Accessing Australia’s Final Exploration Frontier

AGES 2006

Record of Abstracts

28-29 March, Alice Springs Convention Centre

Incorporating the 2006 Mining Services Expo

Hosted by the NT Geological Survey, Department of Primary Industry, Fisheries and Mines
Supported by Mining and Petroleum Services, Department of Business, Economic and Regional Development

www.minerals.nt.gov/ntgs

Northern Territory Government
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**Editor’s note:**
Names of 1:250 000 and 1:100 000 mapsheets are shown in large and small capital letters respectively, eg HAY RIVER, FLYNN.
Welcome to the Northern Territory, and to the seventh successive AGES, our Annual Geoscience Exploration Seminar!

The minerals and energy sector is far and away the major contributor to the economy of the Northern Territory, in accounting for over 20% of GSP in 2004–05, the second largest proportion of any jurisdiction in Australia. It plays a fundamental role in regional development and has enormous potential for supporting the commercial and social development of Indigenous and other communities. The Territory Government recognises that exploration is the lifeblood of the sector, and that discovery success will help underpin the future prosperity of all Territorians.

The Territory is a remote, highly prospective region with an immature exploration history. Our geological environment presents unique technical challenges that make the discovery of new resources difficult. The Territory Government has, since 2003, established a holistic approach to exploration investment attraction through our innovative $15.2 million Building the Territory’s Resource Base program. The primary thrust of this program is to assist in mitigating the technical risk associated with mineral and petroleum exploration.

AGES is used by my Department of Primary Industry, Fisheries and Mines as a key platform to communicate the results and significance of its comprehensive geoscience program. In recent years, this event has been enhanced by incorporating special sessions to discuss and explore Indigenous involvement in exploration and mining. AGES will again be broadened in 2006 by cross-agency cooperation with the Department of Business, Economic and Regional Development, by hosting a Mining Services Expo. This will showcase a number of central Australian businesses and their capabilities to support mining and exploration activity.

In the current resources boom, we find ourselves in an increasingly competitive environment and our challenge is to succeed at differentiating the Territory as a superior investment destination from other prospective jurisdictions in Australia and, indeed, across the world. AGES remains an important part of our strategy to achieve this.

I trust that you will enjoy AGES 2006 and all that central Australia has to offer!
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Toll Express is Australia’s largest express freight carrier with a strong focus on the Northern Territory and the mining sector supported by a comprehensive national network. Toll Express is also strongly supported by other Toll divisions to cater for all freight movements from local to international.

With branches in Alice Springs, Tennant Creek, Katherine and Darwin and one of the strongest freight networks throughout the Northern Territory, Toll Express is the mining sectors integrated solutions company able to meet all requirements from warehousing and consolidation to urgent freight requirements. Toll Express have strong IT capabilities and focus strongly on development of technology and innovations to improve lead times and delivery performance.

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Toll Express Network Coverage
## TUESDAY 28 MARCH

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<td>08:30-08:40</td>
<td>Betty Pearce</td>
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<td>08:40-08:50</td>
<td>Richard Brescianini</td>
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<td>08:50-09:10</td>
<td>Christine Edgoose</td>
<td>Review of geology and mineral resources of Ngalia Basin</td>
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<td>Ian Scrimgeour</td>
<td>Arunta Region – links between tectonics and mineralisation</td>
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<td>09:40-10:00</td>
<td>Tracey Rogers</td>
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***Morning tea 10:00-10:30***

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***Afternoon tea 2:45-3:15***
Session 4

03:15-04:15 The Triple A of exploration: application, approval and accountabilities
A panel of Minerals & Energy experts present:
• Applying and managing your titles
• Submitting reports
• Preparing Mining Management Plans

04:15-05:00 Working with Aboriginal land law
A panel of experts from the National Native Title Tribunal, the Office of Indigenous Policy Coordination and the Aboriginal Land Councils present:
• How mediation services can help you with native title negotiations
• How changes to the Aboriginal Land Rights Act may affect your business
• Working effectively with Aboriginal communities

