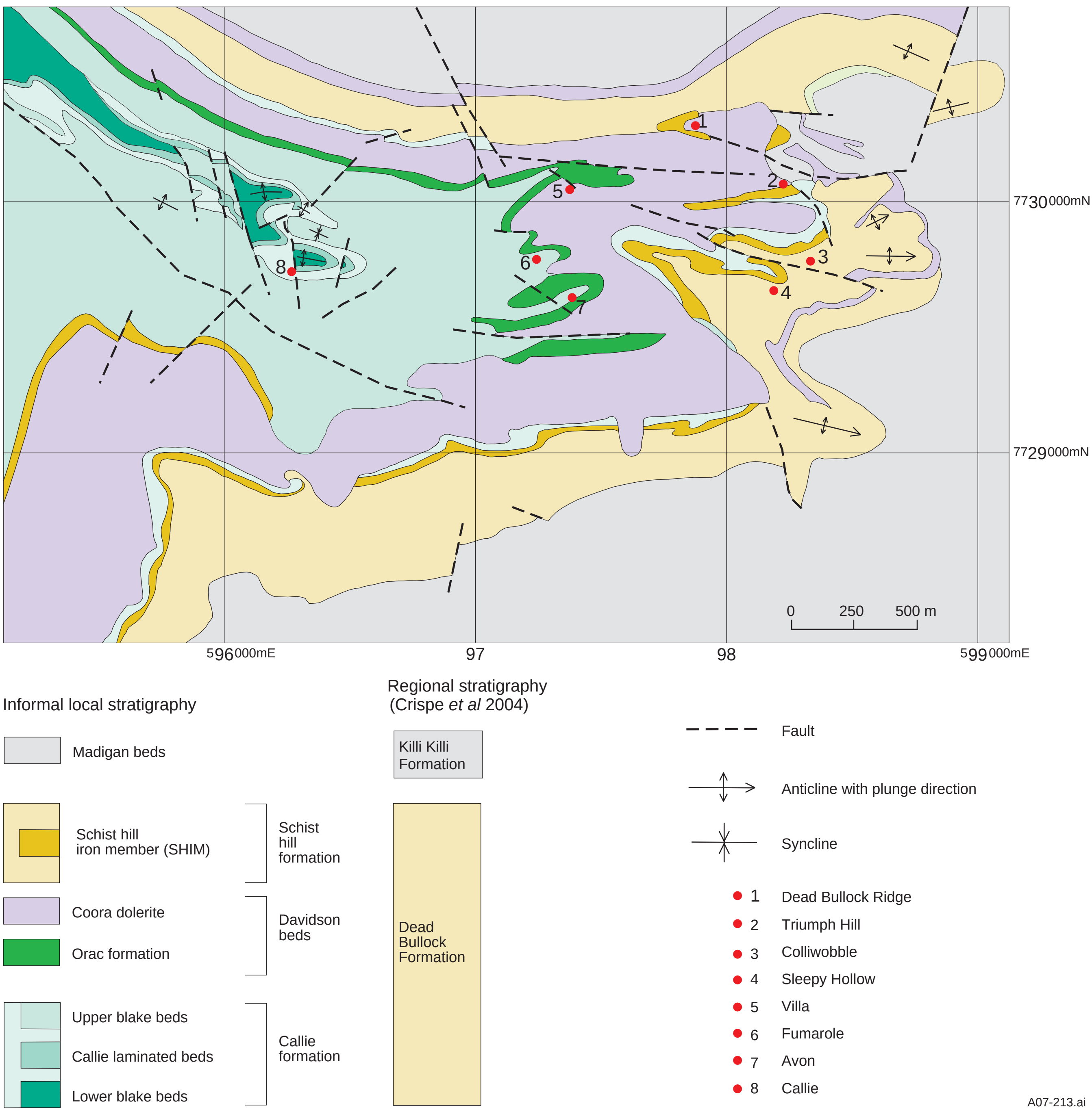

Figure 71. Geology and deposits of DBS goldfield.

Figure 72. (**a**) Dead Bullock Soak goldfield looking east. (**b**) Callie mine open cut.

REGIONAL STRATIGRAPHY [Vandenberg and Crispe (in prep)]	**INFORMAL MINE STRATIGRAPHY** (Normandy NFM Ltd, unpublished reports)		
Killi Killi Formation		Madigan beds (turbiditic greywacke)	
		Swarms of lamprophyre and glimmerite dykes	
Dead Bullock Formation	Davidson beds (siltstone, carbonaceous siltstone, chert, minor sandstone)	Seldom seen schist	Schist hill formation (BIF-hosted mineralisation)
		Manganiferous chert	
		Colgate schist	
		Schist hill iron member (SHIM)	
		Dead bullock member	
		Coora dolerite	
		Upper orac schist	Orac formation (vein-hosted mineralisation)
		Upper orac chert	
		Middle orac schist	
		Lower orac chert	
	Blake beds (interbedded siltstone, carbonaceous siltstone and chert	Upper blake beds	Callie formation (vein-hosted mineralisation at the Callie deposit)
		Pip schist	
		Callie boudin chert	
		End it all dolerite	
		Magpie schist	
		Callie laminated beds	
		Lower blake beds	

Table 6. Stratigraphy of DBS goldfield.

D_3 anticlines, the '*Callie*' and '*Lantin anticlines*', which are separated by the '*Challanger syncline*', and which have been refolded by subsequent deformations (**Figure 73**). Mineralised veins and stringers are confined to a northeast-trending zone cutting the 'Callie anticline' that is known as the 'vein' or 'structural corridor'.

Wygralak *et al* (2005) identified four stages of veining at Callie (**Figure 74**):

- Pre-mineralisation (D_1), bedding-parallel, 5–20 mm thick, extensively folded and boudinaged quartz veins and saddle reefs without alteration selvages.
- Syn-mineralisation (D_5), auriferous, sheeted quartz veins occurring in the structural corridor. These are composed of subhedral quartz and feldspar with accessory epidote, tourmaline, biotite and amphibole. The veins were introduced early in D_5, but were recrystallised and developed weak alteration selvages during late D_5.
- Post-mineralisation (D_6) veins of buck quartz with ankerite, pyrite, chalcopyrite and galena. These include gash quartz veins in dolerite.
- Late post-mineralisation (D_{6+}) ankerite and calcite veins.

Arsenopyrite, the main sulfide, is present in the wallrock along the edge of the auriferous quartz veins, but is absent from the veins themselves. Other sulfides of the gold-stage assemblage include minor pyrite, chalcopyrite and pyrrhotite. The amount of pyrrhotite increases with depth. The main gangue mineral is quartz. Gold-bearing mineral assemblages also include chlorite and amphibole. The highest-grade ore zones are found in well laminated graphite-free rocks, where the laminations intersect quartz veins at high angles.

The alteration assemblage in the auriferous veins consists of aluminium-rich amphibole, chlorite, sericite and biotite, and changes with depth. At upper levels, it is characterised by the presence of calcite, chlorite, silica and pyrite. At the mid-depth level, the assemblage contains chlorite, titanite and rutile. At lower levels, biotite, ilmenite, epidote and pyrrhotite are noted (Wygralak *et al* 2005). Alteration assemblages of non-auriferous veins have not been not studied in detail.

Auriferous veins are concentrated in the D_5 'vein corridor' of sheeted quartz veins striking 070° and dipping 070° south-southeast (**Figures 74a**, **b**). Most mineralisation is within the 'Callie laminated beds', but all other units within the 'vein corridor', except for the dolerite, are also mineralised. The 'vein corridor' is 120 m wide and the Callie mineralisation extends for 1500 m along strike towards the Villa deposit (Smith *et al* 1998). Mineralised veins consist of recrystallised quartz and feldspar, with minor biotite and epidote. Most gold occurs as native metal in the size range 0.2–2.0 mm, but larger grains also occur (**Figure 75**).

Post-mineralisation D_6 faults divide the mineralisation into four shoots. The largest is the '*Wilson shoot*' followed by '*Central shoot*' and the smallest '*Western shoot*'. These collectively form the Callie deposit. The fourth shoot forms the separate Ghan deposit.

Callie mineralisation is controlled by a combination of structural, stratigraphic and geochemical factors (Wygralak *et al* 2005) including:

- D_5 veins, which are confined to the 'structural corridor'
- a high-angle intersection between quartz veins and bedding planes in anticlinal and synclinal hinges
- coarser-grained sedimentary rocks with increased porosity and permeability (eg 'Callie laminated beds', 'Magpie schist', top of 'Lower Blake beds')
- chlorite and chlorite-biotite alteration, which envelops the bulk of mineralisation, but diminishes in the biotite-amphibole zone
- decarbonisation of sedimentary rocks, visible as a distinctive banding.

Callie's remaining gold resource is currently calculated to a depth of 1000 m (**Figure 76**), but mineralisation still continues at depth[11].

Villa

This deposit has produced 1.6 Mt of ore averaging 3.1 g/t Au for 4.96 t gold and there are no remaining resources. Mineralisation at Villa is within the 'Orac formation' and three generations of quartz veins are known. These include D_1 bedding-parallel quartz veins, D_5 sheeted quartz veins and D_6 veins of buck quartz. Gold values are anomalous in all three generations of quartz veins, but ore-grade mineralisation is restricted to disseminations in cherty BIF units. The most heavily mineralised interval is a 3–5 m thick iron-rich unit locally known as the 'Lower orac chert'. Tate (1995) observed four generations of sulfides:

- Diagenetic pyrite.
- Arsenopyrite ± pyrrhotite + gold.
- Pyrite, pyrrhotite ± base metal sulfides + gold.
- Pyrite, sericite, carbonates ± base metal sulfides.

With the exception of the diagenetic pyrite, the sulfides appear to be of replacement origin. The third generation is the main gold-bearing stage, where gold is closely associated with arsenopyrite. Gold occurs as: (a) small (<0.1 mm) grains associated with pyrrhotite in fractures or on grain boundaries of arsenopyrite; (b) as 0.1–1 mm grains associated with amphibole-rich rocks; and (c) rarely in chloritic bands within quartz veins, with little or no sulfides.

Dead Bullock Ridge and Triumph Hill

Mineralisation at these deposits is hosted within the '*Schist hill iron member*' ('SHIM') and is associated with structurally controlled carbonate replacement. Quartz veins are much less abundant than at Callie or Villa and most of these are late buck quartz veins, which postdate

[11] At the time of completion of this report mineralisation was recognised to the depth of 1800 m and was still open at depth (Newmont Australia Ltd, personal communication September 2008).

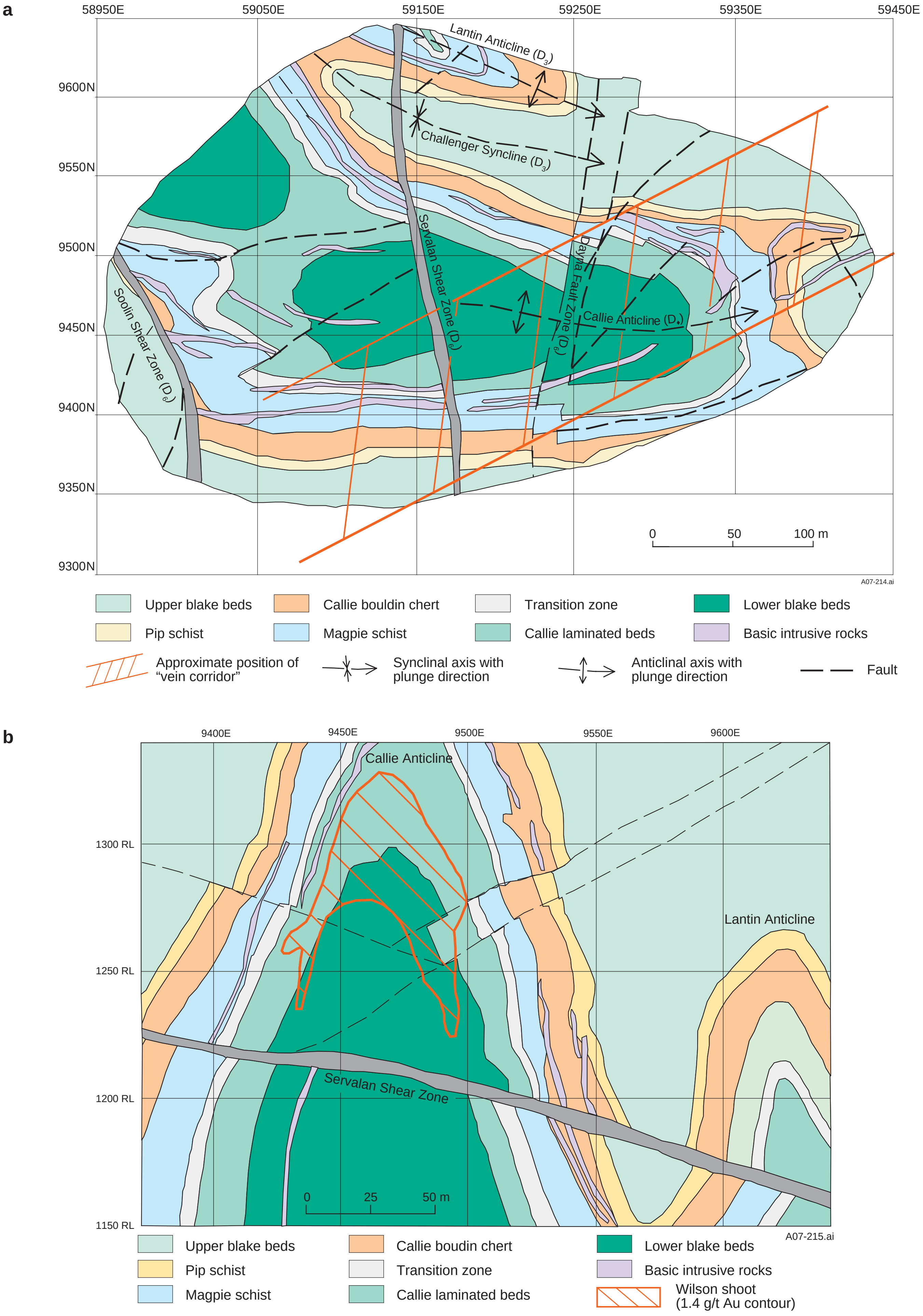

Figure 73. Callie deposit. (**a**) Plan and (**b**) cross-section (local grid; courtesy of Normandy NFM Ltd).

mineralisation (Wygralak *et al* 2005). Most common are scattered veins of chlorite, which have a distinct grey-green colour and are associated with mineralisation. Occurrences of visible gold within the 'SHIM' are always associated with such veins or their wallrock. They also contain arsenopyrite.

Although mineralisation at Triumph Hill is controlled by stratigraphy, some high-grade zones crosscut the 'SHIM'. The variable shape of high-grade zones indicates a poor correlation with stratigraphy at the ore-shoot scale. Significant mineralisation is also hosted by the 'Manganiferous chert'. Gold occurs in amphibole-chlorite rocks containing abundant pyrite ± arsenopyrite, and shows a strong association with arsenopyrite. The relation between gold and sulfides is identical to that at Villa, suggesting the same timing in both 'Orac formation'-hosted and 'SHIM'-hosted deposits.

Other deposits

The DBS goldfield also contains several smaller deposits. *Fumarole* is hosted by the 'Orac formation', and is of similar style to Villa, although much smaller and of lower grade. The Fumarole orebody is restricted to two chert horizons in a steeply dipping open fold. The best ore intersections are located in east-plunging, dilatant anticlinal and synclinal

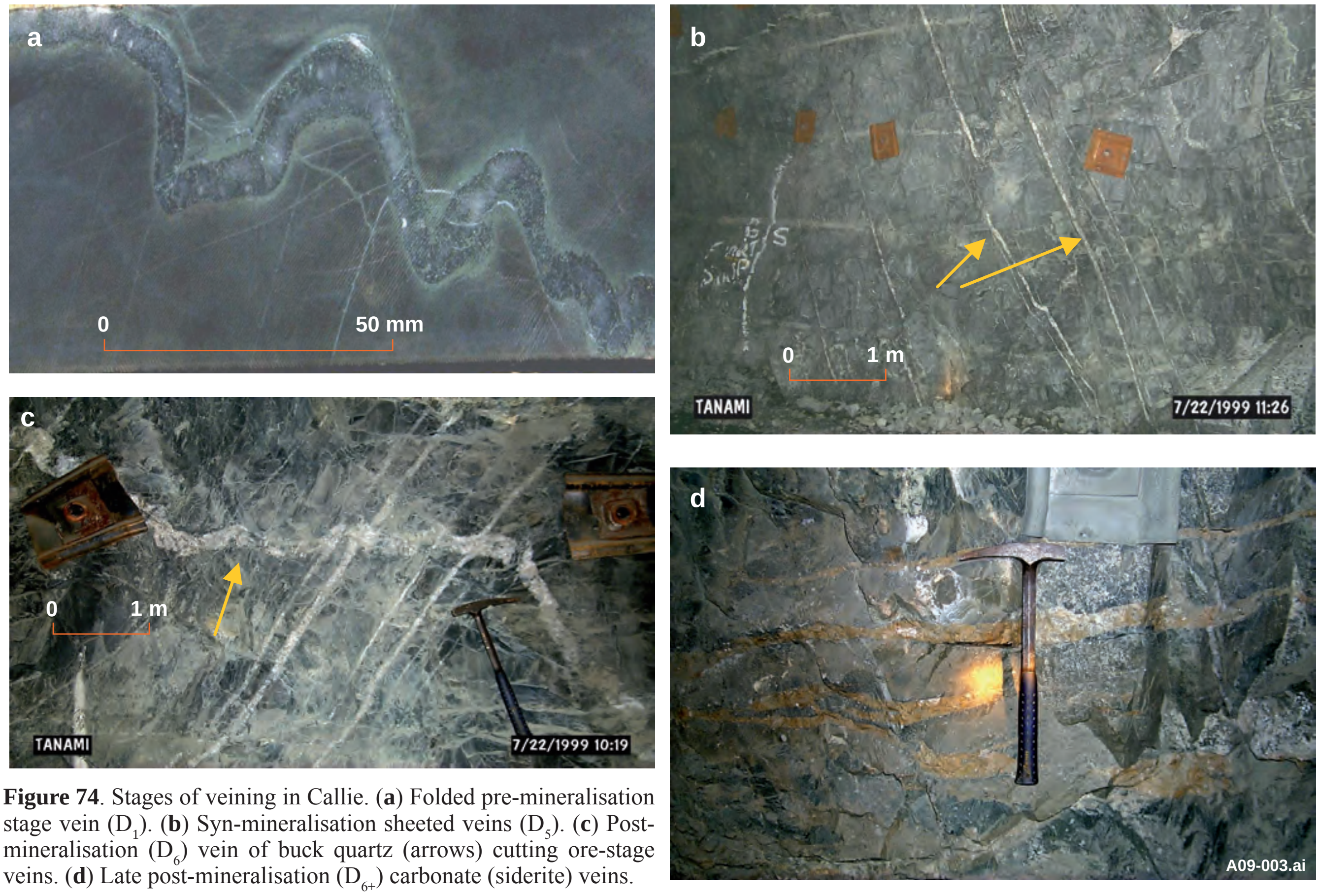

Figure 74. Stages of veining in Callie. (**a**) Folded pre-mineralisation stage vein (D_1). (**b**) Syn-mineralisation sheeted veins (D_5). (**c**) Post-mineralisation (D_6) vein of buck quartz (arrows) cutting ore-stage veins. (**d**) Late post-mineralisation (D_{6+}) carbonate (siderite) veins.

Figure 75. Callie. Native gold in ore-stage quartz vein.

hinges (Lovett *et al* 1993). The *Colliwobble* deposit is a geological extension of the Triumph Hill deposit and the *Ghan* orebody is a near-surface extension of the Callie mineralisation. Finally, the *Avon* and *Sleepy Hollow* orebodies represent small lower-grade BIF-hosted gold deposits.

The Granites goldfield

Mineralisation at The Granites goldfield is hosted by the Dead Bullock Formation, which in this area, comprises laminated to bedded chert, BIF, siltstone, schist, greywacke, basic volcanic rocks, and minor intermediate and acid volcanic rocks (Mayer (1990). The strata are steeply dipping and strongly folded, with superimposed, later open folds. The mine succession is divided into the informally named '*Footwall schist*', '*Host unit*', and '*Hangingwall schist*'.

The '*Footwall schist*' succession is more than 125 m thick and consists of interbedded and lensoidal schists, intruded by The Granites Granite. It is considered to be the local equivalent of the informal 'Dead bullock member' in the DBS goldfield (Wygralak *et al* 2005). The main rock types include amphibole-biotite-albite±quartz±almandine schist, and andalusite-biotite±almandine schist. The principal amphibole species are hornblende and anthophyllite, with lesser cummingtonite, gedrite and actinolite. The 'Footwall schist' contains quartz and calc-silicate veins, which are more predominant towards the top 30 m of the unit. Disseminated chalcopyrite with minor pyrite and pyrrhotite constitute the main sulfides within the 'Footwall schist'. The gold content of the 'Footwall schist' is generally less than 0.1 ppm, except at the footwall lode in the East Bullakitchie deposit, where economic gold mineralisation is present. This lode consists of hornblende-cummingtonite-gedrite-albite±quartz±almandine schist, with occasional chert bands. The sulfide content of this lode is 3–5%, with pyrrhotite dominating.

The '*Host unit*' is 5–35 m thick and has been traced for a distance of about 9 km from Chapmans Hill to Ivy. It is correlated with the 'SHIM' in the DBS goldfield and is the main host to gold mineralisation. The following mineralogical facies have been identified in this unit: *silicate facies, silicate-sulfide facies, carbonate facies* and *oxide facies* (Mayer 1990).

The silicate and silicate-sulfide facies comprise banded hornblende-cummingtonite schist interbedded with hornblende-almandine schist with calc-silicate and chert bands. Sulfides are confined to the laminated amphibolite schist and include, in decreasing order of abundance: pyrrhotite, pyrite, arsenopyrite, and minor chalcopyrite, pentlandite, galena and sphalerite. Visible gold is present as clusters of particles along bedding planes within the amphibolite schist and chert.

The carbonate facies is present towards the top of the 'Host unit' and is well developed at East Bullakitchie. It consists principally of calcite with lesser dolomite and ferroan carbonates, quartz, diopside and grossular, and is interbedded with cummingtonite-hornblende schist and hornblende-almandine schist. Microcrystalline fluorapatite is present as thin concordant lenses. The carbonates are considered to be syngenetic or early epigenetic (pre-metamorphism) in origin (Mayer 1990). The Upper Lode at East Bullakitchie is contained within the carbonate facies.

The oxide facies comprises laminated hornblende and cummingtonite schist, with fine magnetite and ilmenite occurring in thin laminae. The amphibolite schist is interbedded with chert, apatite-quartz layers and clinopyroxene±calcite-pyrrhotite bands. The oxide facies is regionally anomalous in gold with occasional high-grade zones.

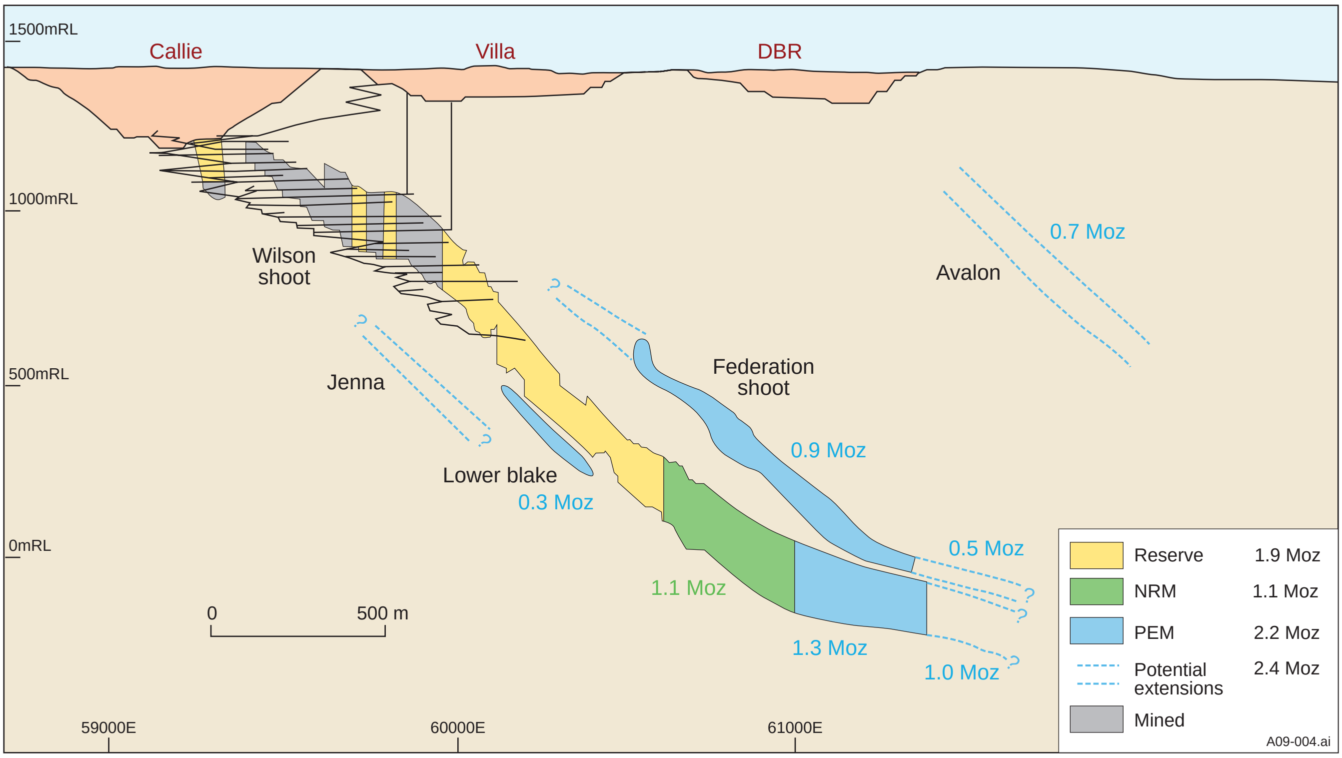

Figure 76. Cross-section of Callie deposit showing resource to depth of 1000 m, as at December 2005 (courtesy of Newmont Australia Ltd).