07:00-late AGES Official Dinner
Dinner speaker - Professor Ross Large, Director ARC Centre of Excellence in Ore Deposits, University of Tasmania

WEDNESDAY 29 MARCH

Session 1

09:00-09:30 Leon Vandenberg New seismic and gravity data from the Tanami

09:30-09:55 Greg Ambrose Drilling in the Amadeus Basin

09:55-10:20 Mike Craig (CRC LEME) NT regolith-landscape framework

Morning tea 10:20-10:50

Session 2

10:50-11:10 David Maidment (GA) New geochronological data from the Tennant Region

11:10-11:35 David Huston (GA) Trends in lead isotope data across northern Australia

11:35-12:00 Chris Carson Western Pine Creek Orogen – tectonics and regional correlations

12:00-12:20 Andrew Wygralak Vein-related mineralisation in the Litchfield Province

12:20-12:30 Richard Brescianini Closing remarks

12:30 Lunch & Close
Review of the geology and mineral resources of the Ngalia Basin

Christine Edgoose

The Ngalia Basin is centred approximately 300 km northwest of Alice Springs. It comprises Neoproterozoic to Palaeozoic sedimentary rocks, up to 6 km thick, preserved in an elongate structure that is the remnant of a much more extensive, polyphase intracratonic basin. Seismic data indicates that the basin is an asymmetrical synclinal structure, which preserves a much thicker succession on a northern margin marked by northerly-dipping thrusts and high-angle reverse faults. The southern margin is a gently north-dipping (basinward) basement-cover interface disrupted by complex faulting. The maximum reported thicknesses of sediments in the Ngalia Basin are about 3200 m for the Neoproterozoic, 800 m for the Cambrian, 300 m for the Ordovician and 3100 m for the Devonian–Carboniferous (Wells and Moss 1983). A complete section is not preserved at any one location. Exposures of basin sediments are largely confined to narrow zones along the northern and southern margins – the rest is obscured by Cenozoic sediments and surficial deposits.

At approximately 16 000 km², the Ngalia Basin is the smallest remnant of the 2 million km² Neoproterozoic Centralian Superbasin, described by Walter et al (1995). Other structural remnants of this superbasin include the Amadeus, Officer, Georgina, Savory, and more recently described Murraba basins.

Wells and Moss (1983) reported that the Ngalia Basin succession records nine alternate periods of both sedimentation and diastrophism. Major unconformities divide the succession into six main packages: four of these comprise a mix of continental and marine sedimentation, and two record later periods of continental sedimentation. The Ngalia and Amadeus basins are interpreted to have been contiguous for most of their history, but the Amadeus Basin preserves up to 14 km of Neoproterozoic and Palaeozoic sediments compared with approximately 6 km for the Ngalia Basin. A correlation of the complete stratigraphy of the two basins at formation level clearly shows large gaps in the stratigraphic record of the latter.

The present-day architecture of the Basin is largely the result of the 400–300 Ma Alice Springs Orogeny. Initial effects of this orogeny involved exhumation of basement, which became a major provenance for the youngest succession, the Carboniferous Mount Eclipse Sandstone, which unconformably overlies the older units. The subsequent peak of deformation (locally known as the Mount Eclipse Movement) terminated deposition in the Basin and initiated major structures such as the Yuendumu and Waite Creek thrusts and associated thrust-related folding (Young et al 1996). Major south-verging thrusting of Arunta Region basement over basin sediments on these major structures points to thick-skinned tectonism along the northern margin, with seismic data indicating displacement in excess of 10 km in places (Wells and Moss 1983). Simultaneous thin-skinned thrusting and folding, related to decollement in the Treuer Member, is also evident from seismic data.