The '*Hangingwall schist*' comprises a more than 150 m-thick succession of fine-grained graphitic aluminosilicates and ferromagnesian schist, grading upward into quartz-biotite schist and metagreywacke. It is correlated with the 'colgate schist' in the Dead Bullock Soak goldfield. Some chert bands are also present, but they are thinner than in the 'host unit'. Pyrrhotite and pyrite are the main sulfides present and these may constitute more than 15% in the graphitic schist. Minor arsenopyrite is present locally.

Numerous dolerite intrusions with irregular outlines are present within the 'Hangingwall schist'. These intrusions are generally massive and non-foliated. Porphyritic andesite dykes, generally less than 3 m thick, have been intersected in drillholes.

Six deposits were identified in The Granites goldfield by North Flinders Mines, these are: *Bunkers Hill, Central Bullakitchie, East Bullakitchie, West Bullakitchie, Quorn* and *Shoe* (**Figure 77**). The individual orebodies are 2–8 m thick, and 50–600 m long. Some lodes have down-pitch extensions of at least 250 m and are open at depth. Average grades range from 1.5 g/t to 9.3 g/t Au. The lodes are stratabound within the 'Host unit' and are primarily confined to this interval. Silicate sulfide and carbonate facies are markedly better mineralised then the silicate or oxide facies. Some gold is remobilised into dilatant structures, formed during one or more episodes of folding (Mayer 1990). Gold occurs as free grains and ranges in size from less than a micron to several millimetres. It is of high purity and has a fineness of 940 gold and 50 silver.

Lithologically the succession at The Granites goldfield is similar to that of the Koolpin Formation in the PCO, although Purvis (1989a–c) has suggested a basaltic to andesitic origin for these rocks and Giles (1990) proposed a bimodal mafic and felsic source, with some input of iron oxides and silicates by exhalative activity during deposition. Lack of enrichment in siderophile elements (Mg, Ti, V, Ni, Sc, Co), depletion of lithophile elements (Na, K, Zr, Ce, Ba) and a significant iron content exceeding 15% within the 'Main host unit' all suggest that this rock package represents a chemically precipitated iron-rich sediment, and can be classified as BIF (Wygralak *et al* 2005).

The Granites goldfield experienced similar deformation events to those in the DBS goldfield. Structural studies of this area have been carried out by Majoribanks (1985), Valenta and Wall (1996), Ding (1990, 1993, 1994) and Vandenberg *et al* (2001).

Adams (1997) recognised four vein types in The Granites goldfield. These include quartz veins, calcite veins, quartz-calcite veins and calcite-quartz veins. The relationship of these veins to gold mineralisation is not clear, although Wygralak *et al* (2005) stated that most of the mineralisation is associated with D_5 veining, but all of the above types contain at least some gold. These veins have a weak alteration selvage of up to 10 mm to either side of the veins and again the relationship with gold mineralisation is ambiguous.

Pyrrhotite, arsenopyrite and loellingite are the main sulfides, followed by pyrite, chalcopyrite, marcasite and, rarely, galena. Gold occurs as separate grains, in arsenopyrite and, less frequently, in pyrrhotite and chalcopyrite. There are several generations of arsenopyrite, pyrrhotite and pyrite. Sulfides commonly concentrate in bedding-parallel schistosity.

Bullakitchie

East Bullakitchie is the largest and highest-grade deposit in The Granites goldfield (**Figure 78**). The deposit was mined by open-cut and underground methods by Normandy NFM. Four lodes were mined with grades averaging 7.8, 6.1, 7.5 and 8.5 g/t Au, respectively (Adams 1997). Mineralisation is within the 'Main host unit' and is associated with extensive carbonate veining. Fermio and Faulkner (1990) indicated that some carbonate in quartz-carbonate veins was probably derived from carbonate protolith rocks. Brinkat (1994) distinguished four categories of veins and mineral bands:

- Layer-parallel calcite banding, representing original carbonate layers.
- Early ptygmatic quartz veins associated with D_1.
- Layer-parallel quartz-calcite, calcite, calc-silicate and quartz veins (main ore stage) associated with D_3.
- Crosscutting quartz-calcite veins related to D_4 deformation.

Scrimgeour and Sandiford (1993) described three alteration zones enveloping layer-parallel calcite veins: (i) an outer zone characterised by the breakdown of biotite and formation of cummingtonite with excess quartz and plagioclase; (ii) a middle zone of cummingtonite, quartz, plagioclase, almandine and hornblende; and (iii) a proximal zone, where cummingtonite is consumed to produce hornblende, epidote and quartz. Near the vein edges, hornblende and quartz are substituted by clinopyroxene, garnet and plagioclase.

The lodes have comparatively low (3%) sulfides, comprising pyrrhotite (65–70%), pyrite and minor arsenopyrite, loellingite and chalcopyrite. Oxides constitute 4% of lodes, with ilmenite prevailing over magnetite.

Adams (1997) stated that most gold is in concordant quartz, quartz-calcite, calc-silicate and calcite veins associated with D_1–D_3, but Wygralak *et al* (2005) considered that the main controls on mineralisation are D_5 shear zones intersecting the entire goldfield and calcite veins carry only part of the mineralisation.

The *West Bullakitchie* deposit does not contain abundant calcite veining and has a considerably lower grade, of 3.1 g/t Au (Adams 1997) than the East Bullakitchie deposit. The 'Main host unit' there averages 15 m in thickness, but it rapidly thins with depth. It contains three lodes (A, B and C); the footwall lode and G Lode (**Figure 78**) are absent. Like East Bullakitchie, this deposit is characterised by comparatively low (<4%) sulfide content. It was mined by open-cut methods.

Shoe

The 'Main host unit' at Shoe is thinner than at Bullakitchie, being 8 m in the west and 20 m in the east (MacLennan 1989). This deposit was mined by Normandy NFM by open-cut and underground methods. Only the A Lode was mined underground. The width of the A Lode is in the range 3–3.5 m; with occasional swells to 5 m. Overall grades averaged 4.5 g/t Au.

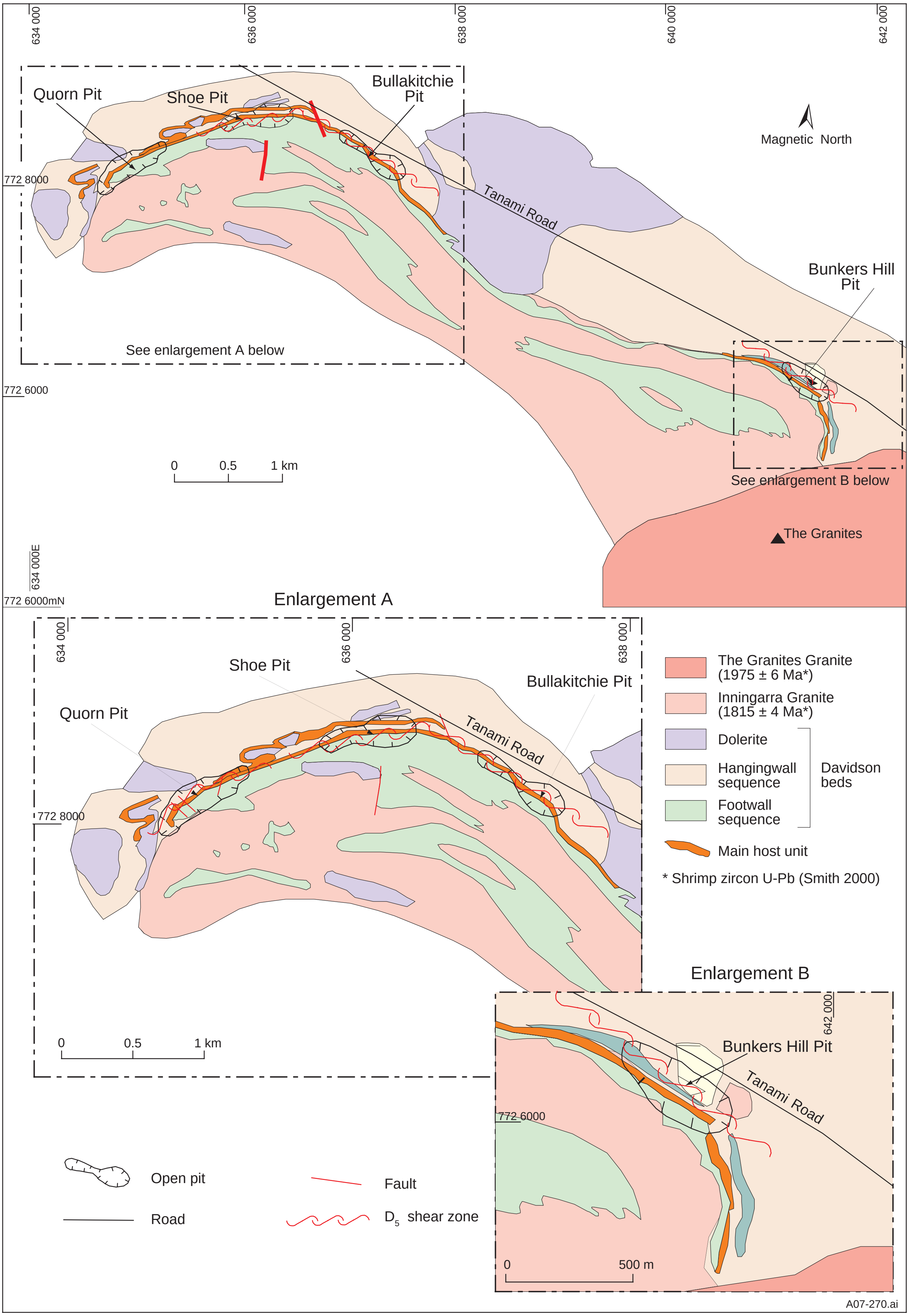

Figure 77. Regional geology of The Granites goldfield (based on Normandy NFM Ltd company map 1997).

The sulfide concentration within the 'Main host unit' averages 10%, with higher concentrations in amphibole-rich rocks. The main sulfides are pyrrhotite, arsenopyrite and loellingite, with lesser pyrite and rare chalcopyrite. The oxide content is low (2%), with magnetite more abundant than ilmenite. Quartz veins are dominant; calc-silicate and quartz-calcite veins are less common. The relationship of these veins to the gold mineralisation is ambiguous.

Quorn

The Quorn deposit is similar to Shoe, although lodes are thinner and more dispersed, reaching an average grade of 2.8 g/t Au (Adams 1997). All three lodes of the 'Main host unit' (A, B and C), as well as portions of the 'Footwall host unit', were mined by Normandy NFM in the pit. The former attains a thickness of 7 m, considerably greater than elsewhere in The Granites goldfield. Early and late dolerite dykes are present. The Granites Granite truncates the entire succession at the southwestern end of the pit.

The sulfide content of the 'Main host unit' lodes averages 7%, but locally, can be as high as 30%. Sulfides include pyrrhotite, arsenopyrite, loellingite, pyrite and minor chalcopyrite. Magnetite and ilmenite amount to about 3%. The sulfide content of the 'Footwall host unit' reaches 5%, being dominantly composed of pyrite and pyrrhotite, and with minor chalcopyrite. The highest gold values are associated with areas of high-density, arsenopyrite-bearing quartz veins.

Bunkers Hill

Bunkers Hill is the lowest-grade deposit (2.1 g/t Au) of The Granites goldfield. It is similar to Shoe and Quorn, but the lodes are contained within a 15–25 m thick 'Main host unit' and are abruptly truncated at shallow depths by The Granites Granite. Sulfide content reaches 5%, with the most common sulfides being pyrite and arsenopyrite (Scott 1993). The high pyrite/low arsenopyrite composition differs notably from that of Shoe and Quorn.

Tanami goldfield

The lodes at the Tanami goldfield are hosted by an alternating succession of basalt and mudstone with rare greywacke and chert belonging to the Mount Charles Formation. The deposits are located between two granite plutons, the Coomarie and Frankenia domes (**Figures 68** and **79**). Both of these granite bodies postdate the Mount Charles Formation and are expressed as pronounced gravity lows.

Gold occurs within clusters of quartz-carbonate veins, associated with sericite-pyrite alteration. The ore shoots range from 1–20 m in thickness, 20–300 m in length and 10–70 m in vertical extent. Higher gold grades occur adjacent to the ore shoot boundaries. Calcite, siderite and quartz are the main gangue minerals and pyrite is the main sulfide, comprising 5–20% of the veins. The ore bodies are oxidised down to a depth of about 60 m.

Most deposits are located within the 15 km long, northeast-trending Tanami goldfield (**Figure 79**). The deposits are grouped in four clusters, concentrated around the Hurricane, Carbine, Redback and Dogbolter areas (**Figure 80**). These clusters are separated by thick (>100 m), regolith-filled palaeovalleys. Two other clusters of deposits are located around the Jims Find and Pendragon areas.

In the Tanami goldfield, the Mount Charles Formation has been informally divided into 'Footwall', 'Mine' and 'Hangingwall' sequences (**Figures 81**, **82**). It is intruded by 1–3 m-thick mafic and felsic dykes. Zircon from a felsic dyke has been SHRIMP dated at 1824 ± 12 Ma (Smith 2001), indicating a close association with the

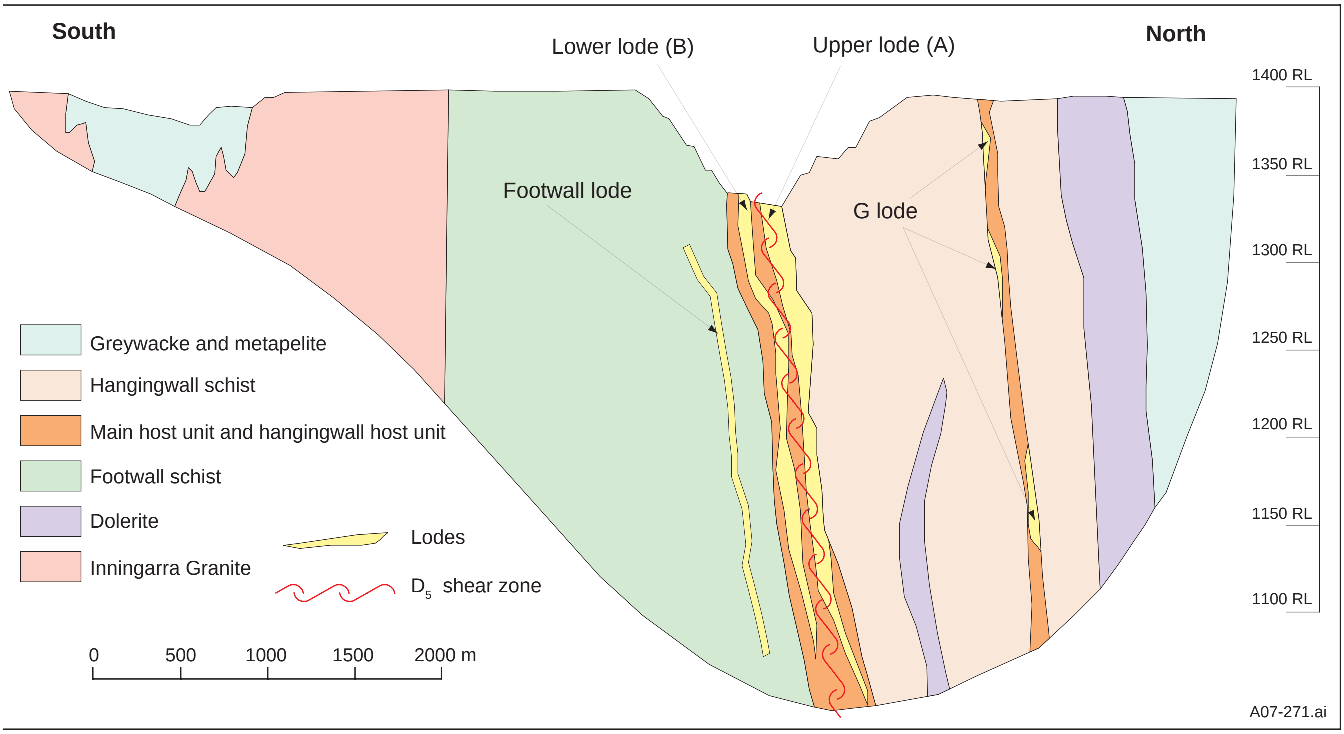

Figure 78. Cross-section of East Bullakitchie deposit (North Flinders Mines Ltd 1995).

granite plutons. The *'Footwall sequence'* is about 400 m thick and comprises basalt and interbedded sedimentary rocks. The *'Mine sequence'* begins with 100–150 m of purple-maroon siltstone and sandstone, locally known as the '*Harleys sediment*'. The overlying '*Redback basalt complex*' comprises 300–500 m of massive, pillow and breccia basalt, interspersed with 30 m-thick intervals of mudstone and sandstone. It is overlain by the 120–200 m-thick *'Hurricane sediment'*, composed of interbedded dark grey siltstone and sandstone. The base of this unit consists of 2–3 m of laminated carbonaceous and graphitic mudstone, locally known as the '*Pale sediment*'. The 'Hurricane sediment' is overlain by 85–130 m of '*Bouncer basalt*' comprising eight pillowed and massive flows, and an interval of autoclastic breccia. It also contains up to 6 m of interbedded laminated siltstone and sandstone. The *'Hangingwall sequence'* is at least 180 m thick and comprises interbedded siltstone and sandstone.

Four generations of faulting are known from the area (Tunks and Marsh 1998). Gold is associated with a complex array of D_5 strike-slip faults, striking 020° and 060° (± 10°). Displacement along individual faults is generally less than 5 m. Veins in these faults are complex and have resulted from repeated crack-seal events.

Five vein generations have been identified by Tunks (1996) and these include pre- and post-mineralised quartz, quartz-carbonate, quartz-sulfide and calcite-sulfide veins. Auriferous veins are of two types: (1) grey quartz±sericite±pyrite veins with chlorite, arsenopyrite, sphalerite and gold, which generally occurs as inclusions

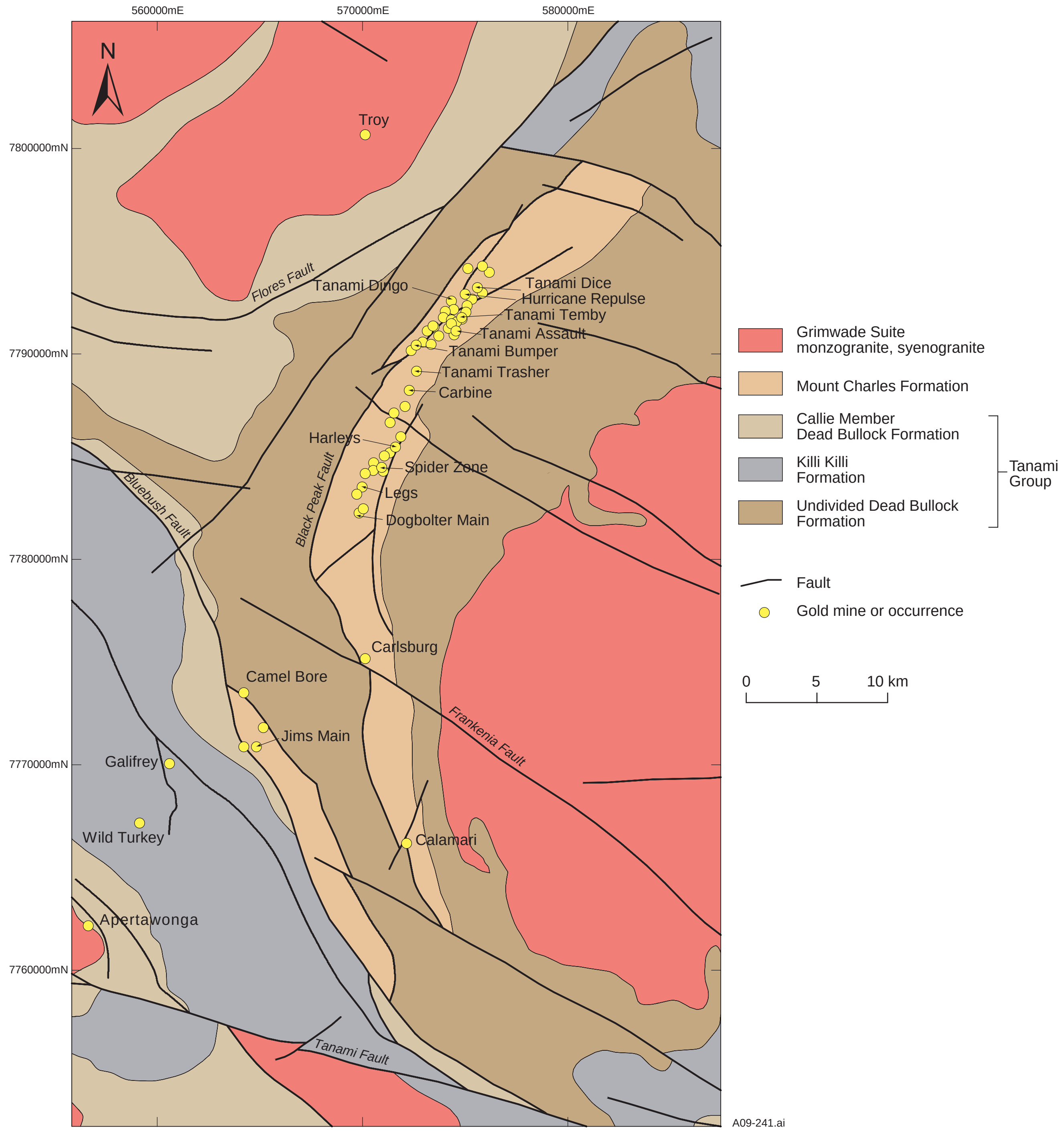

Figure 79. Geology and deposits of Tanami goldfield.

in pyrite and rarely within quartz; and (2) ankerite+white quartz±chalcopyrite±chlorite±gold±sericite±chlorite±calcite veins. The type 2 veins crosscut or occur in the center of the quartz-sericite-pyrite veins and, therefore, represent a younger generation. Ankerite occupies 40–95% of the vein infill. Chalcopyrite is the main sulfide and contains inclusions of gold. The majority of veins are within basalt and are either much narrower or missing from sediment beds occurring between flows.

Wygralak *et al* (2005) considered that the role of the 'Pale sediment' (one of the carbonaceous mudstone interbeds) was mainly to obstruct fluid flow and thereby localise gold veins near the 'Pale sediment'–basalt contact; the 'Pale sediment' also acted as fluid reductant. However, the preferential veining in the basalt flows in contrast mudstone may simply be a reflection of competency contrast.

Depending on the colour, and texture, Wygralak *et al* (2005) identified several varieties of quartz within these veins. Colours vary from light grey to white and textures include crustiform banding, comb textures, silicification and brecciation, indicating a shallow epizonal mineralisation (**Figure 83**). Rare examples of lattice-bladed replacement textures have been observed in drill cores, and ghost spheres[12] and flamboyant textures[13] in thin section.

The host basalt shows widespread propylitic alteration, characterised by ankerite, siderite and chlorite. Mass balance calculations by Tunks (1996) revealed that the basalt underwent 50 wt% depletion of Rb, K, Ba and Sr, 12.5 wt% depletion of Si and 5 wt% depletion of Fe, Ca, Mg and Na. LOI increased by ca 3 wt%, indicating the addition of water and CO_2. The net mass loss was ca 20% and rock volume decreased by ca 7%.

K-silicate alteration is confined to the vein fringes, extending up to 1 cm into the host rock. The altered zone is bleached and comprises sericite + quartz ± pyrite ± carbonates (ankerite and siderite), and minor chalcopyrite, arsenopyrite and chlorite. This alteration has resulted in the addition of K (0.6–1.2 wt%) and S (0.13–1.4 wt%). The depletion of Si (9.7–10.0 wt%), Fe (3.0–4.8 wt%), Ca

[12] Ghost spheres: quartz grains with cloudy spheres 0.1–1.0 mm in diameter, highlighted by distribution of impurities.
[13] Flamboyant textures: radial or 'flamboyant' extinction of individual quartz crystals with more or less rounded outline.

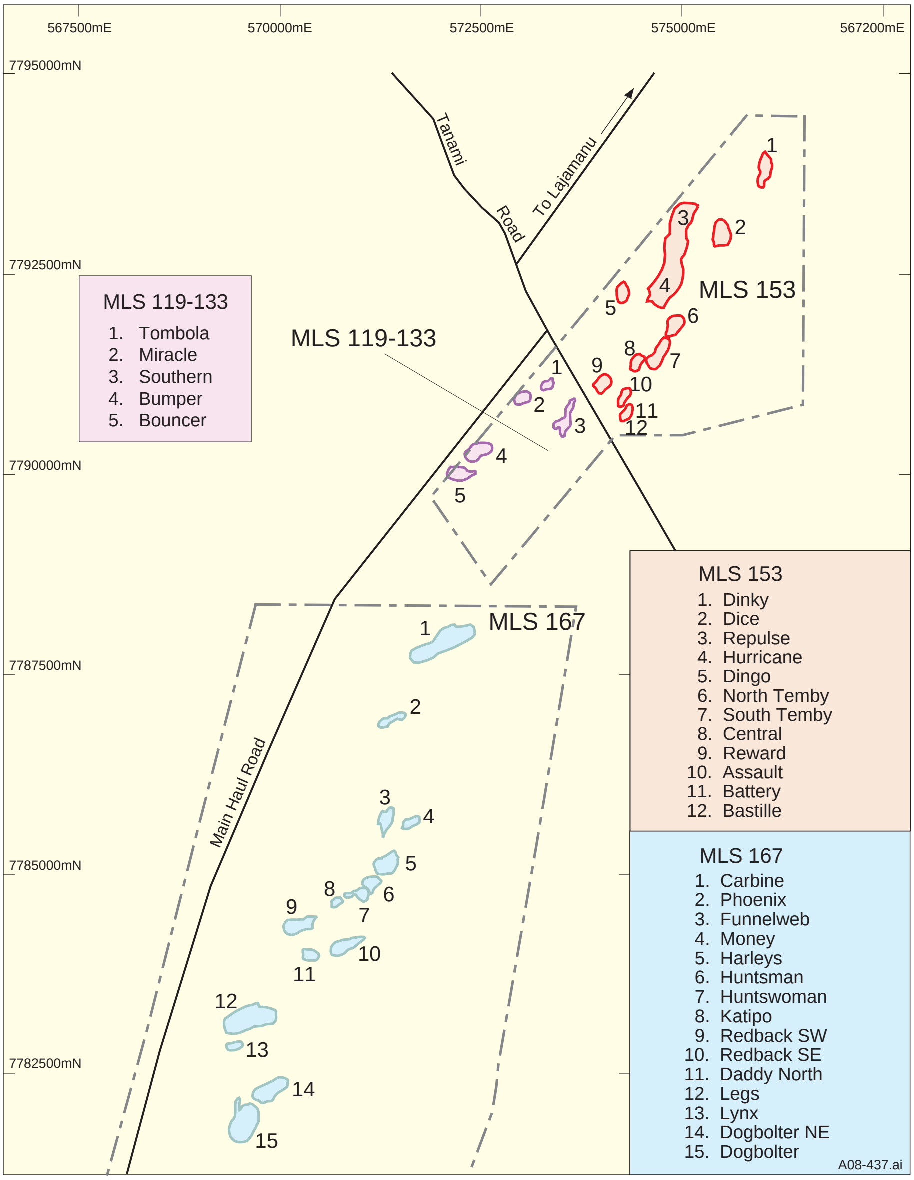

Figure 80. Distribution of deposits in main part of Tanami goldfield.

(1.6–1.8 wt%), Mg (1.9–2.4 wt%) and Na (2.8–2.9 wt%) has been calculated. LOI ranged from 5.9 to 6.5 wt%. The calculated mass loss was 32–36%, which translates into a 13–15% loss in rock volume (Tunks 1996).

There are 58 closely spaced gold occurrences in the Tanami goldfield and 40 of these have been mined by open-cut methods. These gold occurrences extend in a northeast-southwest direction for a total distance of about 38 km. The geological setting of some of the more significant mines, as summarised from Wygralak *et al* (2005), is given below.

Hurricane-Repulse

This is the largest mine within the Tanami goldfield and has produced just under half of the total production from

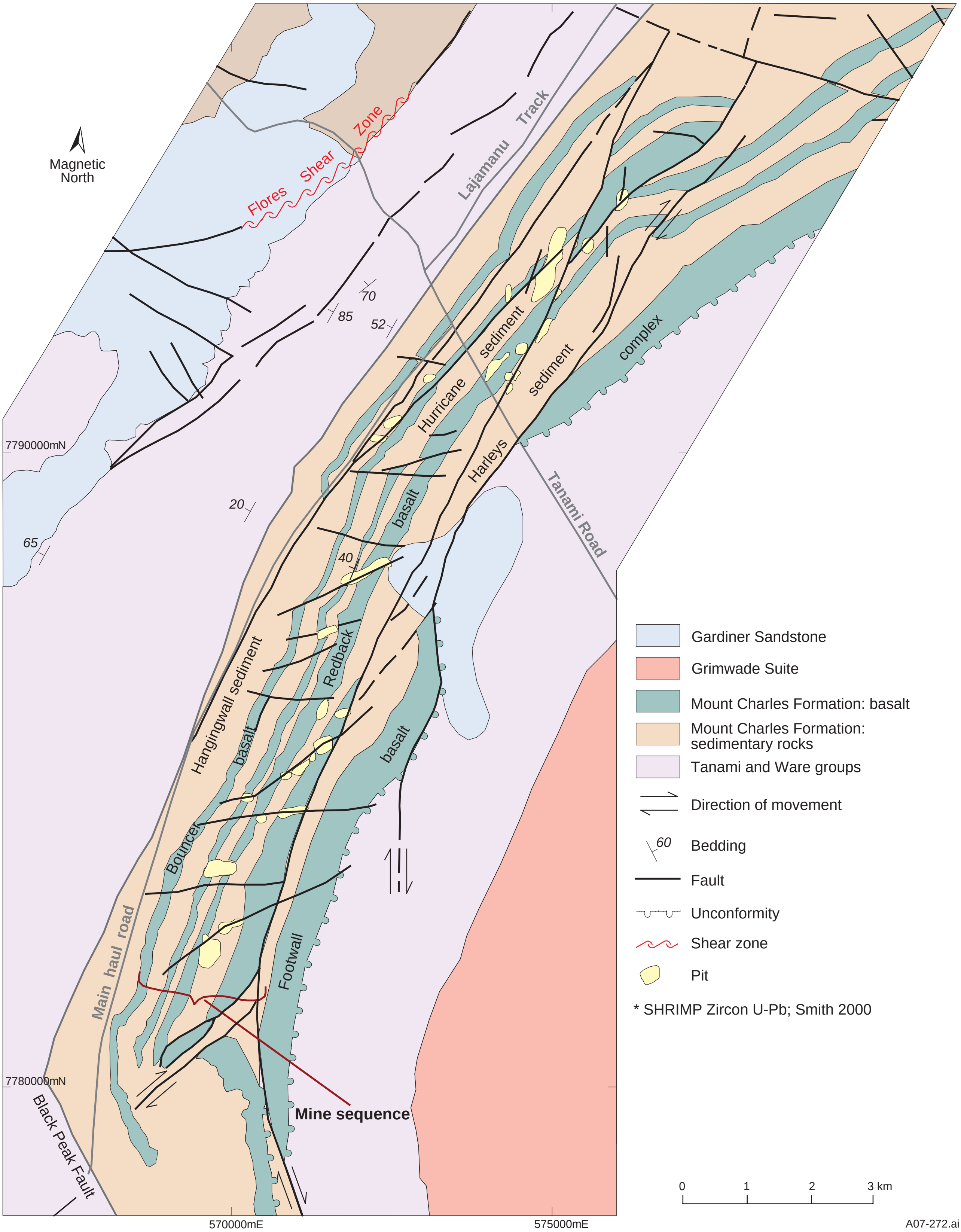

Figure 81. Regional geology of Tanami goldfield, showing local informal stratigraphy (courtesy of Otter Gold Mines Ltd).

the Tanami goldfield, amounting to about 13 t (0.42 Moz) of gold from three orebodies, Repulse, Gap and Hurricane (**Figures 84**, **85**)

The southernmost *Hurricane* orebody is within siltstone, and consists of three mineralised lodes controlled by the intersection of a shallow, east-southeast-dipping fault system and 45–50° east-southeast-dipping sedimentary rocks. Erratic copper mineralisation has been intersected in some drillholes, but this has no economic value.

The *Gap* orebody is located in the middle of the pit and forms a cigar-shaped shoot at the intersection between steep east-dipping D_5 quartz veins and the northwest-dipping 'Bouncer basalt'.

The north-plunging *Repulse* shoot is associated with two subparallel, steeply north-northeast-dipping D_5 faults localised almost entirely within brecciated 'Bouncer basalt' near its contact with the 'Hangingwall sequence'. It terminates to the south against a steep east-northeast-trending D_{6+} fault.

Southern

The southern pit is located about 2.5 km southwest of the Hurricane-Repulse pit. The host succession at this deposit is a continuation of that at Hurricane-Repulse. The 'pale sediment' at the contact of the 'Hurricane sediment' with the underlying, pillowed 'Redback basalt complex' is 4 m thick and composed of alternating light coloured and dark brown bands, within a 10–30 mm-thick mudstone unit (**Figure 86**). Northward, the mineralised zone dips west and closely follows the basalt–sedimentary rock contact. In the central part, mineralisation is controlled by a northeast-trending, east-dipping D_5 fault. Southward, the mineralisation terminates against an east-striking D_{6+} fault. Past production from this deposit is included with that of Hurricane-Repulse. The remaining total resource amounts to 0.42 Mt at 2.3 g/t Au (31 300 oz Au).

Redback SE and SW

These two adjacent deposits are located about 9.5 km southwest of the Hurricane-Repulse pit within interbedded siltstone and sandstone (locally known as the 'Harleys sediment') and pillow basalt of the 'Footwall basalt complex'. Mineralisation is within D_5 shears striking 060° and dipping 60–70° to the southeast. The favourable host is basalt, although some mineralisation is associated with greywacke and lithic sandstone (**Figure 87**).

Quartz lode and quartz stockwork mineralisation are both present. The former comprises 1 to 2 m wide zones of quartz breccia enveloped by pervasive haematite-chlorite alteration. Stockworks include 20 to 50 cm thick zones of irregular quartz-haematite veins at approximately meter intervals. Both types contain disseminated pyrite and chlorite in quartz veins and wallrock.

Past production from these two deposits is included with that of Hurricane-Repulse. The remaining total resource amounts to 97 kt at 5.25 g/t Au (16 400 oz Au) and 142 kt at 2.9 g/t Au (13 300 oz Au) for Redback SE and Redback SW respectively.

Carbine

The Carbine pit is located about 6.5 km southwest of Hurricane-Repulse pit and has produced 1.01 Mt ore averaging 2.7 g/t Au for 89 000 oz Au. The host succession consists of 'Redback basalt complex' and overlying 'Hurricane sediment', separated by a 4 m thick 'pale sediment' mudstone (**Figure 88**). To the north, the 'Redback basalt complex' is unconformably overlain by the Gardiner Sandstone (**Figure 89**). The mineralised zone is 14 m thick and follows a reverse D_5 fault, striking 060° and dipping 70° to the southeast. It is offset by later (late D_5?) subsidiary faults, which segregate the orebody into three shoots displaced by 60–80 m.

The highest grades are at the intersection of the main fault with subsidiary faults within basalt. At the northern end of the pit, the main fault has a reverse sinistral direction of movement. The ore zone follows this structure, but mineralisation occurs only in basalt. This same fault shows late reactivation by thrusting the Gardiner Sandstone against 'Redback basalt complex'.

The main gold-bearing minerals are pyrite and minor arsenopyrite. Gold in these minerals occurs as inclusions. Separate grains of native gold also occur. Late chalcopyrite does not carry gold. The main gangue minerals are quartz, sericite, chlorite, iron oxides and carbonates. Mineralisation extends at least to 400 m depth.

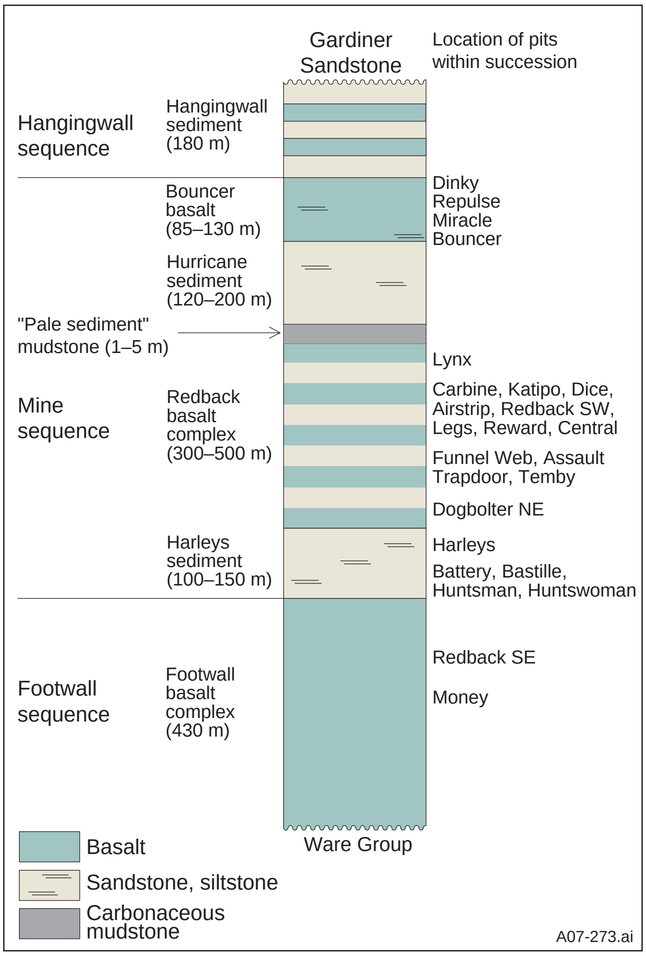

Figure 82. Stratigraphic column showing local informal stratigraphy of Tanami goldfield (courtesy of Otter Gold Mines Ltd).

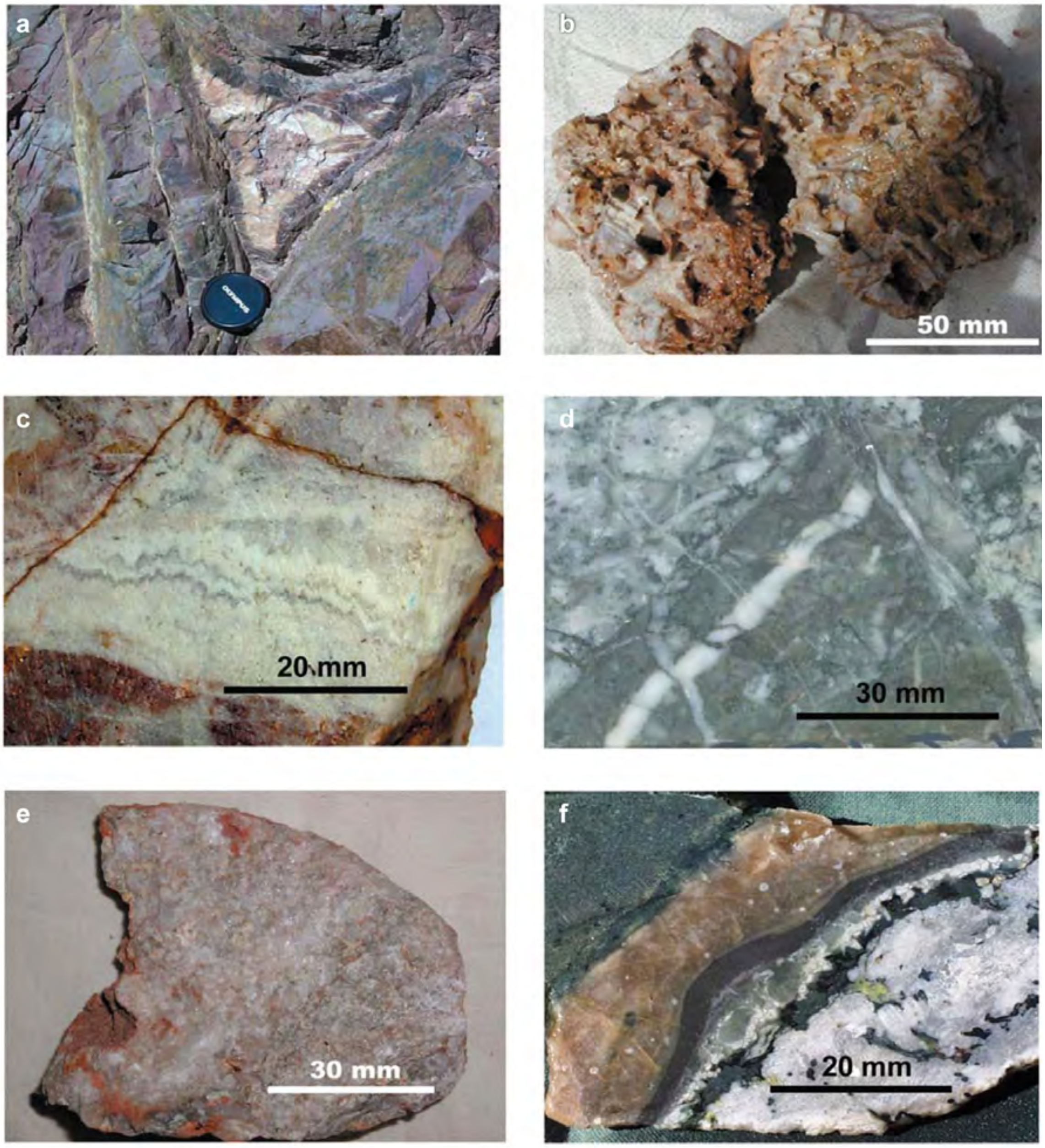

Figure 83. Tanami goldfield: types of quartz. (**a**) Triple point quartz. Lens cap is 50 mm in diameter. (**b**) Hollowed quartz after removal of carbonates. (**c**) Comb texture quartz. (**d**) Light grey and white ore-stage quartz. (**e**) Saccharoidal quartz. (**f**) Chalcedonic quartz.

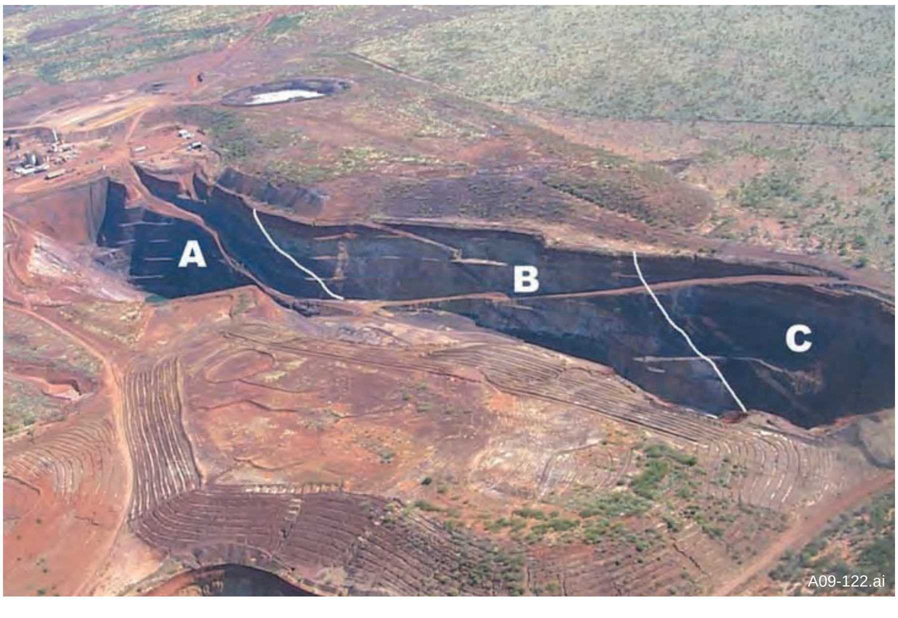

Figure 84. Aerial view of Hurricane-Repulse pit, looking southwest. (**a**) 'Hurricane sediment'. (**b**) 'Bouncer basalt'. (**c**) 'Hangingwall sequence'.

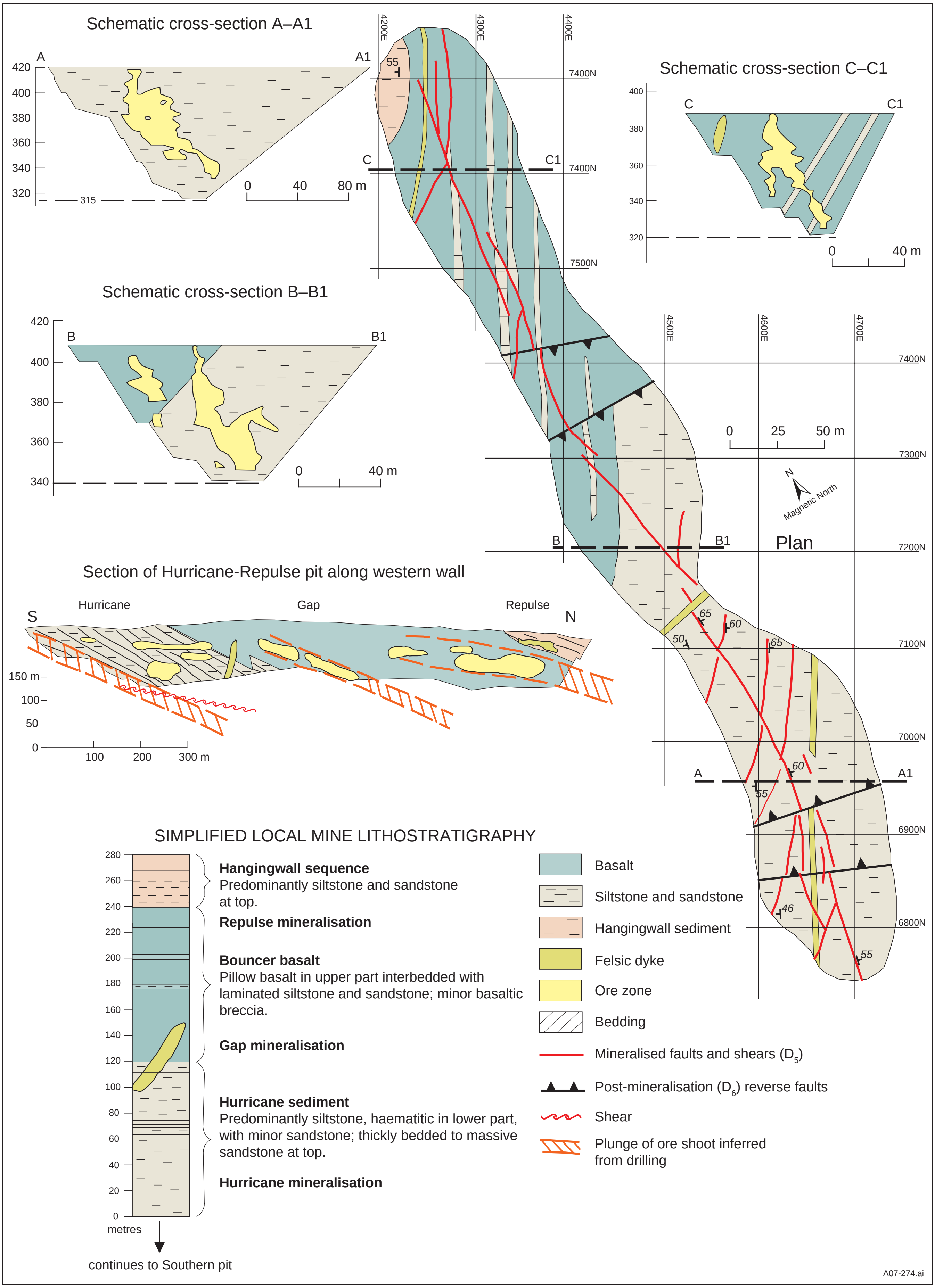

Figure 85. Plan and cross-sections of Hurricane–Repulse deposit. Grid coordinates refer to local mine grid (courtesy Otter Gold Mines Ltd).

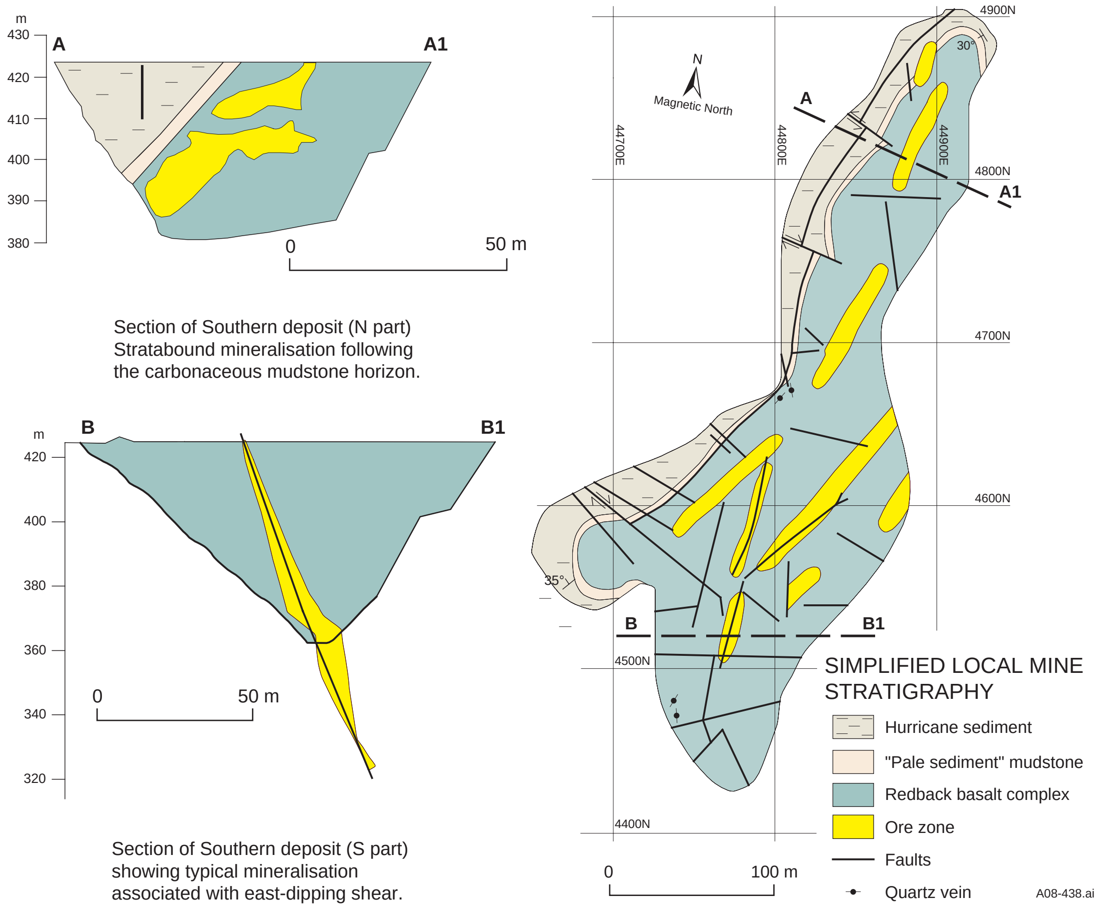

Figure 86. Plan and cross-sections of Southern deposit. Grid coordinates refer to local mine grid (courtesy Otter Gold Mines Ltd).