The Ngalia Basin contains proven reserves of uranium in both sandstone-hosted roll front-type deposits and in near-surface concentrations. The largest of the known roll-front-type deposits is at Bigryli on the central northern margin of the basin. There, sixteen radiometric anomalies related to surface or near-surface carnitite and uraninite mineralisation have been defined over a strike length of 12.5 km. Measured and indicated resources are contained within seven mineralised bodies, which amount to 808 000 t of ore at an average grade of 0.34 % U₃O₈ for 2770 t U₃O₈ (Fidler et al 1990). Bigryli is characterised by relatively high grades and excellent metallurgical recoveries, with the uranium mineralisation accompanied by significant levels of vanadium. The deposits are hosted in steeply dipping beds in the lower part of the Mount Eclipse Sandstone and are syngenetic, having been derived from the same Arunta Region basement provenance as the sedimentary material. Granite of the 1570 Ma Southwark Suite on the basin’s northern margin contains up to 22.5 ppm uranium (Young et al 1996). In the eastern part of the Basin, near-surface calcrite-hosted uranium mineralisation occurs 3–10 m from the surface, at a width of 1.5 m. Initial exploration identified 5700–6200 t of uranium oxide within a grade range of 0.036–0.038 %.

Minor occurrences of copper, barite, fluorite, galena and pyrite are recorded from quartz veins at a few locations in the northern part of the basin.

The Ngalia Basin has been only lightly explored for petroleum, with limited seismic acquisition, two exploration wells drilled, and several shallow stratigraphic holes. It appears that the Basin is more likely to be gas prone.

References
The Arunta Region: Links between tectonics and mineralisation
Ian Scrimgeour

The Arunta Region lies along the southern margin of the North Australian Craton (NAC) in central Australia, and underwent prolonged tectonic activity in a series of events during the period 1810–1560 Ma. These events have varying structural, igneous and metamorphic characteristics, reflecting changing responses to plate margin processes. The southern part of the Arunta is characterised by high-grade, medium- to high-P metamorphism, with evidence for significant burial and exhumation of rocks in a plate margin setting. In comparison, the northern Arunta is dominated by a series of lower-grade events with localised higher-grade, high-T, low-P metamorphism, reflecting intraplate responses to events occurring to the south. Our increasing understanding of the tectonic evolution of the Arunta also allows us to link the evolving tectonic evolution with mineralising events. In the text below, ages of mineralisation are proposed for various deposits and prospects in the Arunta-Tanami. These are based on available published data, field constraints and isotopic data, but it should be kept in mind that absolute dates on mineralisation are rare and often ambiguous, and the exact timing of most deposits remains open for debate.

1850–1820 Ma – Influences from northern Australia

Prior to 1820 Ma, the geological evolution of the Arunta-Tanami was largely influenced by tectonism in northern Australia, including the 1865–1850 Ma Nimbuwah Event in the Pine Creek Orogen, the 1846–1840 Ma Tennant Event (Maidment et al 2006) and the 1830 Ma Halls Creek Orogeny. Topography generated by these events is likely to form the source for the extensive turbidite packages of this age that occur in the Arunta-Tanami. The first deformation event recognised in the Tanami Region occurred during the 1830 Ma Tanami Event. This event is associated with upright folding, greenschist-facies metamorphism and no known magmatism. It may be associated with a widespread unconformity surface across the NAC, although this has not been identified in the Arunta Region. It is interpreted to be an intraplate response to the Halls Creek Orogeny to the northwest, which is thought to reflect the collision of the Kimberley and North Australian Cratons. There is no known mineralisation associated with the Tanami Event in the Arunta-Tanami, although Au-Cu-Bi mineralisation at Tennant Creek may have occurred at this time (Maidment et al 2006).

1810–1690 Ma – Noth-dipping subduction in southeast

After 1820 Ma, the main influence on the evolution of the Arunta-Tanami was tectonism that was focused in the southeastern Arunta. This tectonism, which occurred sporadically over more than 100 million years, is interpreted to reflect an evolving, long-lived north-dipping subduction system off the southeastern margin of the NAC. In the eastern Arunta, a period of volcanism, volcaniclastic sedimentation and bimodal magmatism at 1810–1800 Ma (lower Strangways Metamorphic Complex, Mount Hay Granulite) is interpreted to reflect deposition in a back-arc basin environment. A subduction-related back-arc setting is supported by the geochemistry of mafic magmas associated with this event (Hoatson et al 2005). This back-arc activity led to the formation of numerous small- to moderate-sized VMS Pb-Zn deposits (Uralanamba-type of Hussey et al 2005). The volcaniclastic sediments are overlain by more carbonate-dominated sediments of the Cadney Metamorphics.