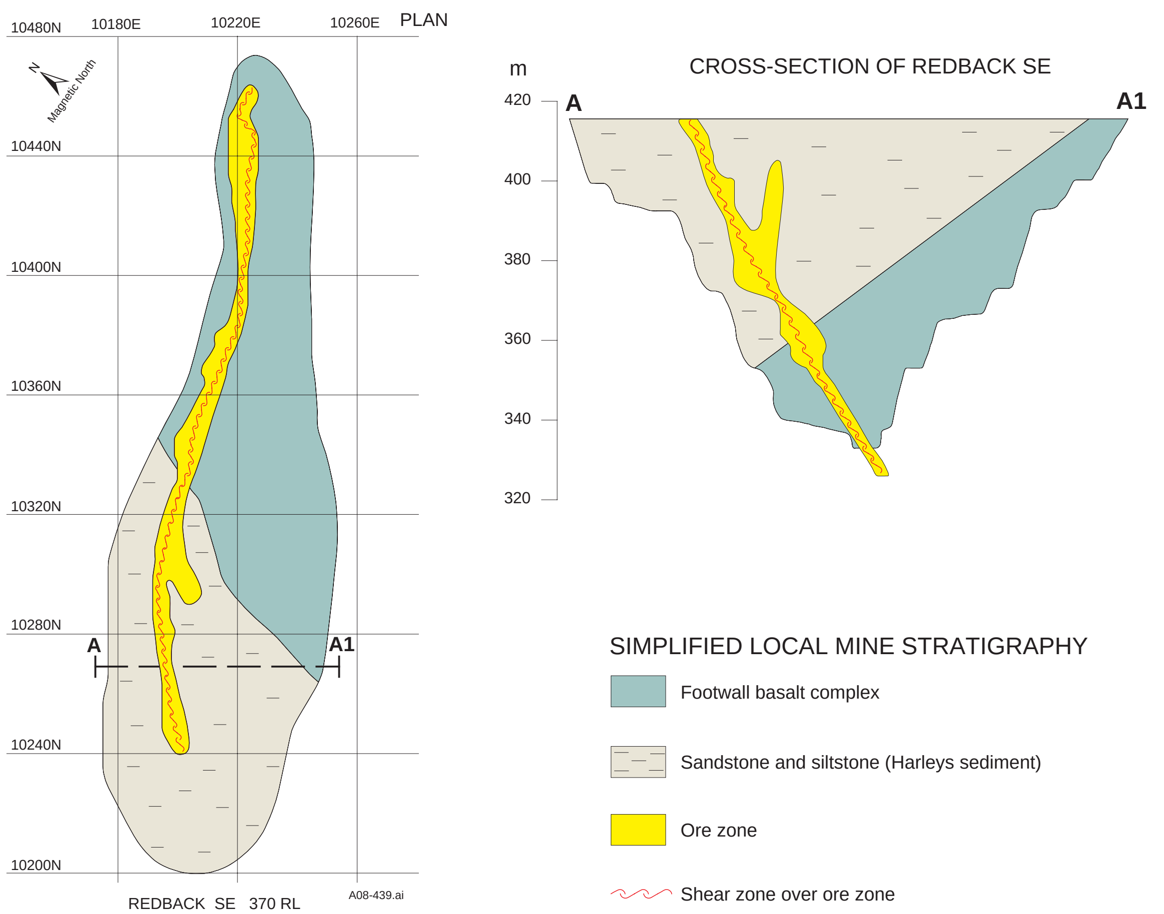

Figure 87. Plan and cross-sections of Redback deposit. Grid coordinates refer to local mine grid (courtesy Otter Gold Mines Ltd).

Legs

The Legs pit is located 11.4 km southwest of Hurricane-Repulse and has produced 1.77 Mt @ 3.05 g/t Au for 174 000 oz Au. Mineralisation is mostly in basalt, but also extends into the 'Hurricane sediment' in the southern end of the pit (**Figure 90**). The lodes follow two parallel, 060°-striking, southeast-dipping D_5 faults, which extend for approximately 360 m. At the southern end of the pit, there is a zone of dilation associated with the convergence of the 060° structures and a subsidiary 020° mineralised structure. The main mineralised structure terminates against a crosscutting D_6 fault. D_6 movement has also led to displacement of the main orebody at the contact between the 'Redback basalt complex' and the 'Hurricane sediment'.

Dogbolter

Dogbolter pit is located 11.5 km southwest of Hurricane-Repulse. Mineralisation is within basalt and the underlying 'Harleys sediment' and is associated with a major D_5 shear striking 020° and dipping steeply east. The shear contains a 3 m-wide zone of quartz veins and is intersected by second-order shears striking 060° (**Figure 91**). The highest-grade mineralisation occurs at the intersections of these two sets of shears. Some mineralisation also occurs in wallrocks adjacent to the main shear. The footwall mineralisation is best developed in basalt near the contact with the 'Harleys sediment'. In both cases, gold occurs in selectively mineralised, steeply dipping, massive quartz veins and stockworks. Ore shoots are enveloped by zones of silicification and haematitic alteration. Dogbolter contains a larger proportion of free gold than the other Tanami deposits. Some gold is also associated with pyrite and pyrrhotite. Past production from this deposit is included with that of Hurricane-Repulse.

Jims Find

This deposit is located about 20 km southwest of Hurricane-Repulse and comprises three pits (Jims Central, Jims Main,

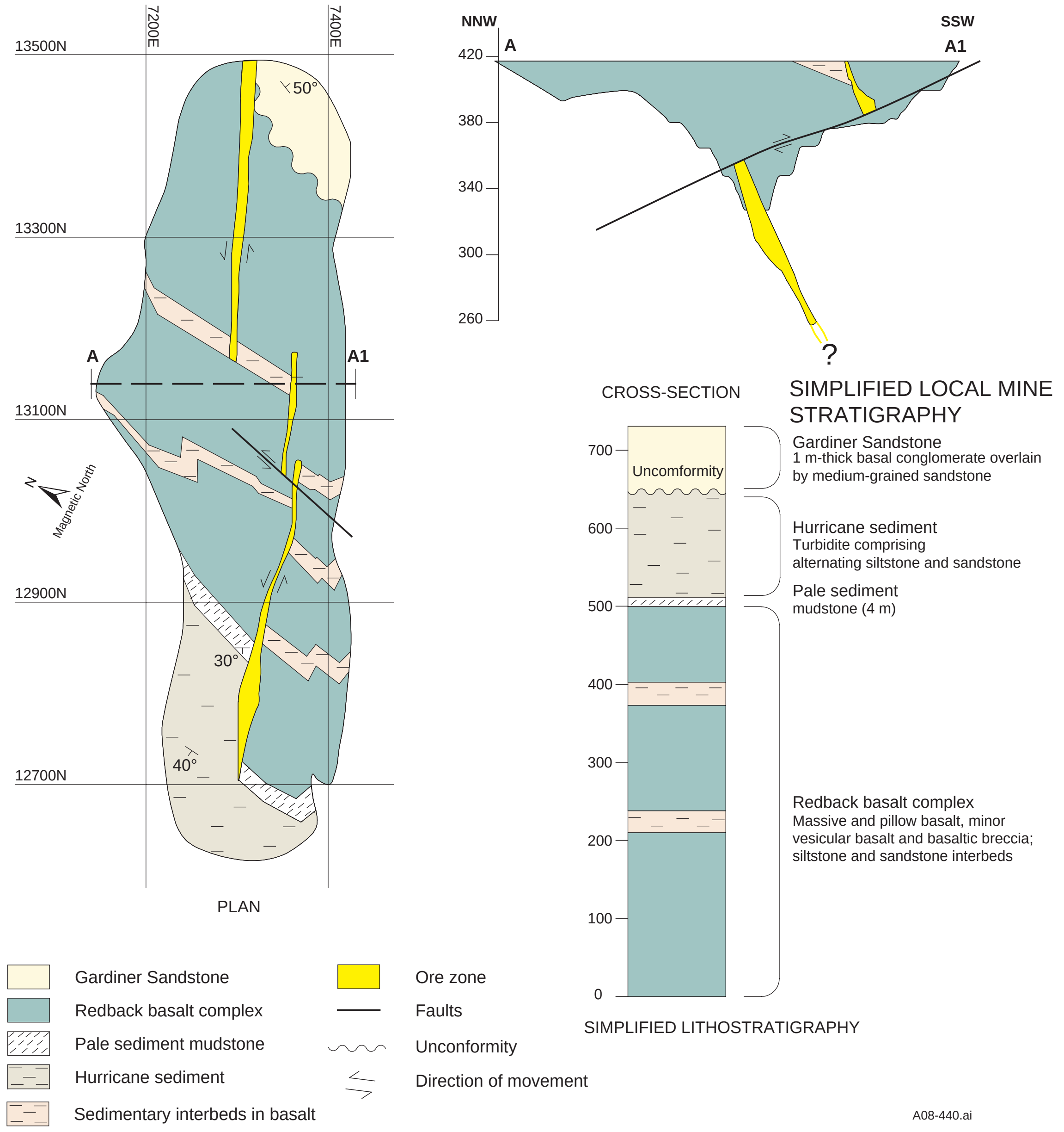

Figure 88. Plan and cross-section of Carbine deposit. Grid coordinates refer to local mine grid (courtesy Otter Gold Mines Ltd).

Figure 89. Carbine open pit. Unconformable contact (highlighted) between the 'Redback basalt complex' (below) and Gardiner Sandstone.

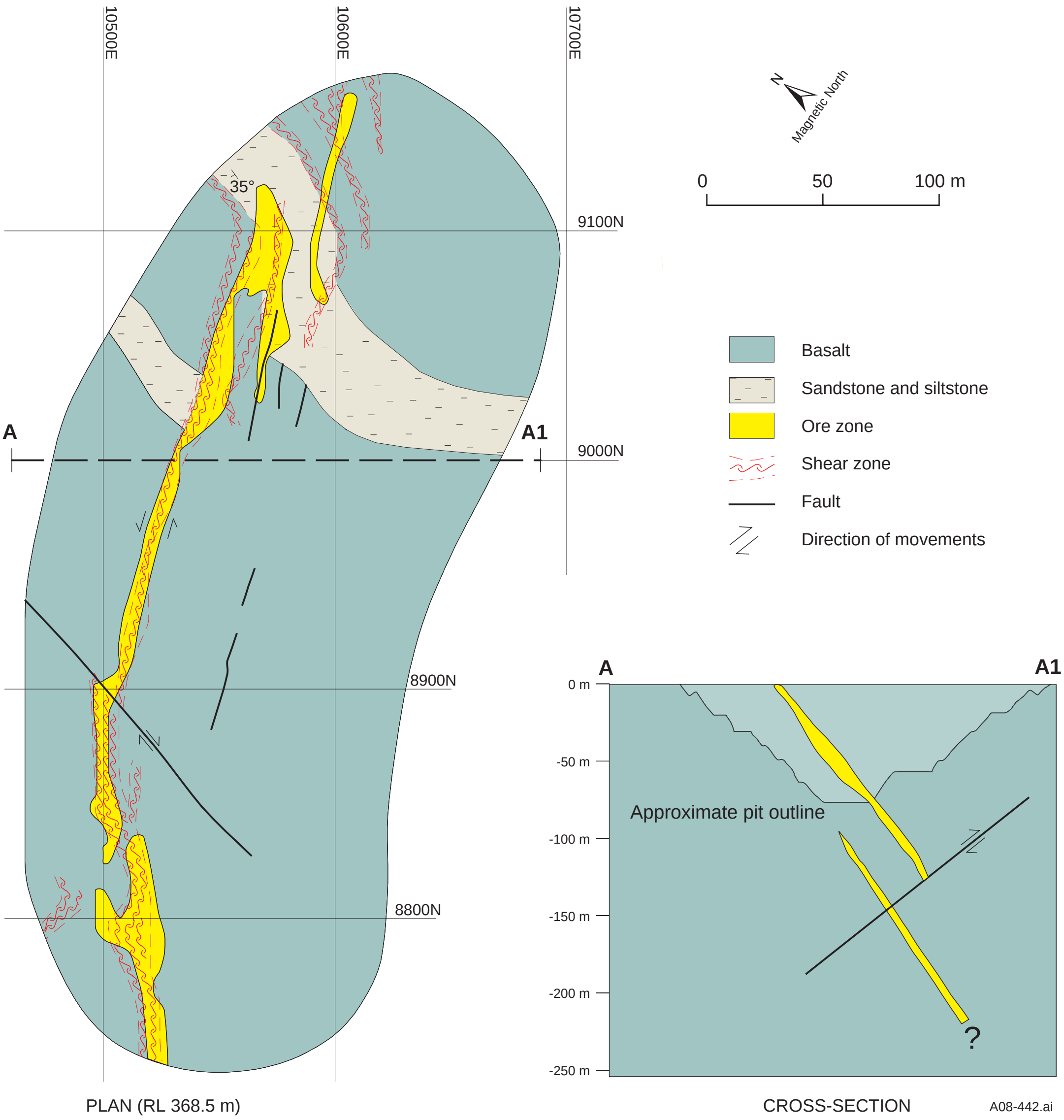

Figure 90. Plan and cross-section of Legs deposit. Grid coordinates refer to local mine grid (courtesy Otter Gold Mines Ltd).

and Jims West), located on the crest of a northwest-trending, doubly plunging domical structure, developed as a result of interference between tight northwest-trending D_5 folds and later, broad west-southwest-trending D_6 deformation. The host rock comprises pillow basalt with numerous interflow mudstone, siltstone and sandstone units. Mineralisation follows an F_5, north-trending, 70–80° west-dipping shear (**Figure 92**). Complex shearing and faulting has disrupted the original structure and created zones of dilation with better gold grades. The shear zone is silicified and enveloped by haematitic alteration. At the southern end of the pit, the mineralised zone is deflected by a siltstone unit striking northwest and dipping 70° to the northeast. The total production from Jims Main was 1.6 Mt of ore at 2.71 g/t Au for 139 420 oz Au. The main gold-bearing mineral is pyrite, which occurs in quartz veins or as a fine dissemination in basalt.

Other deposits

A number of occurrences are located outside the three goldfield regions discussed earlier. This section provides a summary of some of the more significant deposits. Most of these are within Au-quartz veins. The Minotaur deposit has similarities with deposits in The Granites goldfield.

The *Groundrush mine* is located 100 km north-northwest of The Granites goldfield. It originally had a total resource 3.93 Mt at 5.6 g/t Au (Normandy NFM 2000). This deposit was mined by open-pit methods between 2001 and 2004. The orebody is within a 90–160 m-thick foliated dolerite sill intruding metagreywacke of the Killi Killi Formation (**Figure 93**). Mineralisation is in lenticular anastomosing zones of north-northeast-trending quartz veins dipping 70–80° west and is associated with chloritic alteration.

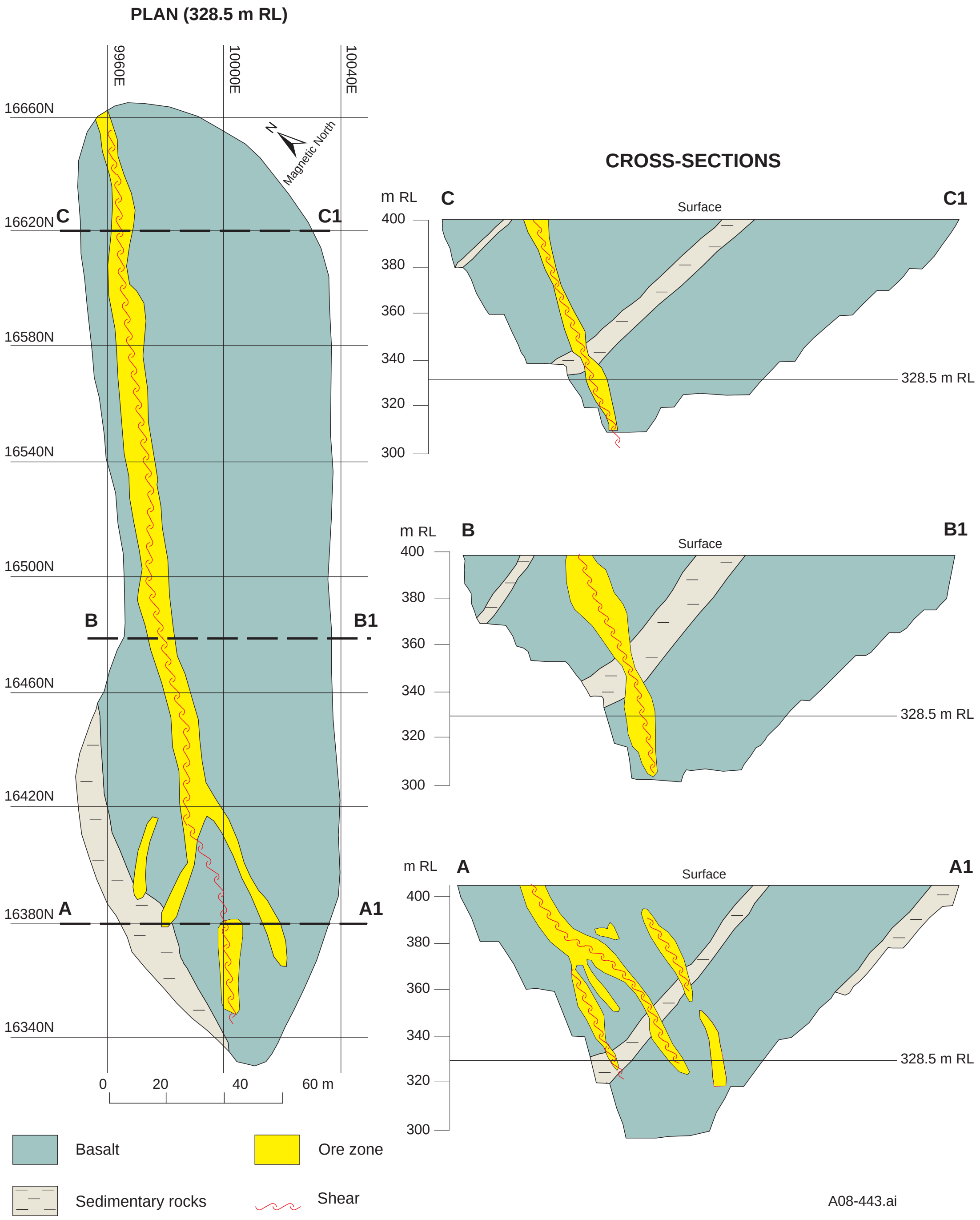

Figure 91. Plan and cross-sections of Dogbolter deposit, after Henderson et al (1995). Grid coordinates refer to local mine grid.

Mineralised lodes are 10–30 m wide and have gold grades of 3–10 g/t. Gold occurs as free metal or is associated with arsenopyrite and, to a lesser extent, with pyrite and pyrrhotite. Mineralisation continues over a strike length of 1.1 km, with intersections in drillholes to 140 m below surface. The orebody is open at depth.

The *Bonsai*, *Beaver Creek* and *Banjo* deposits are located along the southwestern margin of the Coomarie Dome, about 33 km west of the Hurricane-Repulse mine. Mineralisation is within basalt, but is also within sedimentary interbeds. It extends for over 1.5 km, but the orientations of the ore zones in each of the three deposits differ (**Figure 94**): at Bonsai, the ore zone strikes 110°; at Banjo, it strikes 135°; and at Beaver Creek the strike is 000–040°. Rocks are metamorphosed to greenschist facies, with superimposed amphibolite facies assemblages

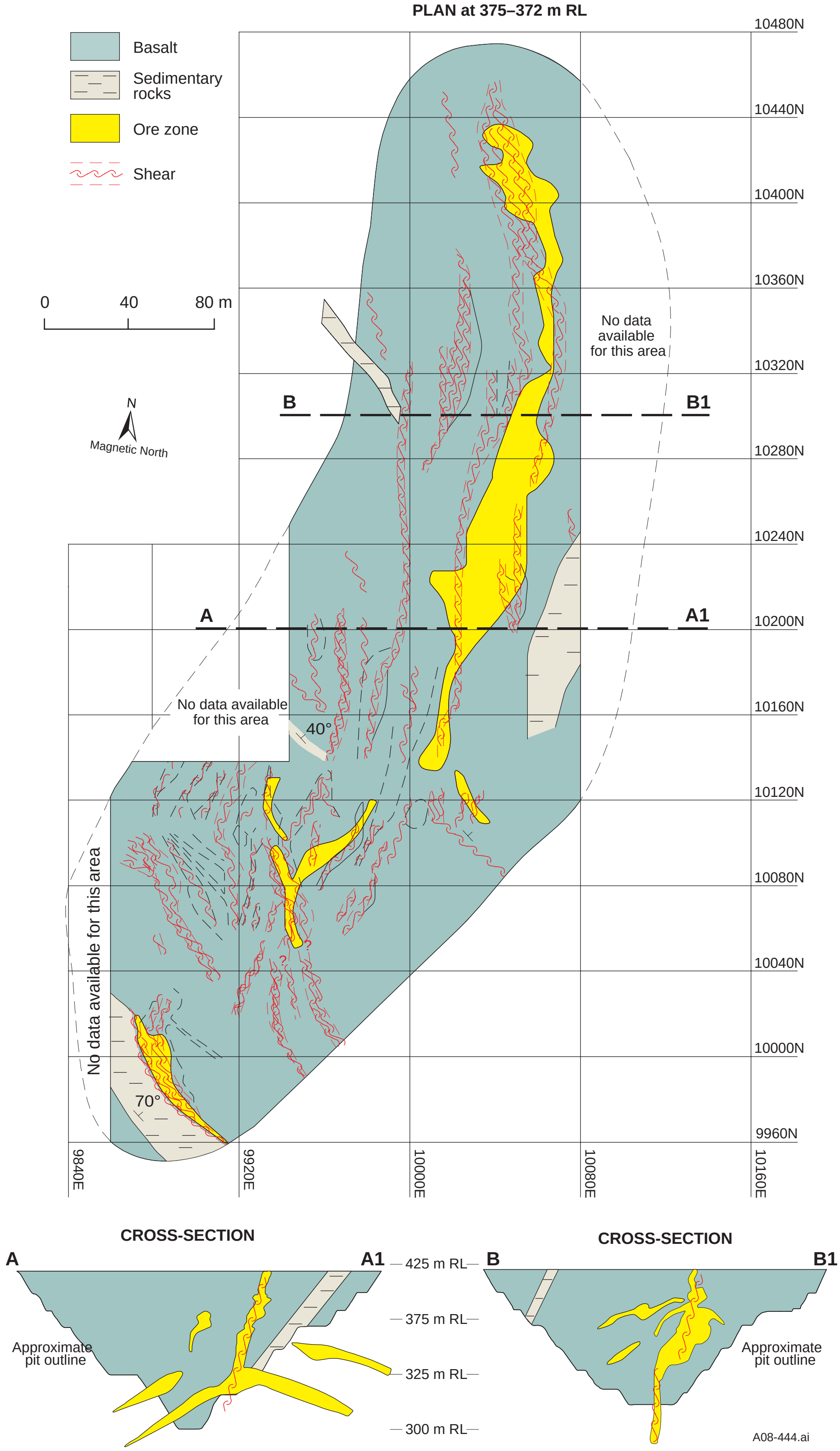

Figure 92. Plan and cross-sections of Jims Main deposit. Grid coordinates refer to local mine grid (courtesy Otter Gold Mines Ltd).

within the contact aureole of the Coomarie Dome. Gold is associated with pyrite within steeply west-dipping quartz veins or within silicification zones associated with shearing. The orebodies form discrete pods within the shear zones. Post-mineralisation shears and felsic dykes occur at Banjo. Beaver Creek is the largest of these deposits and has produced 0.72 Mt of ore at 3.75 g/t Au for 86 795 oz Au.

The *Crusade* and *Tregony* prospects are located about 80 and 100 km, respectively, northeast of the Hurricane-Repulse. These deposits are hosted within the Nanny Goat Volcanics. At the Crusade prospect, the host basalt and dacite are steeply dipping and extensively folded and faulted. Most mineralisation is confined to the footwall basalt. The mineralised zone plunges shallowly northward and is composed of some 20 quartz veins, which closely follow the basalt–dacite contact. The veins dip 50–85° west and are the result of reverse faulting along the lithological contact. Gold-bearing sulfides include pyrite and arsenopyrite, and native gold is also present. The Crusade prospect contains an inferred resource of 0.8 Mt at 2.9 g/t Au (74 900 oz Au). The Tregony prospect is within greywacke and shale of the Killi Killi Formation. The prospect is cut by the north-trending dextral Suplejack Shear. Mineralised pods are developed within south-southwest-trending dilational jogs related to the shear. The mineralised assemblage includes quartz ± chlorite ± pyrite ± arsenopyrite ± gold.

The *Titania* area is located 40 km to the northwest of The Granites goldfield and contains a resource of 4.45 Mt averaging 2.9 g/t Au and probable reserves of 2.26 Mt averaging 3.1 g/t Au in the *Oberon* deposit (Normandy NFM 2001, Gibbons and Webb 1997). The deposit is within lower greenschist-facies pebbly greywacke and siltstone of the Killi Killi Formation. Fine interbeds contain graphite and pyrite. Beds of boudinaged chert up to 2 m thick indicate a chemical component of the protolith. The host sedimentary rocks are intruded by dolerite, which may be strongly foliated. Foliated dolerite is altered to sericite, chlorite, carbonate (mostly dolomite) and feldspar. Massive dolerite contains relict amphibole. Mineralisation is in quartz-K-feldspar-carbonate veins (D_5), containing pyrite in the veins and arsenopyrite in the wallrock. As at Callie,

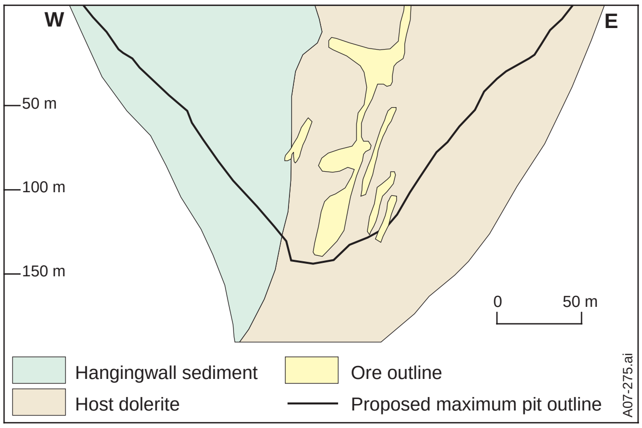

Figure 93. Geological cross-section of Groundrush deposit (after Normandy NFM 2000).

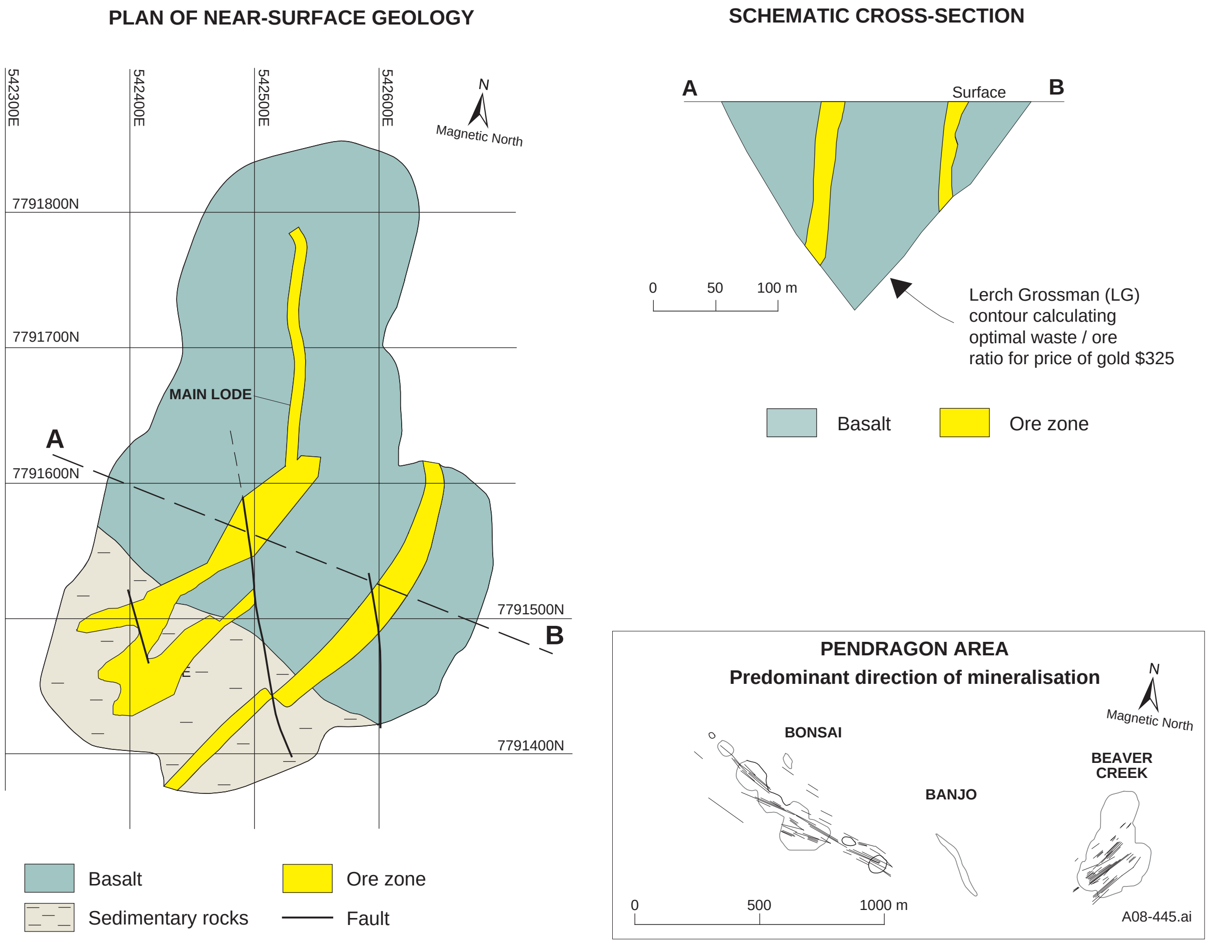

Figure 94. Plan and cross-section of Beaver deposit in Pendragon area (inset; courtesy Otter Gold Mines Ltd).

mineralisation is spatially associated with decarbonisation and the pervasive sericitic alteration of siltstone. There is also a close association between gold and arsenopyrite. Coarse native gold forms clusters of grains associated with D_1 and D_5 veins, and is also present as inclusions in arsenopyrite porphyroblasts.

The *Minotaur* deposit is located in the Windy Hill area, 30 km northeast of The Granites and was mined during 2002–2003. It initially had an indicated resource of 0.83 Mt averaging 2.9 g/t and probable reserves of 0.68 Mt averaging 3.1 g/t Au (Normandy NFM 2001). Mineralisation is within the Dead Bullock Formation. The host unit, locally known as the informal '*Taurus formation*', is correlated with the 'Main host unit' at The Granites goldfield. It is 15–65 m thick and contains hornblende, quartz, cummingtonite ± almandine, clinopyroxene, biotite, plagioclase and chlorite. The 'Taurus formation' contains abundant arsenopyrite and lesser amounts of pyrrhotite and pyrite and minor chalcopyrite, cherty lenses and calc-silicates. The protolith could be a mixed silicate-sulfide BIF. Numerous semi-concordant dolerite sills, as well as flat-lying felsic bodies, including granodiorite, tonalite and pegmatite, penetrate the local succession (Smith and Huntley 1996). Gold occurs as native metal in fine chloritic fractures and veinlets, but is also associated with sulfides (principally arsenopyrite and pyrrhotite). The '*Footwall schist*' also hosts significant mineralisation in quartz-feldspar±chlorite veins.

Ore genesis

Several detailed studies have been carried out to decipher the genesis of gold deposits of the Tanami Region. Adams (1997) studied the structure, mineralogy, fluid inclusion and stable isotope characteristics of the ore and gangue minerals at The Granites goldfield. Tunks (1996) studied the structure, alteration, fluid inclusions and geochemical characteristics of the Tanami goldfield. Wygralak and Mernagh (2001, 2004) studied the fluid inclusion, stable isotope, lead isotope and Ar-Ar geochronology of the region as a whole. These studies have been used by Wygralak *et al* (2005) to constrain the physicochemical characters of the hydrothermal fluids and their evolution from pre-, through syn- to post-mineralisation stage, as well as their provenance. Ahmad (in prep) has summarised various genetic parameters contraining the origin of the Tanami gold deposits and the following section is reproduced from there.

Fluid inclusions

Wygralak *et al* (2005) identified at least six different types (A-F see below) of fluid inclusions in quartz veins from the Tanami Region, which can be classified into two genetic groupings.

Primary fluid inclusions:

- Type A: these contain CO_2-rich liquid phase or CO_2 liquid + vapour phases. They may also contain small amounts of CH_4 or N_2 and may or may not contain an additional H_2O phase.
- Type B: $CH_4 \pm CO_2 + H_2O$-bearing inclusions. These are CH_4-rich and typically contain 10–30 vol% vapour.
- Type C: Monophase $CH_4 \pm N_2 \pm CO_2$ vapour inclusions. These can be distinguished from Type A inclusions by their CH_4- or N_2-rich nature.
- Type D: Two-phase H_2O-vapour inclusions. These are the most common type.
- Type E: Three phase H_2O-vapour-solid (NaCl) inclusions.

Secondary inclusions:

- Type F: Two-phase brine inclusions typically showing signs of necking down. These generally homogenise at relatively low temperatures.

If the three-phase NaCl-bearing Type E inclusions are interpreted as primary inclusions, it would appear that a halite-saturated fluid coexisted with the $H_2O \pm CH_4 \pm N_2 \pm CO_2$-bearing fluid. Furthermore, except for the Southern and Jims Main veins, no CO_2 occurs in inclusions from the Tanami goldfield. These observations record the involvement of three fluids in the formation of auriferous veins at the Tanami Region: (1) a CO_2, H_2O, CH_4 and N_2-bearing low to moderate salinity fluid; (2) a halite-saturated fluid; and (3) a CO_2, H_2O, CH_4-free low- to moderate-salinity fluid. The first two types of fluid characterise high-grade ore veins at The Granites and DBS goldfields and also at the Groundrush deposit. The third type of fluid was prominent at the Tanami goldfield.

Temperature, salinity and estimated depths for various deposits are plotted in **Figure 95**. At The Granites goldfield and at Callie, mineralising fluids range in temperature and salinity, respectively, from 220–310°C and 0–20 eq wt% NaCl for the type 1 fluid. Although Wygralak *et al* (2005) did not provide data for Type E fluid inclusions, it is necessary that the salinity of these fluids exceeded 26% NaCl. Estimated depths of formation of these veins ranged from 2–10 km. The Groundrush deposit has a temperature range of 270–430°C. A paragenesis-controlled fluid inclusion study at the Callie mine demonstrated that both pre-ore and post-ore veins are practically devoid of CO_2-rich inclusions (Wygralak *et al* 2005)

In contrast, the ore fluids in the Tanami goldfield generally lack CO_2, and have a salinity range of 0–21 eq wt% NaCl and a temperature range of 260–340°C. Veins in the Tanami goldfield have textures similar to those found in epithermal veins, and Tunks (1996) found co-existing liquid-rich and vapour-rich fluid inclusions in one sample, consistent with boiling of the ore-forming fluids and indicating a shallow depth range of 1.5–5.6 km.

Laser Raman Spectrometry (LRS) of fluid inclusions in samples from Callie (Guoyi 1994, Wygralak *et al* 2005) demonstrated that inclusions in ore-stage samples from Callie have an abundance of CO_2 in the vapour phase. Although CO_2 was typically the most abundant gas, some inclusions also contained significant N_2 (≤76 mol %) and minor CH_4 (≤12 mol %) in the vapour phase. Other phases noted included $CaCl_2$ and in one case, calcite and rhodochrosite daughter minerals. Hydrates detected in the higher salinity inclusions by LRS during freezing to

-180°C include $CaCl_2 \cdot 6H_2O$, $MgCl_2 \cdot 6H_2O$, $MgCl_2 \cdot 12H_2O$, $KCl \cdot MgCl_2 \cdot 8H_2O$ and $NaCl \cdot 2H_2O$. It may be noted that a CO_2 population is also described to be present in post-ore fluids (Wygralak *et al* 2005).

Mineral geothermometry

Wygralak *et al* (2005) used the chlorite geothermometer of Cathelineau and Nieva (1985) to determine the temperatures of vein formation. The following temperature ranges were obtained from various deposits: Carbine 284–338°C, Jims Main 278–406°C, Dogbolter 263 ± 5°C, Groundrush 297 ± 7°C, Titania 293–322°C and Minotaur 302 ± 4°C. These temperatures are in general agreement with the fluid inclusion temperatures.

The arsenopyrite geothermometer of Kretschmar and Scott (1976) was used by Wygralak *et al* (2005) to estimate the formation temperature of arsenopyrite in deposits, which contained arsenopyrite + pyrite + pyrrhotite assemblages. This geothermometer yielded temperatures of 399 ± 28°C and 345–395°C for Groundrush and Titania, respectively.

Oxygen and hydrogen isotopes

Hydrogen isotopes were measured on the fluid inclusion water and oxygen isotopes on silicates (usually quartz). The latter were converted to $\delta^{18}O$ water using a quartz-water fractionation factor and fluid inclusion temperatures. $\delta^{18}O$ and δD values of waters responsible for the deposition of quartz veins in various deposits from the Tanami Region, along with meteoric, magmatic and metamorphic waters are plotted in **Figure 96**. Data from ore-stage quartz from Callie and The Granites goldfield are consistent with the involvement of magmatic and/or metamorphic fluids. CO_2-H_2O fractionation effects during cooling, or a subordinate component of evolved meteoric water, or a basinal brine can account for a moderate depletion in ^{18}O. In comparison, fluids from the Tanami goldfield are completely outside the magmatic water field and depleted ^{18}O values indicate that ore fluids may have been derived from exchanged meteoric water, with a possible component of low-salinity distal magmatic fluid. This interpretation of the stable isotope data is consistent with fluid inclusion data and textural studies, which indicate that the Tanami goldfield veins were emplaced at relatively low temperatures and shallow crustal levels.

Carbon isotopes fluid inclusion CO_2

CO_2 in fluid inclusions from pre-ore, ore-stage and post-ore quartz from Callie exhibits narrow overlapping ranges of $\delta^{13}C$ values, with medians of -6.2‰, -5.3‰ and -5.9‰, respectively. For The Granites goldfield, these values have a narrow range of -8.4 to -7.7‰, with a median of -8.1‰. There is no carbon isotope data for the Tanami field. The $\delta^{13}C$ values for fluid inclusion CO_2 from The Granites goldfield and Callie are within the range of magmatic carbon, which has a $\delta^{13}C$ value of -7 ± 2‰ (Hoefs 1980). Values of $\delta^{13}C$ in carbonaceous siltstone hosting the Callie mineralisation have a narrow range averaging -23.7‰. At about 300°C, δ^{13} CO_2 values would be about 15‰ heavier than the associated organic carbon, provided equilibrium is maintained and all carbon is converted to CO_2.

Sulfur isotopes

$\delta^{34}S$ values of sulfides from a number of deposits from the Tanami Region are plotted in **Figure 97**. Sulfides in ore-stage veins at The Granites goldfield have ranges of +4.2 to +8.5‰. Post-ore sulfides from this goldfield form a distinctly different group within the range -2.3 to + 4‰ and cluster around 0‰ (Adams 1997). Sedimentary pyrite from the Tanami goldfield has a $\delta^{34}S$ range of +31.7 to +37.2‰. $\delta^{34}S$ values in ore-stage pyrite from the Tanami goldfield are in the range +6.8 to + 12.3‰. The $\delta^{34}S$ values in arsenopyrite associated with gold mineralisation at Callie show a narrow range of 8.8–9.5‰. These values are compatible with the usually accepted magmatic range (Ohmoto and Rye 1979).

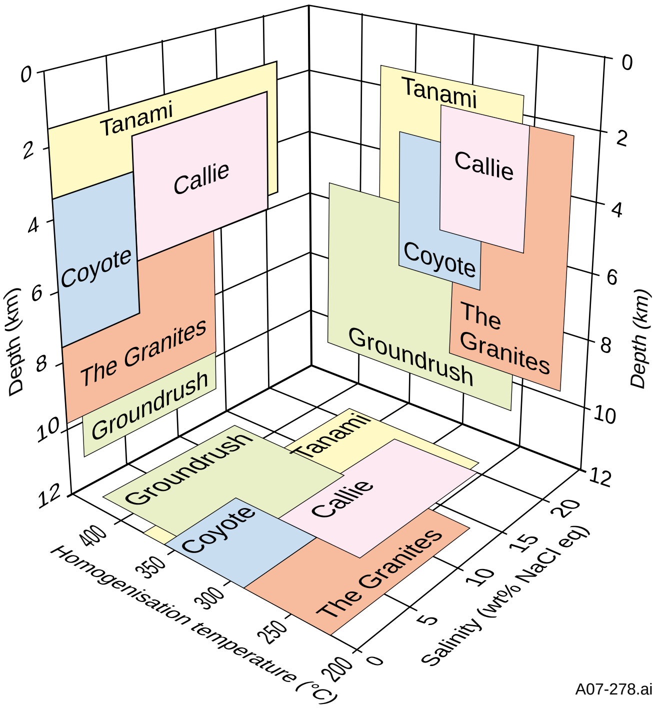

Figure 95. Temperature, salinity and estimated depths for various deposits in Tanami Region.

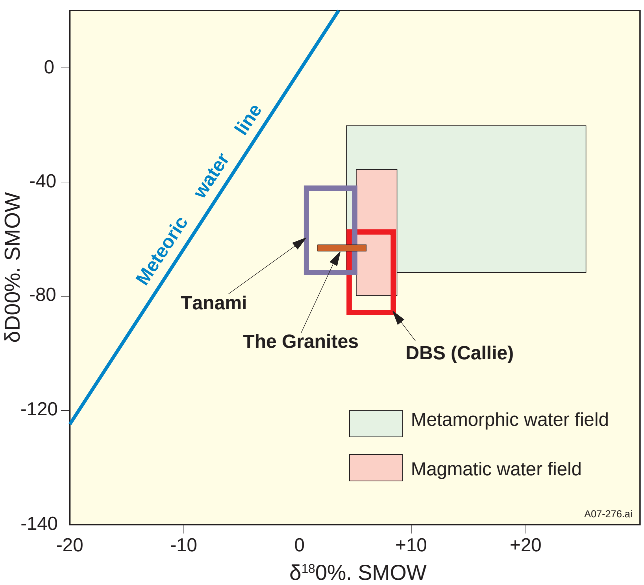

Figure 96. Calculated oxygen and hydrogen isotopic composition of ore-stage fluids. Extent of magmatic and metamorphic water fields after Taylor (1979).

Lead isotopes

Lead isotopes in sulfides from gold ores and K-feldspar separates from adjacent granites were analysed by Wygralak *et al* (2005) to investigate a possible link between the granites and the ore fluid, and the possibility that the ore-bearing fluids have been derived from the magmatic rocks. Wygralak *et al* (2005)discussed the evolution of lead isotopes for various deposits and concluded that the lead in the mineralising fluid is unlikely to have been derived from the nearby granites, with the exception of that from the Shoe deposit. However, it is possible that the fluids interacted with the surrounding rocks and that this has resulted in changes in the lead isotopic ratios.

Additional data from galena that paragenetically brackets the gold event at Callie and is intimately associated with gold at Coyote (WA) plots much closer to the granitoid K-feldspar field and is slightly more evolved than the lead from granitoid K-feldspar (Huston *et al* 2007).

Ar-Ar geochronology

Several samples of mica associated with gold-stage veining in selected gold occurrences were dated by the $^{40}Ar/^{39}Ar$ method (Wygralak and Mernagh 2001). Biotite in veins from Callie that are associated with vein quartz and gold yielded ages of ca 1700 Ma. Ore-zone sericite from Carbine yielded a much older age of ca 1852 Ma, whereas ore zone sericite from Titania and Galifrey yielded younger ages of ca 1685 and 1630 Ma. Fraser (2002) performed further $^{40}Ar/^{39}Ar$ dating on biotite from gold-bearing veins at the Callie mine and on biotite from a variety of Tanami Region granitoids. Samples of biotite from ore-stage auriferous quartz veins in Callie returned ages in the range 1735–1710 Ma. Samples of biotite from the Coomarie and Frankenia domes exhibited ages in the range 1755–1820 Ma. These ages are similar to previously obtained U-Pb ages (Smith 2001, Cross *et al* 2005). Additional ^{40}Ar-^{39}Ar data on sericite from a variety of vein types from the Aileron Province (Wygralak and Mernagh 2008a) yielded ages in the range 1670–230 Ma and these generally young towards the southeast. The youngest ages are from the White Range gold deposit and these obviously show an imprint of the Alice Springs Orogeny. These observations testify to the easily resettable nature of the Ar-Ar data and could be considered to be reflecting a multiplicity of thermal events in this polydeformed terrane.

Xenotime dating

SHRIMP U–Pb dating of ore-related hydrothermal xenotime (YPO_4) from the Callie mine was undertaken by Cross *et al* (2005). The xenotime occurs in the sampled quartz vein as small (5–20 µm) equant, euhedral to anhedral, pale yellow-green crystals. No xenotime was observed outside of the quartz vein. Of seventeen SHRIMP analyses, eight had high common Pb contents and/or were greater than 10% discordant. These xenotimes have ambiguous compositions and the data was excluded from the pooled age calculation. The remaining concordant and near-concordant analyses combined to give a weighted mean $^{207}Pb/^{206}Pb$ age of 1803 ± 19 Ma (95% confidence, MSWD = 0.57). This age is considered to closely represent the age of the host Au-bearing quartz vein and, by inference, the age of mineralisation at Callie (Cross *et al* 2005). It is approximately 100 My older than the 1720 Ma age of mineralisation that was interpreted from $^{40}Ar/^{39}Ar$ studies of hydrothermal biotite from Callie (Fraser 2002) and is in accord with SHRIMP zircon ages of intrusive granites from the Tanami Region (Smith 2001, Cross *et al* 2005).

Physicochemical modelling

Fluid inclusion data on chemical composition (salinity, CO_2, CH_4) homogenisation temperatures, wall rock alteration and ore mineral assemblages have been used by Wygralak *et al* (2005) to constrain the physicochemical conditions of ore deposition, ie pH, T and fO_2, and total sulfur contents in the ore-stage fluid. It has been estimated that at conditions near the CO_2/CH_4 buffer and at a pH of ca 7.5, total sulfur = 0.005 molal, salinity = 12 wt% NaCl, temperature = 300°C, and gold solubility as $Au(HS)^{2-}$ can be as high as 1 ppm. Possible mechanisms for gold precipitation include reduction, loss of sulfur, a decrease in temperature or changes in pH.

Wygralak *et al* (2005) carried out thermodynamic modelling involving the interaction of low- and high-salinity fluids with rock compositions typical of those found in the Tanami Region and concluded that boiling causes major changes in the volatile content of fluids, which generally leads to gold precipitation, depending on the magnitude of fO_2 and pH changes. Open-system boiling appears to be more efficient than closed-system boiling, as most of the gold is precipitated during the first 5% of boiling in the former case.

Greater quantities of gold may be precipitated when fluids interact with carbon-bearing rocks. However, thermodynamic modelling of the fluid–rock interaction with carbon-free rocks produces mineral assemblages that more closely resemble the observed vein and alteration assemblages. This suggests that, in this scenario, initial mineralisation may involve fluid reduction by carbonaceous rocks, and that this mineralisation was subsequently remobilised by continued fluid flow and then reprecipitated as the fluids underwent phase separation and further fluid–rock interaction with the now bleached host rock.

For the Callie mineralisation, Wygralak *et al* (2005) suggested a model in which oxidised fluid moved upward along D_5 structures and reacted with carbon-bearing

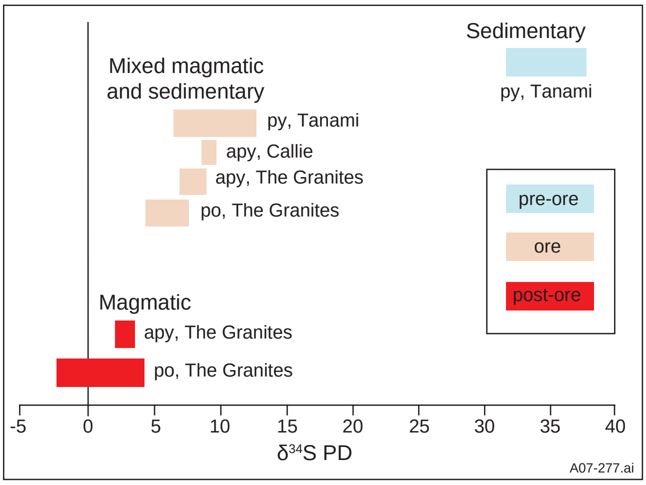

Figure 97. Sulfur isotopic composition of fluids: apy = arsenopyrite; py = pyrite, po = pyrrhotite.

sedimentary rocks along the oxidation front. Oxidation of carbon increased the porosity of the rocks, facilitating further fluid movement. It also produced large amounts of CO_2, which pervasively altered the 'Coora dolerite' and 'End it all dolerite'. They proposed that the contact between the Callie 'Host unit' and 'Magpie schist' represents a redox front rather than a stratigraphic boundary, as advocated by Whittaker (1995). Gold was cyclically remobilised and precipitated as the oxidation front progressed. This multistage mechanism produced the exceptional volume of gold mineralisation at Callie.

Genesis of Tanami gold deposits

Nicholson (1990) proposed that ore fluids at the Tanami goldfield were generated by metamorphic dewatering. Lovett *et al* (1993) considered that gold in the DBS field was precipitated by hydrothermal solutions channelled through pre-existing structures. Subsequent remobilisation of gold during deformation events has probably upgraded the ore and concentrated the ore-bearing fluids into low-pressure areas, such as fold closures. For deposits in The Granites goldfield, Adams (1997) interpreted stable isotope data as favouring a metamorphic fluid, although he did not rule out the possibility of magmatic waters. Recent studies (Wygralak and Mernagh 2001, Wygralak *et al* 2005, Huston *et al* 2007) have cast doubts on the role of granite in the generation of gold.

Important parameters, used to constrain the ore depositional environment, are listed in **Table 7**. The evidence is confusing, but a magmatic/metamorphic influence in the generation of ore fluids cannot be ruled out. Furthermore, a link with the granitic intrusives is evident from the spatial relationships, stable isotopes and xenotime geochronology.

Considering the various pieces of evidence presented in the **Table 7** and discussed in the preceding sections, it is likely the gold was transported as bisulfide complex and was deposited either by reaction with the host rock, or by boiling and loss of sulfur. Decarbonisation of carbonaceous sedimentary rocks has been proposed for the Callie deposit (Wygralak *et al* 2005) as a cause of reduction of ore fluids and precipitation of gold. Reaction with ferruginous sedimentary rocks and fixation of sulfur due to the conversion of iron oxides to pyrite may be another mechanism for gold precipitation, specifically for deposits in The Granites goldfield. Simple boiling, resulting in cooling and partition of H_2S in the vapour phase may account for gold precipitation in the deposits of the Tanami goldfield. There are no constraints on the actual source of gold, it may be of magmatic origin or leached from the surrounding sediment. There is a strong indication of the presence of CO_2-CH_4-dominated, reduced metamorphic fluids. Mixing of these fluids with auriferous oxidised fluid of possibly magmatic parentage along structurally prepared pathways is also a viable mechanism for the generation of the gold deposits of the Tanami Region (Ahmad in prep).

Gold prospectivity

Exploration for gold deposits in the Tanami Region has achieved success through the use of modern mineral exploration techniques. Unconsolidated younger surficial deposits cover much of the area. In spite of recent mapping by NTGS, the geology of the Tanami Region is still not fully understood. The most successful approach has been to drill test very low-level geochemical anomalies within a lithological and structural framework provided by detailed prospect-scale aeromagnetics, gravity and, more recently, seismic data.

All of the presently known gold mineralisation in the region is associated with Palaeoproterozoic rocks, formerly mapped throughout the region as the Mount Charles beds, but now mapped as different units in the Tanami, Dead Bullock Soak and The Granites areas. The extent and distribution of these rocks is a guide to the mineral potential of the Tanami Region, which is divided into areas of high, moderate and low prospectivity.

Parameter	Results	Remarks
Spatial association	Most deposits are in close proximity to ca 1800 Ma granites	A genetic link with granites is possible
Fluid inclusion composition	High concentration of CO_2-CH_4 High salinity - halite saturation High Ca, Mg	Possibly metamorphic influence Possible igneous link Possible metamorphic
Hydrogen and oxygen isotopes	Tanami deposits – outside magmatic/metamorphic range and close to the meteoric water line. The Granite and DBS deposits – within magmatic/metamorphic range	Possibly evolved meteoric water Possibly magmatic or metamorphic
Sulphur isotopes	Ore fluids Post-ore fluids	Possibly magmatic source Magmatic
Lead isotopes	Callie, Coyote and Shoe Tanami	Indicate granitic parentage Nearby granites are unlikely source
^{40}/Ar^{39}Ar dating of micas	Carbine 1852 Ma Callie 1710–1735 Ma Titania and Galifrey 1630–1685 Ma	Can be liked to granitic ages ca 100 Ma younger than granites ca 200 Ma younger than granites
Xenotime	Callie 1803 Ma	ca same as granitic intrusives

Table 7. Parameters constraining ore depositional environment in Tanami Region.

To the east, the relationship with rock units of the Aileron Province of the Arunta Region is not well understood due to poor exposure. Exploration undertaken over parts of this region has yielded encouraging results.

The Tanami Region has not been extensively explored for commodities other than gold. It is likely that this region is not only prospective for gold, but may also contain significant uranium and base-metal deposits.

GOLD IN OTHER INLIERS

Other, less explored Palaeoproterozoic inliers within the Northern Territory may have potential for gold deposits and these are described below.