Synchronous with back-arc basin development and VMS mineralisation in the eastern Arunta, voluminous granitic and
lesser mafic magmatism occurred in the northern Arunta and Tanami, associated with the 1810–1790 Ma Stafford Event. Across the northern Arunta, this event is characterised by localised high-temperature, low-pressure metamorphism, with rapid lateral changes in metamorphic grade and isotopic cooling following the metamorphic peak. Recent work by NTGS in the northern and western Arunta has identified three broadly parallel east-trending belts of high-grade metamorphism associated with the Stafford Event in the northwestern Arunta. More localised medium- to high-grade metamorphism also occurs at Mount Stafford, Waldrons Hill and The Granites. This localised high-grade metamorphism reflects high heat flow with advection of heat by felsic and mafic magmas. The Stafford Event is interpreted as being, at least in part, extensional in nature, given its high heat flow and bimodal magmatism; however, compressional structures such as upright fabrics and tight to isoclinal folds are also associated with this event, suggesting that distinct, and possibly diachronous extensional and compressional events may exist that have not been resolved by existing geochronology. The Stafford Event is considered to be the major event associated with orogenic gold mineralisation in the Tanami (eg Callee, The Granites), where it is was broadly coeval with the granitic intrusion and deformation. Potential for similar mineralisation related to this event extends across the northern Arunta to the Napperby area (Sabre, Falchion?). Significant mafic magmatism throughout the Arunta at this time has potential for mafic-hosted Ni-Cu (eg Waldrons Hill, Prospect D, Mount Hay). The deposition of the Mount Charles Formation in an intracratonic rift setting in the Tanami may be a late-stage feature of the Stafford Event. Deformation and magmatism related to the Stafford Event is interpreted to be an intraplate response to plate margin processes occurring to the southeast.

Following the Stafford Event, the belt of granitic intrusion progressed southward, with widespread felsic and lesser mafic magmatism accompanied by (dominantly) compressional deformation. This event, at 1780–1770 Ma, is known as the Yambah Event and may be interpreted as closure of the back-arc basin and development of a continental arc. Metamorphism in this event was generally low grade, although evidence locally exists for higher-grade metamorphism in the central and southern Arunta. Granites along the southeastern margin of the Arunta have a geochemistry that suggests a subduction-related setting (Zhao and McCulloch 1995), whereas granites further north within the Arunta in the vicinity of highly radiogenic granites. The Chewings Orogeny is believed to have formed in a continental arc, outboard of the NAC. Lower amphibolite-facies volcanics in the Haasts Bluff Domain of the Warumpi Province are associated with this event and have potential for epithermal or mesothermal Au. Deposition of the Yaya Metamorphic Complex occurred at 1660–1640 Ma, proximal to the arc, and has significant potential for VMS-style mineralisation, particularly related to massive cordierite rocks. Transpressional accretion of the Warumpi Province onto the NAC is believed to have occurred in the 1640–1635 Ma Liebig Orogeny. This accretion was accompanied by deep-crustal granite-facies metamorphism, magmatism and exhumation in parts of the Warumpi Province, and with broadly contemporaneous, localised extension and mafic magmatism in the NAC. Evidence for accretion at this time includes rapid, deep burial and exhumation of the Yaya Domain, a linear belt of calc-alkaline felsic to intermediate magmatism, and a hairpin bend in the apparent polar wander path for northern Australia. Intrusion of mafic dykes in the Warumpi Province at 1633 Ma reflects a rapid change in tectonics from transpression to transtension in the period 1640–1630 Ma (Close et al 2005). Renewed extension following the Liebig Orogeny led to deposition of the Iwupataka Metamorphic Complex, which hosts a number of small calc-silicate-hosted Pb-Zn-Ag prospects (Stokes Yard, Ulputura) and an amphibolite-hosted Cu-Au prospect (Haasts Bluff).