Arnhem Inlier

This inlier is located in eastern Arnhem Land and comprises high-grade metamorphics, which have been intruded by a suit of restite-rich S-type granites at about 1850 Ma. Younger A-type, fayalite-bearing granites intruded the metamorphics at about 1835 Ma (Wyborn *et al* 1996, Rawlings *et al* 1997).

Despite its favourable geology, including its Palaeoproterozoic age, low-grade metamorphism and the presence of granites, there is no record of gold exploration in this area. During 1965 to 1973, this region was explored for bauxite, manganese, and to a lesser extent, for base metals. Early prospectors do not seem to have explored this area, perhaps due to the inaccessible nature of the region. Little mineral exploration has been carried out since the mid-1970s, partly because significant areas have been under moratorium under the *Aboriginal Land Rights Act (NT).*

Musgrave Province

The Musgrave Province is a large east-trending Mesoproterozoic inlier that straddles the border of the Northern Territory, South Australia and Western Australia. The geology of the province within the Northern Territory is described in detail in Edgoose *et al* (2003) and the description below only relates to the Northern Territory. The oldest rocks in the Musgrave Province are felsic gneisses with protolith ages in the range 1600–1540 Ma; these are intercalated with minor mafic rocks and metapelite. The felsic gneisses are interpreted to have formed in an arc-related environment (Wade *et al* 2006). These rocks are intruded by voluminous granites of the 1200–1170 Ma Pitjantjatjara Supersuite, and by lesser 1070 Ma granites and dolerites. In the Bloods Range area, a succession of rift-related sedimentary rocks and bimodal volcanics, the Tjauwata Group, were deposited during the 1080–1060 Ma Giles Event. The Musgrave Province was deformed and metamorphosed during the 570–530 Ma Petermann Orogeny, which led to the intercalation of Musgrave basement and basal Amadeus Basin sedimentary rocks at greenschist to lower amphibolite facies conditions within the Petermann Nappe Complex.

There are no records of any gold mining in this region and very little exploration has taken place. Forman (1972) and Edgoose *et al* (2003) have provided accounts of the history of exploration for this area. Traces of gold have been recorded at Foster Cliff (George 1907) and a quartz vein from within the Piltardi Detachment Zone yielded 0.19 ppm Au (Scrimgeour *et al* 1999). Limited exploration in the poorly exposed Tjauwata Group within the Petermann Nappe Complex identified encouraging gold anomalies in soil samples (Hellewell 2004). Follow-up of these anomalies identified quartz-veins within poorly exposed sheared granitoids and metasedimentary rocks of the Tjauwata Group that yielded rock chip results including 29.7 g/t Au and 13.1 g/t Au, with anomalous bismuth, copper, lead and silver (Goldsearch Ltd, ASX Announcement, 16 August 2005). These encouraging results have not been adequately followed up. This area is considered to have promising potential as a greenfields gold province.

It has been claimed that Lasseter's mythical gold reef is located somewhere in the western Musgrave Province, but little evidence exists to support this.

Inverway Metamorphics

The Inverway Metamorphics are exposed in two small outcrops (1 km^2 and 0.5 km^2), located in central LIMBUNYA, within the Birrindudu Basin. Gravity data indicate the presence of a larger, north-trending basement ridge in this area (Whitworth 1970) underneath Birrindudu Basin sedimentary rocks. The Inverway Metamorphics consist of steeply dipping and foliated lower greenschist-facies greywacke, shale and siltstone. Concordant quartz veins are present and form massive 0.2–4.0 m-thick reefs of milky white quartz or thinner (0.01–0. 1 m thick) veins of light grey quartz with haematite.

The lithological and geochronological similarity of this rock unit to the Tanami Group and South Alligator Group suggests it may have gold potential. However, no significant exploration has taken place, and no traces of gold mineralisation have been discovered to date (Scriven 1991).

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APPENDIX 1

Gold deposit data (page 118 through to 131).

Most production and resources are correct to December 2007. Deposit number refers to the MODAT mineral deposit database. Size classification is based on production plus resources of Au, as follows:

Occurrence, less than 100 kg;
Small, 100–1000 kg;
Medium, 1000–5000 kg;
Large, greater than 5000 kg.

Name Of 1:250,000 Sheet (Geological Unit)	No.	Type	Easting AGD 66	Northing AGD 66	Size	Formation	Shape	Production of au (kg)	Resource (Mt of ore)	Grade (g/t)
ALICE SPRINGS (Arunta Region)										
Arltunga alluvials 1	168	Alluvial	471000	7405400	Occurrence	Alluvium & gravel (Czs)	Placer			
Arltunga alluvials 2	170	Alluvial	469100	7407700	Occurrence	Alluvium & gravel (Czs)	Placer			
Arltunga alluvials 3	181	Alluvial	475000	7411100	Occurrence	Alluvium & gravel (Czs)	Placer	4.80		
Arltunga alluvials 4	184	Alluvial	475000	7411700	Occurrence	Alluvium & gravel (Czs)	Placer			
Arltunga alluvials 5	164	Alluvial	477800	7411300	Occurrence	Alluvium & gravel (Czs)	Placer			
Arltunga alluvials 6	198	Alluvial	479500	7410800	Occurrence	Alluvium & gravel (Czs)	Placer	0.70		
Atlas	130	Au-Qtz	434300	7419600	Occurrence	Sericite schist (Pzr)	Vein			
Black Devil	188	Au-Qtz	474600	7406900	Occurrence	Heavitree Quartzite	Vein			
Black Eagle Claim	134	Au-Qtz	435000	7418900	Occurrence	Sericite schist (Pzr)	Vein	17.80		
Chinamen Workings	176	Au-Qtz	475100	7409400	Occurrence	Atnarpa Igneous Complex	Vein			
Christmas Reef	165	Au-Qtz	470600	7407700	Occurrence	Cavanagh Metamorphics	Vein	0.26		
Ciccones	137	Au-Qtz	436800	7418500	Occurrence	Heavitree Quartzite	Vein	3.00		
Claraville	157	Au-Qtz	469600	7410900	Occurrence	Atnarpa Igneous Complex	Vein	11.00		
Coorong Claim	129	Au-Qtz	434000	7419200	Occurrence	Sericite schist (Pzr)	Vein	2.70		
Coronation Claim	126	Au-Qtz	432600	7419200	Occurrence	Cadney Metamorphics	Vein	0.47		
Excelsior (White Range)	162	Au-Qtz	475100	7406400	Small	Heavitree Quartzite	Vein	2350	1.43	0.8
Fat Dingo	196	Au-Qtz	479800	7410500	Occurrence	Cavanagh Metamorphics	Vein	0.17		
Garland's Claim	132	Au-Qtz	436500	7419100	Occurrence	Sericite schist (Pzr)	Vein	3.00		
Golden Eagle Claim	135	Au-Qtz	435300	7419200	Occurrence	Sericite schist (Pzr)	Vein	0.39		
Golden Goose	127	Au-Qtz	433400	7419400	Occurrence	Heavitree Quartzite	Vein	6.20		
Great Western	166	Au-Qtz	474500	7407100	Occurrence	Sericite schist (Pzr)	Vein	19.00		
Jenkins II (main workings)	183	Au-Qtz	474900	7411300	Occurrence	Randall Creek Metamorphics	Vein	6.60		
John's Bulls Surprise	150	Au-Qtz	454500	7408500	Occurrence	Sericite schist (Pzr)	Vein			
Joker	160	Au-Qtz	472800	7407000	Occurrence	Heavitree Quartzite	Vein	8.20		
Junction Claim	128	Au-Qtz	433700	7419500	Occurrence	Sericite schist (Pzr)	Vein	2.60		
Luces	163	Au-Qtz	474700	7406700	Small	Heavitree Quartzite	Vein	included in Excelsior		
Magdala	199	Au-Qtz	479000	7411000	Occurrence	Cavanagh Metamorphics	Vein	2.60		
McDonnell Range Reef	159	Au-Qtz	470600	7408100	Occurrence	Cavanagh Metamorphics	Vein	7.70		
Melba Claim	131	Au-Qtz	432900	7419000	Occurrence	Cadney Metamorphics	Vein	1.10		
Old Camp	118	Au-Qtz	422500	7421400	Occurrence	Heavitree Quartzite	Vein			
Patsy's Show	136	?	436700	7418400	Occurrence	Bitter Springs Fm	Stratiform	Included in Ciccones		
Pyritic Show	138	Au-Qtz	436900	7418500	Occurrence	Heavitree Quartzite	Vein			
Round Hill	175	Au-Qtz	474500	7409600	Occurrence	Atnarpa Igneous Complex	Vein	3.50		
Sloans Gully	115	Au-Qtz	419300	7422700	Occurrence	Heavitree Quartzite	Vein	25.00		
Sloans Gully (Old Times) alluvials	116	Alluvial	421400	7421900	Occurrence	Alluvium & gravel (Czs)	Placer	2.00		
Unnamed	117	Au-Qtz	422500	7422400	Occurrence	Bitter Springs Fm	Vein			
Unnamed	119	Au-Qtz	424500	7420600	Occurrence	Heavitree Quartzite	Vein			
Unnamed	121	Au-Qtz	426500	7419900	Occurrence	Bitter Springs Fm	Vein			
Unnamed	122	Au-Qtz	427100	7419800	Occurrence	Bitter Springs Fm	Vein			
Unnamed	124	Au-Qtz	434500	7421900	Occurrence	Sericite schist (Pzr)	Vein			
Unnamed	161	Au-Qtz	474700	7406300	Occurrence	Heavitree Quartzite	Vein			
Unnamed	167	Au-Qtz	474200	7405200	Occurrence	Heavitree Quartzite	Vein			
Unnamed	169	Au-Qtz	469900	7406200	Occurrence	Bitter Creek Fm	Vein			
Unnamed	171	Au-Qtz	469500	7408500	Occurrence	Atnarpa Igneous Complex	Vein			
Unnamed	172	Au-Qtz	467100	7408200	Occurrence	Atnarpa Igneous Complex	Vein			

Name Of 1:250,000 Sheet (Geological Unit)	No.	Type	Easting AGD 66	Northing AGD 66	Size	Formation	Shape	Production of au (kg)	Resource (Mt of ore)	Grade (g/t)
Unnamed	173	Au-Qtz	475800	7411000	Occurrence	Atnarpa Igneous Complex	Vein			
Unnamed	174	Au-Qtz	479200	7410900	Occurrence	Cavanagh Metamorphics	Vein			
Unnamed	177	Au-Qtz	474600	7410300	Occurrence	Atnarpa Igneous Complex	Vein			
Unnamed	178	Au-Qtz	477200	7411907	Occurrence	Atnarpa Igneous Complex	Vein			
Unnamed	179	Au-Qtz	473600	7410800	Occurrence	Atnarpa Igneous Complex	Vein			
Unnamed	180	Au-Qtz	473300	7411300	Occurrence	Atnarpa Igneous Complex	Vein			
Unnamed	182	Au-Qtz	475600	7410900	Occurrence	Randall Peak Metamorphics	Vein			
Unnamed	186	Au-Qtz	477200	7411800	Occurrence	Randall Peak Metamorphics	Vein			
Unnamed	189	Au-Qtz	478600	7412100	Occurrence	Hillsoak Bore Metamorphics	Vein			
Unnamed	190	Au-Qtz	479500	7411900	Occurrence	Cadney Metamorphics	Vein			
Unnamed	192	Au-Qtz	478900	7411100	Occurrence	Cadney Metamorphics	Vein			
Unnamed	193	Au-Qtz	478900	7410800	Occurrence	Gneiss (pEx)	Vein			
Unnamed	194	Au-Qtz	478500	7410400	Occurrence	Atnarpa Igneous Complex	Vein			
Unnamed	195	Au-Qtz	479100	7409400	Occurrence	Atnarpa Igneous Complex	Vein			
Unnamed	197	Au-Qtz	479400	7411100	Occurrence	Gneiss (pEx)	Vein			
Unnamed	200	Au-Qtz	480100	7411300	Occurrence	Cadney Metamorphics	Vein			
Unnamed	201	Au-Qtz	479800	7411800	Occurrence	Cadney Metamorphics	Vein			
Unnamed	202	Au-Qtz	480100	7412500	Occurrence	Cadney Metamorphics	Vein			
Unnamed	203	Au-Qtz	481100	7412400	Occurrence	Riddoch Amphibolite Member	Vein			
Unnamed	207	Au-Qtz	484700	7409800	Occurrence	Gneiss (pEx)	Vein			
Unnamed Alluvials	133	Alluvial	435200	7419000	Occurrence	Alluvium & gravel (Czs)	Placer			
Valentines	158	Au-Qtz	470200	7409000	Occurrence	Cavanagh Metamorphics	Vein	2.10		
Wheal Fortune	191	Au-Qtz	479300	7411600	Occurrence	Cadney Metamorphics	Vein	15.90		
Wheal Mundi	187	Au-Qtz	478200	7411900	Occurrence	Atnarpa Igneous Complex	Vein	14.90		
Wipe Out	185	Au-Qtz	474200	7412300	Occurrence	Atnarpa Igneous Complex	Vein	3.00		
ALLIGATOR RIVER (Pine Creek Orogen)										
Jabiluka	41	U-Au	271400	8617000	Medium	Cahill Fm	Stratabound		1.10	10.7
Koongarra	79	U-Au	270700	8576400	Small	Cahill Fm	Stratabound		3.11 t gold	
BONNEY WELL (Tennant Inlier)										
Aztec	27	Au-Qtz	496200	7706100	Occurrence	Kurinelli Sandstone	Vein	10.00		
Cairns	29	Au-Qtz	499300	7701700	Occurrence	Taragan Sandstone	Vein	3.60		
Dav	4	Au-Qtz	451600	7754400	Occurrence	Quartz-feldspar porphyry	Vein			
Davidsons	16	Au-Qtz	478500	7737000	Occurrence	Granophyre Intrusive	Vein			
Great Davenport	28	Au-Qtz	497300	7705400	Occurrence	Kurinelli Sandstone	Vein	5.00		
Kovacs	2	Au-Qtz	426900	7756100	Occurrence	Junalki Fm	Vein			
Kurundi (Richards)	17	Au-Qtz	467300	7730200	Occurrence	Edmirringee Volcanics	Vein	1.12		
Millers	3	Au-Qtz	449200	7757300	Occurrence	Epenarra Volcanics	Vein	2.00		
Opengidgi	5	Au-Qtz	452200	7753600	Occurrence	Junalki Fm	Vein			
Power of Wealth	15	Au-Qtz	454400	7737900	Occurrence	Kurinelli Sandstone	Vein	3.60		
Priesters (Weka)	14	Au-Qtz	458500	7738100	Occurrence	Kurinelli Sandstone	Vein	1.00		

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DARWIN (Pine Creek Orogen)										
16/4	186	Au-Qtz	772100	8569900	Occurrence	Mount Bonnie Fm	Vein			
Annie Oakley	179	Au-Qtz	769300	8570600	Occurrence	Mount Bonnie Fm	Vein	0.47		
Backhoe	182	Au-Qtz	770700	8570100	Occurrence	Mount Bonnie Fm	Vein	included in Rustlers Roost		
Beef Bucket	183	Au-Qtz	771000	8570600	Occurrence	Mount Bonnie Fm	Vein	included in Rustlers Roost		
Dolly Pot	184	Au-Qtz	771400	8570900	Occurrence	Mount Bonnie Fm	Vein	included in Rustlers Roost		
Donkey Hill	215	Au-Qtz	794500	8579600	Occurrence	Mundogie Sandstone	Vein			
Expectant	185	Au-Qtz	771600	8570900	Occurrence	Mount Bonnie Fm	Vein			
Giants Reef	168	Au-Qtz	729700	8572600	Occurrence	Rum Jungle Complex	Vein			
Golden Boulder	56	Au-Qtz	693500	8594300	Small	Burrell Creek Fm	Vein	19.23		
Henrys Prospect	200	Au-Qtz	778200	8576200	Occurrence	Gerowie Tuff	Vein			
Its A Boy	187	Au-Qtz	772400	8572300	Occurrence	Mount Bonnie Fm	Vein			
Joseph	175	Au-Qtz	754500	8569700	Occurrence	Burrell Creek Fm	Vein			
Maureen	172	Au-Qtz	740500	8564500	Occurrence	Koolpin Fm	Vein			
Maureen Extended	173	Au-Qtz	740500	8564500	Occurrence	Koolpin Fm	Vein			
Pighole Battery	188	Alluvial	775100	8569800	Occurrence	Czs	Irregular			
Quest 29	205	Au-Qtz	779000	8566800	Small	Koolpin Fm	Vein		1.2	2.9
Robertson	178	Au-Qtz	764700	8577500	Occurrence	Gerowie Tuff	Vein			
Rustlers Roost	180	Au-Qtz	770000	8570500	Small	Mount Bonnie Fm	Vein	3424.51	23.493	1.27
Shauns Find	209	Au-Qtz	782800	8564200	Occurrence	Koolpin Fm	Vein			
Snake Hill	211	Au-Qtz	783800	8564800	Occurrence	Koolpin Fm	Vein			
Stop 16	176	Au-Qtz	757500	8570500	Occurrence	Burrell Creek Fm	Vein			
Sweet Ridge(Pig Hole 5)	181	Au-Qtz	770600	8571300	Occurrence	Mount Bonnie Fm	Vein			
Toms Gully	194	Au-Qtz	778200	8579900	Small	Wildman Siltstone	Vein	3335.7	1.172	9.75
Unnamed	174	Au-Qtz	748100	8572000	Occurrence	Burrell Creek Fm	Vein			
Williams	177	Au-Qtz	764500	8564500	Occurrence	Burrell Creek Fm	Vein	5.79		
FERGUSSON RIVER Pine Creek Orogen)										
Big Mouth	4	Au-Qtz	681400	8439300	Occurrence	Burrell Creek Fm	Vein	75.09		
Boiler	7	Au-Qtz	682200	8439100	Occurrence	Burrell Creek Fm	Vein			
Brown Snake	21	Au-Qtz	813700	8442200	Occurrence	Burrell Creek Fm	Vein			
Bubbles Prospect	13	Au-Qtz	663700	8429700	Occurrence	Chilling Sandstone	Vein			
Grants	6	Au-Qtz	681700	8439200	Occurrence	Burrell Creek Fm	Vein			
New Show	8	Au-Qtz	682200	8439100	Occurrence	Burrell Creek Fm	Vein			
Ping Quees	5	Au-Qtz	681400	8439300	Occurrence	Burrell Creek Fm	Vein			
Specky Creek	10	Au-Qtz	664900	8437300	Occurrence	Murra Kamangee Granodiorite	Vein			
Terry's Prospect	11	Au-Qtz	667100	8439200	Occurrence	Ti Tree Granophyre	Vein			
Tower Prospect	25	Au-Qtz	822300	8440700	Occurrence	Burrell Creek Fm	Vein			
Woolgni 1	23	Au-Qtz	819800	8440800	Occurrence	Burrell Creek Fm	Vein			
Woolgni 2	24	Au-Qtz	820300	8441000	Small	Burrell Creek Fm	Vein	143.50	0.235	2.65
FREW RIVER (Tennant Inlier)										
ADA	6	Au-Qtz	502000	7718600	Occurrence	Kurinelli Sandstone	Vein			
Alfred	12	Au-Qtz	502900	7713600	Occurrence	Dolerite Intrusive	Vein			
Anticline Valley	19		503400	7691900	Occurrence	Treasure Volcanics	Unknown			
Black Hills	7	Au-Qtz	506000	7718500	Occurrence	Dolerite Intrusive	Vein			
Crystal	16	Au-Qtz	522000	7695300	Occurrence	Dolerite Intrusive	Vein	30.00		

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Dempseys Choice (Battery)	2	Au-Qtz	504100	7720600	Occurrence	Dolerite intrusive	Vein	3.90		
Doctors Hole	3	Au-Qtz	505400	7720100	Occurrence	Dolerite Intrusive/ Rooneys Fm	Vein			
Gem	11	Au-Qtz	503000	7714600	Occurrence	Dolerite Intrusive	Vein			
Gidyea	13		552500	7718200	Occurrence	Taragan Sandstone	Unknown			
Hookers	5	Au-Qtz	509100	7719800	Occurrence	Rooneys Fm	Vein	1.20		
Kurinelli (First Chance)	9	Au-Qtz	503600	7718000	Occurrence	Dolerite Intrusive/ Rooneys Fm	Vein	8.10		
Mia Mia	17	Au-Qtz	517000	7694800	Occurrence	Treasure Volcanics	Vein			
Mick & Peta's	14	Au-Qtz	506000	7705600	Occurrence	Kurinelli Sandstone	Vein	2.00		
Tarragans (Black Cairns)	15	Au-Qtz	502000	7701800	Occurrence	Dolerite Intrusive	Vein	3.00		
Trevor	8	Au-Qtz	505600	7718400	Occurrence	Rooneys Fm	Vein	0.35		
Unnamed	10	Au-Qtz	505800	7717900	Occurrence	Dolerite Intrusive	Vein			
ILLOGWA CREEK Arunta Region)										
Hale River	51	Au-Qtz	500600	7410100	Occurrence	Unnamed Unit	Vein			
KATHERINE Pine Creek Orogen)										
Alpha	74	Au-Qtz	187700	8435000	Occurrence	Burrell Creek Fm	Vein			
Bravo	76	Au-Qtz	187700	8435000	Occurrence	Burrell Creek Fm	Vein			
Chessman	129	Au-Qtz	221000	8406700	Occurrence	Maud Dolerite	Vein			
Delta	75	Au-Qtz	187800	8435500	Occurrence	Burrell Creek Fm	Vein			
Driffield 1	13	Au-Qtz	195300	8445900	Occurrence	Burrell Creek Fm	Vein			
Driffield 10	22	Au-Qtz	197200	8445500	Occurrence	Burrell Creek Fm	Vein			
Driffield 11	23	Au-Qtz	197000	8445300	Small	Burrell Creek Fm	Vein			
Driffield 12	24	Au-Qtz	196800	8445200	Occurrence	Burrell Creek Fm	Vein			
Driffield 13	25	Au-Qtz	196500	8445200	Small	Burrell Creek Fm	Vein			
Driffield 14	26	Au-Qtz	196300	8444200	Small	Burrell Creek Fm	Vein			
Driffield 15	27	Au-Qtz	195500	8444800	Small	Burrell Creek Fm	Vein	165.00		
Driffield 16	28	Au-Qtz	195600	8444500	Occurrence	Burrell Creek Fm	Vein			
Driffield 17	29	Au-Qtz	195300	8446300	Occurrence	Burrell Creek Fm	Vein			
Driffield 2	14	Au-Qtz	195900	8445700	Small	Burrell Creek Fm	Vein			
Driffield 3	15	Au-Qtz	196100	8445000	Occurrence	Burrell Creek Fm	Vein			
Driffield 4	16	Au-Qtz	195500	8445000	Small	Burrell Creek Fm	Vein			
Driffield 5	17	Au-Qtz	196800	8445800	Occurrence	Burrell Creek Fm	Vein			
Driffield 6	18	Au-Qtz	196600	8445700	Occurrence	Burrell Creek Fm	Vein			
Driffield 7	19	Au-Qtz	196700	8445800	Occurrence	Burrell Creek Fm	Vein			
Driffield 8	20	Au-Qtz	196700	8445600	Occurrence	Burrell Creek Fm	Vein			
Driffield 9	21	Au-Qtz	197000	8445400	Small	Burrell Creek Fm	Vein			
Golf & Golf West	73	Au-Qtz	188300	8436500	Small	Burrell Creek Fm	Vein	31.00	3.08	0.91
Hotel	69	Au-Qtz	189400	8437100	Occurrence	Burrell Creek Fm	Vein			
Jones Brothers Reef	77	Au-Qtz	188300	8436500	Occurrence	Burrell Creek Fm	Vein	27.00		
Juliet	68	Au-Qtz	189400	8437100	Occurrence	Burrell Creek Fm	Vein			
Maud Creek 1	133	Au-Qtz	224300	8401900	Medium	Maud Dolerite/Tollis Fm	Vein	16.80	13.58	2.28
Maud Creek 2	134	Au-Qtz	226300	8401900	Occurrence	Maud Dolerite/Tollis Fm	Vein			
Maud Creek 3	135	Au-Qtz	226500	8401700	Occurrence	Maud Dolerite/Tollis Fm	Vein			
Maud Creek 4	138	Au-Qtz	226000	8401900	Occurrence	Maud Dolerite/Tollis Fm	Vein		0.02	3.1
Maud Creek 5	136	Au-Qtz	222700	8411800	Occurrence	Maud Dolerite	Vein			
Mount Gates	128	Au-Qtz	187000	8436000	Occurrence	Maud Dolerite	Vein			
Mount Todd (Batman)	72	Au-Qtz	226900	8401900	Large	Burrell Creek Fm	Vein	10044.15	176	1.03
Penguin	71	Au-Qtz	189000	8437400	Occurrence	Burrell Creek Fm	Vein			
Quigley's Extended	66	Au-Qtz	189600	8438200	Small	Burrell Creek Fm	Vein	27.40		