During 1690–1610 Ma, the active plate margin was in the southwest and this area remains fundamentally under-explored.

1590–1530 Ma: Cratonisation

North-directed deformation and orogenesis occurred in the southern and central Arunta during the 1590–1560 Ma Chewings Orogeny. In the southern Arunta, this event involved Barrovian-style metamorphism and mylonitic deformation, whereas localised higher-T metamorphism occurred in the central Arunta in the vicinity of highly radiogenic granites. The Chewings Orogeny represents a period of significant tectonism throughout much of Proterozoic Australia and may reflect an intraplate response to the collision of the NAC with the South Australian Craton. This event effectively cratonised the Arunta, until a series of intraplate reworking events in the Palaeozoic. This time-slice is extremely important in the Gawler Craton of South Australia, but no mineralisation of this age has been recognised in the Arunta Region. No magmatism has been identified during the Chewings Orogeny, but post-tectonic granites with an age of 1570–1530 Ma (Southwark Suite), in the Mount Doreen region, have minor associated copper and tungsten mineralisation in adjacent country rocks (Young et al 1995).
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We are investing $2 billion in the expansion of our Alcan Gove refinery in the Northern Territory, to increase alumina production capacity from 2 million tonnes per annum to 3.8 million tonnes.

The Tomago smelter in NSW (Alcan owns 51.55%) is undergoing a $210 million technology upgrade to increase production capacity by 70,000 tonnes.

The Alcan Engineering team in Brisbane is using state-of-the-art process technology to design our Gove refinery expansion.

We partner

Our new $2 million Queensland Research and Development Centre collaborates with the CSIRO and the Queensland Government in the development of alumina refining technology.

We sponsor key community and cultural events including the annual Garma Festival and the national Landcare Awards.

Alcan Gove’s YNOTS best practice training program opens the doors to employment for Indigenous people.
The Arunta underwent significant reworking from the Cambrian through to the Carboniferous, commencing with extensional deformation, mafic magmatism and high-grade metamorphism of the Harts Range Metamorphic Complex (Iridina Province) in the interval 510–460 Ma. This intraplate rift has potential for mafic-hosted mineralisation (eg Hammer Hill Ni-Cr), as well as metamorphosed sediment-hosted base metal mineralisation such as BHT-type mineralisation. Inversion of the rift basin occurred at 450 Ma along localised shear zones that appear to have accommodated relatively little fluid flow. Compressional deformation continued, probably intermittently, until 300 Ma, during the long-lived Alice Springs Orogeny. During the latter stages of this event, in the Carboniferous, significant amounts of fluid were mobilised along shear zones in a belt that trends southeast from the Napperby region through to Arltunga, resulting in significant mobilisation and deposition of gold (eg Arltunga, Winnecke, 7Falcon). The Bruces Cu-Au prospect and much of the uranium and rare-earth mineralisation in the eastern Arunta (eg Nolans Bore) can be attributed to large-scale Palaeozoic fluid-flow events (Hussey 2003).

Conclusions

An understanding of the complex tectonic evolution of the Arunta is essential in assessing the relative fertility of various domains for mineralisation. Most known Proterozoic mineralisation in the Arunta can be related to a long-lived north-dipping subduction system in the southeast at 1810–1690 Ma, with base metal and copper-gold mineralisation forming in back-arc basins and mafic magmatic systems proximal to the plate margin, whereas orogenic gold and granite-related tungsten, tin and base metals formed distal to the margin within the craton. During 1690–1610 Ma, the active plate margin was in the southwest and this area (the Warumpi Province) remains fundamentally under-explored.

References

Information projects that were undertaken, or started in the last year include:

• a stocktake of the petroleum reports
• an improvement of the content of minerals Industry Reports Management System (IRMS) records
• further geochemical data capture
• a major upgrade to the Geophysical Image Web Server
• the compilation of functional specifications for the development of an integrated corporate database for spatial data.