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Quigley's Reef (Central pit)	64	Au-Qtz	189700	8437900	Small	Burrell Creek Fm	Vein	36.00	1.2 includes all Quigleys	2.10
Quigley's Reef (North pit)	63	Au-Qtz	189600	8438100	Small	Burrell Creek Fm	Vein	125.00		
Quigley's Reef (South pit)	65	Au-Qtz	189500	8437700	Small	Burrell Creek Fm	Vein	123.20		
Regatta	70	Au-Qtz	190000	8437000	Small	Burrell Creek Fm	Vein		0.014	9.80
Robin	67	Au-Qtz	188300	8434800	Occurrence	Burrell Creek Fm	Vein			
Tollis	78	Au-Qtz	188400	8435900	Occurrence	Burrell Creek Fm	Vein		5.68	0.82
Tollis Reef	79	Au-Qtz	187200	8434600	Occurrence	Burrell Creek Fm	Vein			
Unnamed	30	Au-Qtz	189200	8442300	Occurrence	Burrell Creek Fm	Vein			
Unnamed Alluvials	10	Alluvial	199700	8449400	Occurrence	Czs	Placer			
Western Shear	137	Au-Qtz	225300	8402000	Occurrence	Maud Dolerite	Vein			
MOUNT DOREEN (Arunta Region)										
Terry's Pit	32	Au-Qtz	659700	7530900	Occurrence	Lander Rock beds	Vein			
MOUNT EVELYN Pine Creek Orogen)										
Arm	131	Au-Qtz	193000	8485800	Small	Mount Bonnie Fm	Vein			
Aston Hill	223	Au-Qtz	197000	8469300	Occurrence	Burrell Creek Fm	Vein	1.00		
Azaria	139	Au-BIF	190000	8454800	Occurrence	Mount Bonnie Fm	Stratabound			
Banana	111	Au-Qtz	188500	8487500	Occurrence	Mount Bonnie Fm	Vein			
Billabong (Milo)	128	Au-Qtz	192700	8486000	Occurrence	Mount Bonnie Fm	Vein			
Birdie	118	Au-Qtz	192000	8487300	Occurrence	Mount Bonnie Fm	Vein			
Boulder (Lake Wandie)	214	Alluvial	198700	8472700	Occurrence	Czs	Placer	47.50		
Brilliant	231	Au-Qtz	202000	8465200	Occurrence	Burrell Creek Fm	Vein			
Cornwall	143	Au-Qtz	193300	8483400	Occurrence	Burrell Creek Fm	Vein	40.00		
Coronation Hill	89	Au-Qtz	240900	8496600	Medium	Zamu Dolerite	Vein		4.85	4.30
Crow	137	Au-Qtz	192200	8484900	Occurrence	Mount Bonnie Fm	Vein			
Dingo	138	Au-BIF	190000	8485000	Occurrence	Mount Bonnie Fm	Stratabound	30.00		
Dustbowl	104	Au-Qtz	187300	8489000	Occurrence	Koolpin Fm	Vein			
Eagle	115	Au-Qtz	192000	8487500	Occurrence	Mount Bonnie Fm	Vein			
Eastern Extension	216	Alluvial	198700	8472700	Occurrence	Czs	Placer	4.00		
Eitherway	112	Alluvial	187500	8486500	Occurrence	Mount Bonnie Fm	Irregular			
Emu	134	Au-Qtz	191600	8485300	Occurrence	Mount Bonnie Fm	Vein	30.00		
Eureka Creek	140	Au-Qtz	193600	8485100	Occurrence	Mount Bonnie Fm	Vein			
Fosters	135	Au-Qtz	193000	8485300	Occurrence	Mount Bonnie Fm	Vein			
Four (Moline North)	122	Au-BIF	191700	8486500	Small	Mount Bonnie Fm	Stratabound	85.00		
Four Crown	120	Au-BIF	191400	8486700	Occurrence	Mount Bonnie Fm	Stratabound			
Fourex	121	Au-Qtz	191300	8486500	Occurrence	Mount Bonnie Fm	Vein			
Gilmortona (Kim prospect)	221	Alluvial	199700	8471000	Occurrence	Czs	Placer	10.00		
Gregs Prospect	212	Au-Qtz	195000	8473500	Occurrence	Burrell Creek Fm	Vein			
High Chinese	144	Au-Qtz	194700	8482500	Occurrence	Mount Bonnie Fm	Vein			
Highway	117	Au-Qtz	192100	8497500	Small	Mount Bonnie Fm	Vein	160.00		
Kendergarden	116	Au-Qtz	191600	8487500	Small	Mount Bonnie Fm	Vein	150.00		
Last Hope	239	Au-Qtz	201000	8458800	Occurrence	Burrell Creek Fm	Vein	0.60		
Lo	114	Au-Qtz	192100	8487600	Occurrence	Mount Bonnie Fm	Vein			
Low Chinese	148	Au-Qtz	197000	8479400	Occurrence	Burrell Creek Fm	Vein			
Mango	110	Au-BIF	189800	8488100	Occurrence	Mount Bonnie Fm	Stratabound			
Moline Dam	125	Au-BIF	192200	8486000	Small	Mount Bonnie Fm	Stratabound	1560.00	1.98	2.46
Mundogie Hill	6	Au-Qtz	210800	8552900	Occurrence	Mundogie Sandstone	Vein			

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Northern Hercules (Eureka)	119	Au-Qtz	192100	8487000	Small	Mount Bonnie Fm	Vein	4500.00 includes all deposits in Moline area	3.03	2.89
Paw Paw	146	Au-Qtz	195600	8480700	Occurrence	Burrell Creek Fm	Vein			
Police Camp	222	Alluvial	198400	8470800	Occurrence	Czs	Placer	31.00		
Redback	130	Au-Qtz	192900	8485900	Occurrence	Mount Bonnie Fm	Vein			
Rock Scorpion	217	Alluvial	196900	8471600	Occurrence	Czs	Placer			
Rockwall Prospect	213	Alluvial	196000	8472700	Occurrence	Czs	Placer			
Saunders Rush	224	Au-Qtz	204000	8469200	Occurrence	Burrell Creek Fm	Vein			
Saunders Rush Alluvials	225	Alluvial	204000	8469200	Occurrence	Czs	Placer	50.00		
Shamrock	132	Au-Qtz	197100	8486000	Occurrence	Burrell Creek Fm	Vein			
Simple Dreams	142	Au-Qtz	192600	8483500	Occurrence	Burrell Creek Fm	Vein			
Skinners	159	Au-Qtz	198100	8478100	Occurrence	Burrell Creek Fm	Vein			
Sneakys	233	Au-BIF	206500	8464700	Occurrence	Burrell Creek Fm	Stratabound			
South Alligator Valley deposits		U-Au				Koolpin Fm	Vein	359.00		
Southern Hercules (School)	123	Au-BIF	192400	8486600	Small	Mount Bonnie Fm	Stratabound	600.00		
Stockyard	124	Au-BIF	190000	8486000	Occurrence	Mount Bonnie Fm	Stratabound			
Swan	133	Au-BIF	191100	8485400	Occurrence	Mount Bonnie Fm	Stratabound	54.00		
Tableland	236	Au-Qtz	209200	8461700	Occurrence	Burrell Creek Fm	Vein			
Trig	126	Au-BIF	192500	8485800	Small	Mount Bonnie Fm	Stratabound	70.00		
Trig South	127	Au-BIF	192600	8485900	Occurrence	Mount Bonnie Fm	Stratabound			
Tumbling Dice	136	Au-BIF	191900	8485100	Small	Mount Bonnie Fm	Stratabound	780.00		
Unnamed	97	Alluvial	191000	8492000	Occurrence	Czs	Placer			
Unnamed	113	Au-Qtz	194500	8487700	Occurrence	Burrell Creek Fm	Vein			
Unnamed	145	Au-Qtz	195500	8481800	Occurrence	Mount Bonnie Fm	Vein			
Unnamed	215	Au-Qtz	196700	8472400	Occurrence	Burrell Creek Fm	Vein			
Unnamed	232	Au-Qtz	201100	8465100	Occurrence	Burrell Creek Fm	Vein			
Unnamed	245	Alluvial	191000	8459100	Occurrence	Czs	Placer			
Vivs	129	Au-Qtz	192900	8486000	Occurrence	Mount Bonnie Fm	Vein			
Wandie Belle	218	Alluvial	197300	8471300	Small	Czs	Placer	204.00		
Wandie King	220	Alluvial	197700	8470900	Small	Czs	Placer	252.00		
Waterhole	141	Au-Qtz	190800	8483200	Occurrence	Burrell Creek Fm	Vein			
Welcome Stranger	219	Alluvial	197700	8471200	Occurrence	Czs	Placer	22.40		
West Brilliant	230	Au-Qtz	200300	8465400	Occurrence	Mount Bonnie Fm	Vein			
Yemelba (Battery area)	13	Au-Qtz	226200	8543600	Occurrence	Masson Fm	Vein			
Yemelba Alluvial	14	Alluvial	225800	8543300	Occurrence	Czs	Placer	1.00		
Yemelba North	12	Au-Qtz	226200	8544400	Occurrence	Masson Fm	Vein	7.80		
MOUNT SOLITAIRE (Tanami Region/Arunta Region)										
Minotaur	1	Au-BIF	661200	7748600	Small	Mount Charles beds			1.84	2.3
Peters Prospect	2	Au-BIF	677600	7765500	Occurrence	Mount Charles beds	Stratabound			
NAPPERBY (Arunta Region)										
Aileron Gold Reefs	19	Au-Qtz	324400	7493300	Occurrence		Vein			
Lander 1	48	Au-Qtz	255000	7564000	Occurrence	Lander Rock beds	Vein			
Pine Hill	14	Au-Qtz	272400	7544300	Occurrence	Lander Rock beds	Vein			
PINE CREEK (Pine Creek Orogen)										
Afghan Gully	179	Au-BIF	772500	8499200	Small	Koolpin Fm	Stratiform	12.50		
Alligator	121	Au-Qtz	762100	8509700	Small	Gerowie Tuff	Vein	198.00	3.84	1.45

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Alligator Alluvials	120	Alluvial	760900	8509900	Occurrence	Czs	Placer			
Bashi Bazook	301	Au-Qtz	806100	8469200	Occurrence	Burrell Creek Fm	Vein			
Big Howley	128	Au-Qtz	753500	8506600	Small	Mount Bonnie Fm	Vein	404.00	0.35	2.1
Bonrook	330	Au-Qtz	812300	8461700	Occurrence	McCarthy's Granite	Vein			
Bridge Creek	94	Au-Qtz	751200	8512900	Occurrence	Gerowie Tuff	Vein	37.00	1.64	1.56
Bridge Creek Alluvials	93	Alluvial	751100	8513100	Small	Czs	Placer			
Brittania	102	Au-Qtz	764800	8511900	Small	Gerowie Tuff	Vein	26.00		
Burgan	345	Au-Qtz	762300	8509600	Small	Gerowie Tuff	Vein		0.30	2.38
Caledonian	292	Au-Qtz	807300	8472100	Occurrence	Burrell Creek Fm	Vein	14.00		
Caledonian Alluvials	291	Alluvial	810800	8473600	Occurrence	Czs	Placer			
Chin Phillips	311	Au-Qtz	807000	8468200	Occurrence	Burrell Creek Fm	Vein	360		
Chinese Howley	130	Au-Qtz	754500	8505400	Small	Gerowie Tuff	Vein	125.00	2.6	5.1
Christmas	306	Au-Qtz	806800	8468700	Small	Burrell Creek Fm	Vein			
Copperfield South	353	Au-Qtz	810500	8456500	Occurrence	Burrell Creek Fm	Vein			
Corbets	177	Au-BIF	772900	8499600	Occurrence	Koolpin Fm	Stratiform			
Cosmo Howley	151	Au-BIF	757200	8502200	Medium	Koolpin Fm	Stratiform	18750.00	10.0	2.75
Crocodile	119	Au-Qtz	761900	8509800	Small	Gerowie Tuff	Vein	198.00		
Crocodile Alluvials	118	Alluvial	761100	8509800	Occurrence	Czs	Placer			
Czarina	302	Au-Qtz	806300	8469000	Occurrence	Burrell Creek Fm	Vein	21.00		
Davis No 2	181	Au-BIF	777500	8499000	Small	Koolpin Fm	Stratiform	140.00		
Eleanor	308	Au-Qtz	806800	8468500	Small	Burrell Creek Fm	Vein	586.00		
Elizabeth	275	Au-Qtz	797600	8489000	Small	Burrell Creek Fm	Vein	107.00		
Elsinore	312	Au-Qtz	807400	8467700	Occurrence	Burrell Creek Fm	Vein	20.00		
Enterprise	299	Au-Qtz	805500	8469700	Medium	Mount Bonnie Fm	Vein	19400.00		
Esmeralda	343	Au-Qtz	805900	8477300	Small	Mount Bonnie Fm	Vein		0.64	1.84
Faded Lily	123	Au-Qtz	762500	8509500	Small	Gerowie Tuff	Vein	2760.00	3.40	1.73
Faded Lily Alluvials	122	Alluvial	762300	8509300	Small	Czs	Placer		0.19	1.10
Fishers Lode	174	Au-BIF	772700	8499900	Small	Koolpin Fm	Stratiform	125.00		
Fountain Head	154	Au-Qtz	771200	8509700	Small	Burrell Creek Fm	Vein	307.00		
Fountain Head Alluvials	153	Alluvial	771300	8509900	Small	Czs	Placer	217.00	1.6	1.70
Frances Creek	208	Au-Qtz	809900	8504500	Small	Mundogie Sandstone	Vein	4.00		
Gandys Hill	295	Au-Qtz	804500	8470800	Small	Mount Bonnie Fm	Vein	included in Enterprise		
Glencoe	103	Au-Qtz	771000	8512700	Small	Mount Bonnie Fm	Vein	112.00	1.50	1.90
Golden Dyke	183	Au-BIF	772500	8498200	Small	Koolpin Fm	Stratiform	793.00	1.60	3.80
Good Shepherd	173	Au-BIF	772000	8501400	Occurrence	Koolpin Fm	Stratiform			
Goodall	51	Au-Qtz	757100	8538100	Medium	Burrell Creek Fm	Stockwork	7104.00		
Great Northern	50	Au-Qtz	762700	8539400	Small	Burrell Creek Fm	Vein	112.00		
Great Western	44	Au-Qtz	759800	8542800	Small	Burrell Creek Fm	Vein	included in Great Northern		
H21 Prospect	338	Au-Qtz	754500	8549000	Occurrence	Burrell Creek Fm	Vein			
H22 Prospect	339	Au-Qtz	729500	8543000	Occurrence	Burrell Creek Fm	Vein			
H23 Prospect	340	Au-Qtz	736000	8540000	Occurrence	Burrell Creek Fm	Vein			
Homeward Bound	344	Au-Qtz	763000	8509000	Small	Gerowie Tuff	Vein			
Howley Alluvials	129	Alluvial	754700	8505500	Small	Czs	Placer	373.00	0.41	0.30
Howley North	127	Au-Qtz	752000	8508500	Occurrence	Mount Bonnie Fm	Vein			
Howley Ridge	352	Au-Qtz	751000	8510000	Small	Gerowie Tuff	Vein		1.21	1.34
International	294	Au-Qtz	804700	8470800	Occurrence	Mount Bonnie Fm	Vein	9.00		
Iron Blow	165	Au-Pb-Zn	776100	8504400	Small	Mount Bonnie Fm	Stratabound	124.00	1.07	2.16
Ios	347	Au-Qtz	751300	8517000	Small	Zamu Dolerite	Vein		0.81	1.6
John Bull	117	Au-Qtz	760000	8510000	Small	Gerowie Tuff	Vein	198.00		

Name Of 1:250,000 Sheet (Geological Unit)	No.	Type	Easting AGD 66	Northing AGD 66	Size	Formation	Shape	Production of au (kg)	Resource (Mt of ore)	Grade (g/t)
John Bull Alluvials	116	Alluvial	760600	8510100	Occurrence	Czs	Placer			
Kazi	349	Au-Qtz	752800	8523500	Small	Gerowie Tuff	Vein		1.58	2.1
Klondyke	155	Alluvial	771300	8508700	Occurrence	Czs	Placer			
Kohinoor	309	Au-Qtz	807000	8468500	Small	Burrell Creek Fm	Vein	41.00		
Lady Joesphine West	158	Au-Qtz	772300	8407200	Occurrence	Burrell Creek Fm	Vein			
Langleys	184	Au-BIF	775700	8498000	Small	Koolpin Fm	Stratiform	150.00		
Maid of Erin	298	Au-Qtz	805000	8470400	Occurrence	Mount Bonnie Fm	Vein	12.00		
Manners	124	Au-Qtz	762700	8509100	Occurrence	Koolpin Fm	Vein			
Margaret Diggings	187	Alluvial	779000	8496700	Small	Czs	Placer	40.00		
McKeddies	113	Alluvial	809100	8511200	Occurrence	Czs	Placer			
McKinley	87	Au-Qtz	796300	8516800	Occurrence	Mount Bonnie Fm	Vein			
Millars Lode	287	Au-Qtz	802100	8481200	Small	Burrell Creek Fm	Vein	1760.00		
Mount Bonnie	171	Au-Pb-Zn	775900	8501300	Small	Mount Bonnie Fm	Stratabound	620.00	0.65	1.7
Mount Paqualin	64		751400	8521700	Occurrence	Koolpin Fm	Stratiform			
Mount Ringwood Alluvials	45	Alluvial	783800	8542900	Occurrence	Czs	Placer			
Mount Tymn	61	Au-Qtz	740500	8527500	Occurrence	Burrell Creek Fm	Vein			
North Ringwood	46	Au-Qtz	784600	8543100	Occurrence	Burrell Creek Fm	Vein	87.00		
Old Workings	342	Au-Qtz	789000	8543000	Occurrence	Burrell Creek Fm	Vein			
Pelican	341	Au-Qtz	786000	8544000	Occurrence	Burrell Creek Fm	Vein			
Ping Quees Workings	285	Au-Qtz	801800	8481900	Small	Burrell Creek Fm	Vein	included in Millars		
Port Darwin Camp	168	Alluvial	774200	8502100	Occurrence	Czs	Placer			
Princess Louise	162	Au-Qtz	775900	8505800	Small	Gerowie Tuff	Vein	124.00		
Prospecting Claim Lode	283	Au-Qtz	801200	8482300	Small	Burrell Creek Fm	Vein	included in Millars		
Radfords Blow	163	Au-Qtz	775600	8505000	Occurrence	Mount Bonnie Fm	Vein	5.00		
Rhodes	350	Au-Qtz	751400	8518900	Small	Zamu Dolerite	Vein		0.77	1.88
Ringwood	48	Au-Qtz	787200	8539200	Occurrence	Burrell Creek Fm	Vein	87.00		
Rising Tide	101	Au-Qtz	763000	8512000	Small	Koolpin Fm	Vein	13.00	2.5	1.4
Sagabiel	303	Au-Qtz	806500	8469000	Occurrence	Burrell Creek Fm	Vein		1.94	1.72
Sandy Creek	169	Alluvial	773400	8501700	Small	Czs	Placer	142.00	0.50	0.40
Santorini	351	Au-Qtz	749800	8525700	Small	Gerowie Tuff	Vein			
Sikonos	348	Au-Qtz	751000	8512000	Small	Zamu Dolerite	Vein		0.4	1.97
Silver Coin Alluvials	305	Alluvial	807500	8469000	Small	Czs	Placer	250		
South Ringwood	49	Au-Qtz	786800	8538600	Occurrence	Burrell Creek Fm	Vein	87.00		
Spring Hill	262	Au-Qtz	794100	8494200	Small	Mount Bonnie Fm	Vein	697.00	12.75	0.80
Star of the North	43	Au-Qtz	754500	8546400	Small	Burrell Creek Fm	Vein	included in Great Northern		
Sultana	300	Au-Qtz	806200	8469500	Occurrence	Burrell Creek Fm	Vein	1.00		
Sundance	16		722300	8556000	Small	Coomalie Dolomite	Irregular	192.00	0.20	5.00
Union Extended	263	Au-Qtz	799800	8492500	Small	Burrell Creek Fm	Vein	165.00		
Union Extended Alluvials	265	Alluvial	800200	8492000	Small	Czs	Placer		0.30	0.30
Union Reefs (Crosscourse Lode)	284	Au-Qtz	801700	8482000	Large	Burrell Creek Fm	Vein	10375.16	17.6	1.7
Union Reefs Alluvials	286	Alluvial	801700	8481100	Small	Czs	Placer	300		
Unnamed	31	Au-Qtz	723200	8542300	Occurrence	Burrell Creek Fm	Vein			
Unnamed	47	Au-Qtz	785500	8541000	Occurrence	Burrell Creek Fm	Vein			
Unnamed	62	Au-Qtz	740500	8526500	Occurrence	Burrell Creek Fm	Vein			
Unnamed	125	Au-Qtz	763300	8508700	Occurrence	Gerowie Tuff	Vein			
Unnamed	277	Alluvial	798000	8487800	Occurrence	Czs	Placer			
Unnamed	290	Alluvial	813600	8474600	Occurrence	Czs	Placer			

Name Of 1:250,000 Sheet (Geological Unit)	No.	Type	Easting AGD 66	Northing AGD 66	Size	Formation	Shape	Production of au (kg)	Resource (Mt of ore)	Grade (g/t)
Unnamed	293	Au-Qtz	804200	8471200	Occurrence	Burrell Creek Fm	Vein			
Unnamed	296	Alluvial	800900	8470200	Occurrence	Czs	Irregular			
Unnamed	307	Alluvial	800700	8468700	Occurrence	Czs	Placer			
Unnamed	310	Au-Qtz	807200	8468400	Occurrence	Burrell Creek Fm	Vein			
Virginia	30	Au-Qtz	722500	8542900	Occurrence	Burrell Creek Fm	Vein	1.00		
Watts Creek	211	Alluvial	805700	8499500	Occurrence	Czs	Placer	1.00		
West of Christmas	304	Au-Qtz	806700	8468800	Occurrence	Burrell Creek Fm	Vein			
Western Arm	346	Au-Qtz	749000	8516100	Small	Mount Bonnie Fm	Vein		2.47	1.31
Woolwonga	89	Au-Qtz	776100	8516200	Small	Mount Bonnie Fm	Vein	4031.00		
Woolwonga Alluvials	88	Alluvial	776500	8516300	Small	Czs	Placer			
Yam Creek	160	Au-Qtz	775800	8506400	Small	Mount Bonnie Fm	Vein	238.00	1.47	1.28
Yam Creek Alluvials	161	Alluvial	775700	8506100	Occurrence	Czs	Placer			
Zapopan	126	Au-Qtz	763800	8508700	Small	Gerowie Tuff	Vein	6069.00[1]	0.48	4.80
PORT KEATS (Pine Creek Orogen)										
B1	10	Au-Qtz	656000	8430000	Occurrence	Berinka Volcanics	Vein			
TANAMI (Tanami Region)										
Banjo North		Au-Qtz	541716	7792000	Small	Mount Charles Fm	Vein			
Beaver Creek		Au-Qtz	542493	7791503	Small	Mount Charles Fm	Vein		0.63	4.1
Bonsai		Au-Qtz	541244	7791689	Small	Mount Charles Fm	Vein		0.1	3.2
Browns Range	1	Au-Qtz	516600	7895900	Small	Mount Charles Fm	Vein			
Carbine		Au-Qtz	571999	7787998	Small	Mount Charles Fm	Vein			
Crusade		Au-Qtz	661500	7882000	Small	Mount Charles Fm	Vein		1.135	2.8
Galifrey		Au-Qtz	560469	7769877	Small	Tonalite	Vein		0.225	1.1
Guam	7	Au-Qtz	575000	7794000	Occurrence	Mount Charles Fm	Vein			
Jasper Hill	2	Au-Qtz	611800	7836100	Occurrence	Mount Charles Fm	Vein			
Kokoda		Au-Qtz	661500	7885000	Occurrence	Mount Charles Fm				
Kudo	39	Au-Qtz	574000	7789000	Occurrence	Mount Charles Fm	Vein			
Marlena		Au-Qtz	538845	7793638	Small	Mount Charles Fm				
Stoney Ridge	3	Au-Qtz	612900	7834700	Occurrence	Mount Charles Fm	Vein			
Tanami Airstrip	13	Au-Qtz	574900	7792300	Small	Mount Charles Fm	Vein			
Tanami Assault	26	Au-Qtz	574200	7791000	Small	Mount Charles Fm	Vein			
Tanami B-C	22	Au-Qtz	574200	7791300	Small	Mount Charles Fm	Vein			
Tanami Bastille	28	Au-Qtz	574200	7790800	Small	Mount Charles Fm	Vein			
Tanami Battery	27	Au-Qtz	574400	7791000	Small	Mount Charles Fm	Vein			
Tanami Bouncer	37	Au-Qtz	572200	7790000	Small	Mount Charles Fm	Vein			
Tanami Bumper	36	Au-Qtz	572400	7790300	Small	Mount Charles Fm	Vein			
Tanami Central	24	Au-Qtz	574400	7791500	Small	Mount Charles Fm	Vein			
Tanami Dice	10	Au-Qtz	575500	7793100	Small	Mount Charles Fm	Vein			
Tanami Dingo	15	Au-Qtz	574200	7792400	Small	Mount Charles Fm	Vein			
Tanami Dinky	8	Au-Qtz	576000	7794000	Small	Mount Charles Fm	Vein			
Tanami Gatling	35	Au-Qtz	572800	7790400	Occurrence	Mount Charles Fm	Vein			
Tanami Grapple	12	Au-Qtz	575200	7792500	Small	Mount Charles Fm	Vein			
Tanami Hurricane-Repulse	14	Au-Qtz	574800	7792700	Medium	Mount Charles Fm	Vein	13007.00[2]	2.17	2.70
Tanami Lauries	23	Au-Qtz	574200	7791500	Small	Mount Charles Fm	Vein			
Tanami Melon	21	Au-Qtz	573800	7791600	Occurrence	Mount Charles Fm	Vein			
Tanami Miracle	31	Au-Qtz	573000	7790900	Small	Mount Charles Fm	Vein			
Tanami Reward	25	Au-Qtz	574000	7791200	Small	Mount Charles Fm	Vein			

[1] Includes total gold production from the Brocks Creek area by GBS during till June 2008.
[2] Includes the entire Tanami goldfield.

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Tanami Second Southern	33	Au-Qtz	573200	7790300	Occurrence	Mount Charles Fm	Vein			
Tanami Shovel	20	Au-Qtz	573900	7791900	Occurrence	Mount Charles Fm	Vein			
Tanami Snoopy	11	Au-Qtz	575700	7792800	Occurrence	Mount Charles Fm	Vein			
Tanami Southern	32	Au-Qtz	573500	7790700	Small	Mount Charles Fm	Vein			
Tanami Splinter	9	Au-Qtz	575700	7794100	Occurrence	Mount Charles Fm	Vein			
Tanami Tangent	19	Au-Qtz	574300	7792000	Small	Mount Charles Fm	Vein			
Tanami Temby	18	Au-Qtz	574700	7791600	Small	Mount Charles Fm	Vein			
Tanami Temby North	16	Au-Qtz	574900	7791900	Small	Mount Charles Fm	Vein			
Tanami Temby South	17	Au-Qtz	574600	7791500	Small	Mount Charles Fm	Vein			
Tanami Tombola	29	Au-Qtz	573400	7791500	Occurrence	Mount Charles Fm	Vein			
Tanami Trasher	38	Au-Qtz	572500	7789000	Small	Mount Charles Fm	Vein			
Tanami Unnamed	30	Au-Qtz	573000	7790600	Occurrence	Mount Charles Fm	Vein			
Tanami Unnamed	34	Au-Qtz	573300	7791200	Occurrence	Mount Charles Fm	Vein			
The Grange	4	Au-Qtz	610000	7830000	Occurrence	Mount Charles Fm	Vein			
Troy	6	Au-Qtz	570000	7800500	Occurrence	Mount Charles Fm	Vein			
TENNANT CREEK (Tennant Inlier)										
Ace High	121	Au-Mt	417200	7829500	Occurrence	Warramunga Fm	Stratabound	3.40		
Aga Khan	94	Au-Mt	425900	7831700	Occurrence	Warramunga Fm	Stratabound	3.00		
Ajax	151	Au-Mt	416900	7826000	Occurrence	Warramunga Fm	Stratabound	0.10		
Anomaly C6 (Explorer 104)	96	Au-Mt	405900	7831300	Occurrence	Warramunga Fm	Pipe			
Arcadia	164	Au-Mt	405600	7824100	Occurrence	Warramunga Fm	Podiform			
Argo (Explorer 46)	166	Au-Mt	418400	7824700	Small	Warramunga Fm	Pipe	2050.00		
Arizona	105	Au-Mt	423000	7830800	Occurrence	Warramunga Fm	Stratabound	1.00		
Bernborough	20	Au-Mt	410100	7855100	Occurrence	Bernborough Fm	Podiform			
Billy Boy		Au-Mt	436695	7832900	Occurrence	Warramunga Fm	Podiform			
Big Ben	139	Au-Mt	413200	7827300	Occurrence	Warramunga Fm	Stratabound	0.90		
Bishops Creek	45	Au-Mt	406200	7849300	Occurrence	Warramunga Fm	Podiform			
Black Angel	54	Au-Mt	384100	7844700	Small	Warramunga Fm	Podiform	175.50		
Black Boy	203	Au-Mt	432100	7819600	Occurrence	Warramunga Fm	Podiform			
Black Cat	71	Au-Mt	430700	7833700	Occurrence	Warramunga Fm	Stratabound	31.80		
Black Eye	41	Au-Mt	389500	7849400	Occurrence	Warramunga Fm	Podiform	5.00		
Blue Bird	149	Au-Mt	447600	7826900	Occurrence	Warramunga Fm	Podiform	16.10		
Blue Moon	115	Au-Mt	439100	7832200	Small	Warramunga Fm	Pipe	417.30		
Bull Pup	16	Au-Mt	380700	7862400	Occurrence	Wundirgi Fm	Vein	1.70		
Burnt Shirt	122	Au-Mt	417100	7829200	Occurrence	Warramunga Fm	Podiform	63.00		
Caroline	98	Au-Mt	411400	7831600	Occurrence	Warramunga Fm	Stratabound	9.05		
Carraman	4	Au-Mt	416800	7865300	Occurrence	Warramunga Fm	Vein	4.00		
Cat's Whiskers (Eldorado An. 4	189	Au-Mt	416300	7821300	Occurrence	Warramunga Fm	Podiform	3.60		
Chariot (Chardonnay)	-	Au-Mt	405300	7826500	Small	Warramunga Fm	Tabular			
Cleos Gift (TC36)	49	Au-Mt	408000	7847500	Occurrence	Warramunga Fm	Podiform	0.70		
Colorado	100	Au-Mt	411700	7831000	Occurrence	Warramunga Fm	Stratabound	0.14		
Comet	158	Au-Mt	424500	7825300	Occurrence	Warramunga Fm	Pipe			
Comstock	209	Au-Mt	442400	7819000	Occurrence	Warramunga Fm	Stratabound	35.80		
Crusader	53	Au-Mt	383900	7844700	Occurrence	Warramunga Fm	Podiform	1.20		
Curlew (Explorer 63)	59	Au-Mt	392600	7838600	Occurrence	Warramunga Fm	Stratabound			
Desert Gold	206	Au-Mt	436700	7819300	Occurrence	Warramunga Fm	Stratabound	0.90		
Desert Hope	211	Au-Mt	443700	7818400	Occurrence	Warramunga Fm	Stratabound	1.30		
Desert Queen	21	Au-Mt	405000	7854600	Occurrence	Warramunga Fm	Podiform	0.30		
Dolomite	157	Au-Mt	416900	7825000	Occurrence	Felsic porphyry	Vein	9.40		

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Dot	169	Au-Mt	413200	7830700	Occurrence	Warramunga Fm	Stratabound	0.50		
Edna Beryl	6	Au-Mt	416500	7864700	Small	Warramunga Fm	Stratabound	137.00	0.006	36.00
Eldorado	185	Au-Mt	415400	7821800	Small	Warramunga Fm	Pipe	3793.40	0.03	20.8
Eldorado An. 3	187	Au-Mt	416100	7821800	Occurrence	Warramunga Fm	Podiform		0.04	3.00
Ellen M.	188	Au-Mt	416100	7821400	Occurrence	Warramunga Fm	Podiform	0.40		
Enterprise	183	Au-Mt	414500	7821800	Small	Warramunga Fm	Pipe	170.00		
Estralita	182	Au-Mt	414100	7822100	Occurrence	Warramunga Fm	Stratabound	1.20		
Explorer 109	127	Au-Mt	418900	7828500	Occurrence	Warramunga Fm	Pipe			
Explorer 117 (Semillon)	44	Au-Mt	394200	7848600	Occurrence	Warramunga Fm	Podiform			
Explorer 118 (Pinot)	39	Au-Mt	394400	7851000	Occurrence	Warramunga Fm	Podiform			
Explorer 13	61	Au-Mt	400200	7837200	Occurrence	Warramunga Fm	Pipe			
Explorer 26 (Hermitage)	9	Au-Mt	410800	7864100	Occurrence	Warramunga Fm	Podiform			
Explorer 28	160	Au-Mt	404000	7823800	Occurrence	Warramunga Fm	Podiform			
Explorer 38	165	Au-Mt	417800	7824500	Occurrence	Warramunga Fm	Podiform		11.50	0.90
Explorer 41	64	Au-Mt	405300	7836400	Occurrence	Warramunga Fm	Podiform			
Explorer 45	142	Au-Mt	414100	7827400	Occurrence	Warramunga Fm	Podiform			
Explorer 93	42	Au-Mt	388400	7849000	Occurrence	Warramunga Fm	Podiform			
Eyes of Youth	75	Au-Mt	411700	7833400	Occurrence	Warramunga Fm	Podiform			
Fassifern	150	Au-Mt	416500	7825900	Occurrence	Warramunga Fm	Stratabound	22.00		
Gecko	26	Au-Mt	401900	7851200	Medium	Warramunga Fm	Podiform	3450		
Giant Moon	68	Au-Mt	436400	7834100	Occurrence	Warramunga Fm	Podiform			
Gibbet	138	Au-Mt	411700	7826700	Occurrence	Warramunga Fm	Podiform			
Gigantic	69	Au-Mt	436700	7834000	Occurrence	Warramunga Fm	Stratabound	16.10		
Golden Chance	28	Au-Mt	401000	7851100	Occurrence	Warramunga Fm	Podiform	5.20		
Golden Dingo	205	Au-Mt	433300	7818100	Occurrence	Warramunga Fm	Podiform			
Golden Forty	173	Au-Mt	428600	7823300	Small	Warramunga Fm	Pipe	1761.70		
Golden Kangaroo	171	Au-Mt	429900	7823700	Small	Warramunga Fm	Vein	1.60	0.02	22.00
Golden Key	90	Au-Mt	425800	7832000	Occurrence	Warramunga Fm	Podiform	0.40		
Golden Mile	146	Au-Mt	445600	7826700	Occurrence	Warramunga Fm	Podiform	3.00		
Golden Slipper	19	Au-Mt	405000	7856500	Occurrence	Warramunga Fm	Vein	3.80		
Granites	12	Au-Mt	410500	7863500	Occurrence	Warramunga Fm	Podiform	0.10		
Great Bear	118	Au-Mt	427800	7830000	Occurrence	Warramunga Fm	Podiform	5.40		
Great Eastern	174	Au-Mt	429200	7823000	Occurrence	Warramunga Fm	Stratabound	8.70		
Great Northern	103	Au-Mt	415000	7831200	Occurrence	Warramunga Fm	Podiform	17.30		
Great Western	40	Au-Mt	394500	7849300	Occurrence	Warramunga Fm	Podiform	15.60		
Hammerjack	180	Au-Mt	412800	7822300	Small	Warramunga Fm	Podiform	189.10		
Havelock (Tasman)	37	Au-Mt	400300	7850400	Occurrence	Warramunga Fm	Podiform	0.90		
Hidden Mystery	76	Au-Mt	413100	7833000	Occurrence	Warramunga Fm	Podiform	0.40		
Hill 98	136	Au-Mt	411500	7827500	Occurrence	Warramunga Fm	Podiform	6.00		
Hopeful Star	85	Au-Mt	431000	7832600	Occurrence	Warramunga Fm	Podiform	29.60		
Hopeful Star East	86	Au-Mt	431300	7832500	Occurrence	Warramunga Fm	Podiform	7.70		
IMO	181	Au-Mt	412500	7822000	Occurrence	Warramunga Fm	Podiform			
International (Rosebud)	154	Au-Mt	419600	7825700	Occurrence	Warramunga Fm	Podiform	0.06		
Iris	89	Au-Mt	425400	7832000	Occurrence	Warramunga Fm	Podiform	0.05		
Ivanhoe	62	Au-Mt	400800	7837100	Small	Warramunga Fm	Podiform	847		
Jaqueline The Great (Euro)	95	Au-Mt	410700	7831900	Occurrence	Warramunga Fm	Podiform			
Joker	192	Au-Mt	427600	7821500	Occurrence	Warramunga Fm	Podiform	30.80		
Jubilee	120	Au-Mt	406600	7830000	Small	Warramunga Fm	Podiform	246.80		
Juno	190	Au-Mt	420300	7821000	Medium	Warramunga Fm	Podiform	26070.00		
Kathleen	125	Au-Mt	417900	7829000	Occurrence	Warramunga Fm	Podiform	35.90		
Kimberly Kids (ABC)	200	Au-Mt	426400	7820000	Occurrence	Warramunga Fm	Podiform	16.30		

Name Of 1:250,000 Sheet (Geological Unit)	No.	Type	Easting AGD 66	Northing AGD 66	Size	Formation	Shape	Production of au (kg)	Resource (Mt of ore)	Grade (g/t)
Kiora	159	Au-Mt	431100	7825500	Occurrence	Warramunga Fm	Stratabound	31.70		
Klondyke	5	Au-Mt	417000	7865200	Occurrence	Warramunga Fm	Podiform	0.30		
Lady Mary	117	Au-Mt	438000	7830600	Occurrence	Warramunga Fm	Podiform	0.40		
Last Hope	15	Au-Mt	380300	7862700	Occurrence	Wundirgi Fm	Vein	12.90		
Leichardt	124	Au-Mt	417400	7829000	Occurrence	Warramunga Fm	Podiform	26.00		
Little Ben	145	Au-Mt	413500	7826500	Occurrence	Warramunga Fm	Podiform	3.40		
Little Wonder	81	Au-Mt	427600	7832600	Occurrence	Warramunga Fm	Podiform	2.60		
Lone Star	107	Au-Mt	424000	7830500	Small	Warramunga Fm	Pipe	176.20		
Mammoth	79	Au-Mt	426900	7832800	Occurrence	Warramunga Fm	Podiform	3.90		
Maple Leaf	110	Au-Mt	424800	7830800	Occurrence	Warramunga Fm	Podiform	0.80		
Marathon	2	Au-Mt	414200	7865900	Occurrence	Warramunga Fm	Podiform			
Marion Ross	29	Au-Mt	400700	7851300	Occurrence	Warramunga Fm	Podiform	5.70		
Mary Anne	87	Au-Mt	417200	7832200	Occurrence	Warramunga Fm	Vein	5.80		
Mary Lane	74	Au-Mt	411500	7833400	Occurrence	Warramunga Fm	Vein	0.60		
Mascot (Trig)	73	Au-Mt	410500	7833600	Occurrence	Warramunga Fm	Podiform	10.85		
Mauretania	83	Au-Mt	430800	7833100	Occurrence	Warramunga Fm		6.70		
Memsahib	93	Au-Mt	426100	7831900	Occurrence	Warramunga Fm	Podiform	4.40		
Metallic Hill	116	Au-Mt	437800	7831100	Occurrence	Warramunga Fm	Stratabound	4.80		
Miriam	179	Au-Mt	412600	7822300	Occurrence	Warramunga Fm		0.20		
Morning Star (Raias Revenge)	18	Au-Mt	406500	7856900	Occurrence	Warramunga Fm	Podiform			
Mount Argo	46	Au-Mt	406800	7848800	Occurrence	Warramunga Fm	Podiform	1.20		
Mount Margaret	82	Au-Mt	428600	7833100	Occurrence	Warramunga Fm				
Mount Otto	97	Au-Mt	408600	7831500	Occurrence	Warramunga Fm		0.50		
Mount Samuel (Sheridan)	176	Au-Mt	411300	7822600	Small	Warramunga Fm	Podiform	139.00		
Navigator 11	56	Au-Mt	383300	7841500	Occurrence	Warramunga Fm	Podiform			
New Hope	207	Au-Mt	440900	7819400	Small	Warramunga Fm	Podiform	45.00		
New Moon	84	Au-Mt	432100	7833200	Occurrence	Warramunga Fm	Pipe	0.40		
Nobles Nob	199	Au-Mt	425600	7819900	Medium	Warramunga Fm	Podiform	34580.50		
Nobles Nob West	198	Au-Mt	424600	7819800	Occurrence	Warramunga Fm	Stratabound			
North Star	10	Au-Mt	410700	7863700	Occurrence	Warramunga Fm	Podiform	0.60		
Northern Star	14	Au-Mt	410100	7863600	Small	Warramunga Fm	Podiform	810.50		
Occidental	47	Au-Mt	407000	7848500	Occurrence	Warramunga Fm	Podiform	2.20		
Olivewood	38	Au-Mt	400000	7849800	Occurrence	Warramunga Fm	Podiform	3.70		
One-oh-two	35	Au-Mt	399200	7850200	Occurrence	Warramunga Fm	Podiform			
Orlando	32	Au-Mt	397900	7850100	Small	Warramunga Fm	Vein	3772.00		
Orlando East	33	Au-Mt	398200	7850000	Small	Warramunga Fm	Vein	455.10		
Ortelle Star	126	Au-Mt	418000	7828600	Occurrence	Warramunga Fm	Pipe	0.30		
Outlaw (Black Sheep)	177	Au-Mt	411900	7822400	Occurrence	Warramunga Fm	Pipe	5.90		
Patties	184	Au-Mt	414700	7821800	Occurrence	Warramunga Fm	Pipe	48.20		
Peko	168	Au-Mt	424800	7823800	Medium	Warramunga Fm	Pipe	7481	3.75	1.1
Perseverance	148	Au-Mt	447200	7827000	Occurrence	Warramunga Fm	Podiform	6.00		
Perseverance Extended	147	Au-Mt	446900	7826900	Occurrence	Warramunga Fm	Podiform			
Peter Pan	140	Au-Mt	413700	7827300	Occurrence	Warramunga Fm	Vein	6.30		
Pinnacles	152	Au-Mt	417200	7826000	Occurrence	Warramunga Fm	Pipe	43.60		
Plain Jane	109	Au-Mt	424200	7830700	Occurrence	Warramunga Fm	Pipe	21.00		
Plumb	208	Au-Mt	441900	7819100	Occurrence	Warramunga Fm	Podiform			
Premier	58	Au-Mt	389400	7839000	Occurrence	Warramunga Fm	Pipe	0.40		
Pup	156	Au-Mt	416600	7825000	Occurrence	Warramunga Fm	Pipe	1.20		
Queen of Sheba	22	Au-Mt	405500	7855000	Occurrence	Warramunga Fm		13.70		
R22	193	Au-Mt	430000	7822500	Occurrence	Warramunga Fm	Podiform			

Name Of 1:250,000 Sheet (Geological Unit)	No.	Type	Easting AGD 66	Northing AGD 66	Size	Formation	Shape	Production of au (kg)	Resource (Mt of ore)	Grade (g/t)
Red Ned	178	Au-Mt	412300	7822400	Occurrence	Warramunga Fm	Pipe	12.90		
Red Terror	204	Au-Mt	432500	7819600	Occurrence	Warramunga Fm	Pipe	43.90		
Renate	129	Au-Mt	437900	7827500	Occurrence	Warramunga Fm	Pipe	0.45		
Rising Sun	202	Au-Mt	427400	7819700	Small	Warramunga Fm	Podiform	407.20		
Shamrock	119	Au-Mt	414000	7830300	Occurrence	Warramunga Fm	Podiform	0.30		
Skipper	162	Au-Mt	405200	7823900	Occurrence	Warramunga Fm	Pipe	16.00		
Skipper Extended	161	Au-Mt	404900	7824000	Small	Warramunga Fm	Podiform	201.30		
Southern Cross	175	Au-Mt	410800	7823100	Occurrence	Warramunga Fm	Pipe	25.00		
Southern Star	155	Au-Mt	415800	7825500	Occurrence	Warramunga Fm	Podiform	13.80		
Susan	153	Au-Mt	419300	7826000	Occurrence	Warramunga Fm	Podiform	4.00		
TC12	137	Au-Mt	411700	7826900	Occurrence	Warramunga Fm	Podiform			
TC40	77	Au-Mt	425900	7833400	Occurrence	Warramunga Fm	Podiform			
TC8	135	Au-Mt	410600	7826800	Small	Warramunga Fm	Pipe	1420.00	0.10	0.3
The Extension	130	Au-Mt	400200	7826700	Occurrence	Warramunga Fm	Podiform	5.90		
The Mount	186	Au-Mt	415800	7821500	Occurrence	Warramunga Fm	Podiform	1.80		
Three Keys	80	Au-Mt	427500	7832800	Occurrence	Warramunga Fm	Podiform	9.10		
Three thirty (Black Snake)	172	Au-Mt	429400	7823400	Occurrence	Warramunga Fm	Podiform	22.40		
True Blue	104	Au-Mt	421700	7831000	Occurrence	Warramunga Fm	Podiform	0.50		
Trump	11	Au-Mt	425500	7830500	Occurrence	Warramunga Fm	Podiform	0.10		
Tunnel	195	Au-Mt	433000	7822400	Occurrence	Warramunga Fm	Podiform	0.80		
Two Blues (Archangel)	197	Au-Mt	425000	7820500	Occurrence	Warramunga Fm	Podiform	20.20		
Unnamed	70	Au-Mt	425900	7834100	Occurrence	Warramunga Fm	Podiform			
Unnamed	194	Au-Mt	430800	7822600	Occurrence	Warramunga Fm	Podiform			
Unnamed	196	Au-Mt	433400	7822100	Occurrence	Warramunga Fm	Podiform			
Unnamed	170	Au-Mt	429500	7823700	Occurrence	Warramunga Fm	Podiform			
Unnamed	108	Au-Mt	424100	7830800	Occurrence	Warramunga Fm	Podiform			
Unnamed	36	Au-Mt	399700	7850000	Occurrence	Warramunga Fm	Podiform			
Vivid (Explorer 166)	17	Au-Mt	408600	7857000	Occurrence	Warramunga Fm	Podiform			
Warrego (Explorer 5)	43	Au-Mt	377000	7849100	Medium	Warramunga Fm	Pipe	39607.00	0.036	0.9
Weabers Find	201	Au-Mt	426700	7819600	Occurrence	Warramunga Fm	Podiform	3.00		
Wedge (Golden Boy)	123	Au-Mt	417400	7829100	Occurrence	Warramunga Fm	Podiform			
West Gibbet	134	Au-Mt	409400	7826800	Occurrence	Warramunga Fm	Podiform			
West Peko	167	Au-Mt	423000	7824300	Small	Warramunga Fm	Pipe			
Westward Ho	163	Au-Mt	405400	7824100	Occurrence	Warramunga Fm	Pipe	28.70		
Wheal Doria	141	Au-Mt	414000	7827400	Small	Warramunga Fm	Podiform	102.60		
Whippet	7	Au-Mt	425800	7865600	Small	Warramunga Fm	Pipe	583.70		
White Devil	55	Au-Mt	384600	7844800	Medium	Warramunga Fm.	Podiform	23110	0.35	15.7
THE GRANITES (Tanami Region)										
Anomaly 2	25	Au-Qtz	620000	7727000	Occurrence	Dead Bullock Fm	Vein			
Apertawonga	12	Au-Qtz	556500	7762000	Occurrence	Dead Bullock Fm	Vein			
Bulldog		Au-Qtz	574000	7784000	Small	Dead Bullock Fm	Vein			
Calamari	10	Au-Qtz	572000	7766000	Occurrence	Dead Bullock Fm	Vein			
Cashel		Au-Qtz	702469	7728764	Small	Dead Bullock Fm	Vein			
Carlsburg	9	Au-Qtz	570000	7775000	Occurrence	Dead Bullock Fm	Vein			
Challenger	13	Au-Qtz	615000	7778400	Occurrence	Dead Bullock Fm	Vein			
Chimera		Au-Qtz	661730	7748360	Small	Dead Bullock Fm	Vein			
Daddy		Au-Qtz	570100	7784900	Small	Mount Charles Fm	Vein			
DBS - Avon	32	Au-BIF	597100	7729700	Small	Dead Bullock Fm	Stratabound		0.198	2.90
DBS - Callie	33	Au-BIF	596300	7729800	Medium	Dead Bullock Fm	Stratabound	184868[3]	14.50	4.98

[3] Includes entire DBS and The Granites goldfields.

Name Of 1:250,000 Sheet (Geological Unit)	No.	Type	Easting AGD 66	Northing AGD 66	Size	Formation	Shape	Production of au (kg)	Resource (Mt of ore)	Grade (g/t)
DBS - Colliwobble	27	Au-BIF	597900	7729800	Small	Dead Bullock Fm	Stratabound		0.553	3.00
DBS - Fumarole	31	Au-BIF	597000	7729800	Small	Dead Bullock Fm	Stratabound		0.384	2.90
DBS - Gahn	34	Au-BIF	595800	7730100	Small	Dead Bullock Fm	Stratabound		0.057	3.00
DBS - Ridge	29	Au-BIF	598100	7730100	Small	Dead Bullock Fm	Stratabound		1.23	3.3
DBS - Sleepy Hollow	28	Au-BIF	597700	7720700	Small	Dead Bullock Fm	Stratabound		0.145	2.30
DBS - Triumph Hill	26	Au-BIF	598300	7730000	Small	Dead Bullock Fm	Stratabound		0.259	3.3
DBS - Villa	30	Au-BIF	597200	7730100	Small	Dead Bullock Fm	Stratabound		2.75	3.70
Dogbolter Main	7	Au-Qtz	569500	7781700	Small	Dead Bullock Fm	Vein			
Dogbolter Northeast	39	Au-Qtz	569900	7782300	Small	Mount Charles Fm	Vein		1.155	3.8
Funnelweb		Au-Qtz	571200	7786500		Mount Charles Fm				
Harleys	3	Au-Qtz	570800	7789000	Small	Mount Charles Fm	Vein			
Hordern Hills	24	Au-Qtz	638000	7716000	Occurrence	Dead Bullock Fm	Vein			
Huntsman		Au-Qtz	570900	7785500	Small	Mount Charles Fm	Vein			
Jims Main	8	Au-Qtz	556500	7777000	Small	Mount Charles Fm	Vein		2.545	2.5
Jims West		Au-Qtz	566000	7775000	Small	Mount Charles Fm	Vein			
Katipo		Au-Qtz	570500	7785400	Small	Mount Charles Fm	Vein			
Legs		Au-Qtz	570000	7784000	Small	Mount Charles Fm	Vein			
Lynx		Au-Qtz	569500	7784000	Small	Mount Charles Fm	Vein			
Magellan 2	35	Au-Qtz	560000	7773000	Occurrence	Dead Bullock Fm	Vein			
Minotaur	40	Au-Qtz	661200	7748300	Small	Dead Bullock Fm	Vein		0.84	2.61
Money		Au-Qtz	571500	7786300	Small	Mount Charles Fm	Vein			
Oberon		Au-Qtz	602249	7756335	Small	Dead Bullock Fm	Vein		4.80	2.4
Officer Hill	36	Au-Qtz	568000	7710000	Occurrence	Dead Bullock Fm	Vein			
Old Pirate		Au-Qtz	516959	7767045	Occurrence	Dead Bullock Fm	Vein			
Phoenix		Au-Qtz	571500	7787500	Small	Mount Charles Fm	Vein			
Ptilotus	16	Au-Qtz	621000	7756000	Occurrence	Mount Charles Fm	Vein			
Red Eye	14	Au-Qtz	600300	7763000	Occurrence	Mount Charles Fm	Vein			
Redback North	1	Au-Qtz	572000	7788000	Occurrence	Mount Charles Fm	Vein			
Redback Rise NW Pod	2	Au-Qtz	572000	7789500	Small	Mount Charles Fm	Vein			
Redback Rise Spider Zone	4	Au-Qtz	570800	7784300	Small	Mount Charles Fm	Vein		1.968	3.6
Redback SE	6	Au-Qtz	570800	7784100	Small	Mount Charles Fm	Vein			
Redback SW	5	Au-Qtz	570400	7784300	Small	Mount Charles Fm	Vein			
The Granites Bunkers Hill	17	Au-BIF	641500	7725700	Small	Dead Bullock Fm	Stratabound		0.85	3.40
The Granites Central Bullakitchie	19	Au-BIF	637200	7728400	Small	Dead Bullock Fm	Stratabound			
The Granites East Bullakitchie	18	Au-BIF	637800	7727700	Small	Dead Bullock Fm	Stratabound			
The Granites Ivy	23	Au-BIF	633000	7728000	Small	Dead Bullock Fm	Stratabound			
The Granites Quorn	22	Au-BIF	634900	7728300	Small	Dead Bullock Fm	Stratabound		1.49	3.46
The Granites Shoe	21	Au-BIF	636300	7728700	Small	Dead Bullock Fm	Stratabound		1.30	4.67
The Granites West Bullakitchie	20	Au-BIF	637100	7728400	Small	Dead Bullock Fm	Stratabound			
Titania	15	Au-Qtz	600200	7759000	Occurrence	Dead Bullock Fm	Vein		4.11	2.60
Wild Turkey	11	Au-Qtz	559000	7767000	Occurrence	Dead Bullock Fm	Vein			

Most production and resources are correct to December 2007. Deposit number refers to the MODAT mineral deposit database. Size classification is based on production plus resources of Au, as follows: Occurrence, less than 100 kg; Small, 100–1000 kg; Medium, 1000-5000 kg; and Large, greater than 5000 kg.