A project to check and capture drilling and associated geochemistry data from the Tennant Creek area resulted in the addition of 6476 new open file drill collars to the geochemistry database. Over 38 000 corresponding geochemistry records, from these and additional closed file drillholes, were also added. Another project to capture drill collars from the McArthur Basin area resulted in the addition of 750 records. These data were included in an updated Digital Information Package (DIP 001), released in January 2006, and are also available via the geochemistry layers delivered through STRIKE. During 2005, data from newly open filed reports have been regularly captured in standard templates and are currently being loaded into the database. Newly open filed data will now be added on a regular basis.

An ongoing project to upgrade the minerals Industry Reports Management System (IRMS) database content has resulted in a significant updating of 900 records. Of an estimated 7000 records with no information in key fields in January 2004, approximately 2100 reports have subsequently been reindexied at the end of February 2006. Another 6000 plus records have experienced some improvement using batch modification techniques. Updated records are available via the IRMS searching interface on the website, which is updated monthly, and via a quarterly CD, released as DIP 005.

A stocktake of the petroleum report, seismic support data and logs collection is in progress. This stocktake has identified reports, logs etc that have not been indexed in the database, as well as items that have incorrect records and others that have been entered twice. Records are being added and amended as necessary and over three hundred legacy petroleum reports have been added to the petroleum IRMS database in the last twelve months.

An ongoing project to upgrade the minerals Industry Reports Management System (IRMS) database content has resulted in a significant updating of 900 records. Of an estimated 7000 records with no information in key fields in January 2004, approximately 2100 reports have subsequently been reindexed at the end of February 2006. Another 6000 plus records have experienced some improvement using batch modification techniques. Updated records are available via the IRMS searching interface on the website, which is updated monthly, and via a quarterly CD, released as DIP 005.

A major upgrade to the Geophysical Image Web Server interface was completed in April 2005. The interface to the Territory-wide images includes new functions such as linked images, the ability to download subsets of the images via email and the ability to annotate images, as well as improvements to the transparency function. In November, the GIWS software was upgraded and GIWS implemented as an open standard compliant web mapping service (WMS). This means that GIWS can be directly accessed from open standard compliant software such as MapInfo, without plugins.

A major project identified in the NTGS Information Management Strategic Plan 2004–2008 (IMSP) is the development of an integrated corporate database for all the spatial data collected by the Geological Survey. The database is to be a phased development over a number of years, but will eventually incorporate the existing geochemistry, drilling, core library and mineral occurrence databases, as well as field observation and mapping data that are currently not held in a database. It will also provide links to other departmental systems such as IRMS and the Titles Administration System, and to the Department of Planning and Infrastructure’s Integrated Land Information System or ILIS. A major proportion of 2005 was spent preparing detailed functional specifications, resulting in the release of a tender for a proof of concept in December. A decision on the tender has yet to be made, but the project is due to start by the end of March 2006, with the proof of concept phase due to be completed by October 2006. In the short to medium term, the database will primarily impact the internal processes and efficiency of NTGS, but in the longer term, it will enable public client delivery systems to be directly connected to the production database, resulting in more efficient and timely data delivery and a reduction in duplication.
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NT mineral exploration overview 2005
John Dunster

Commodity review
Most mineral commodity prices increased during 2005, many to record levels. Uranium has been climbing steadily since mid 2003 and gold since early 2001. These commodities and copper, lead and zinc “boomed” during the second half of 2005. Nickel prices decreased overall from a peak in May 2005.

Gold (45%) and uranium (20%) accounted for most of the exploration expenditure in NT during 2005. Diamonds came third with 10%. Despite the decline in the nickel price and the fact that NT has unproven nickel potential, nickel exploration accounted for 5% of total expenditure. This is in contrast to a meagre 7% spent exploring for other base metals, such as lead-zinc-silver and copper-cobalt, for which the NT has world-class endowment, active mines and developments under feasibility studies.

Exploration update
The exploration and mining highlights for the calendar year 2005 are described below in terms of commodity.

Gold
• At the Cosmo Deep deposit in the Pine Creek Orogen, Northern Gold NL (now GBS Gold Australia Pty Ltd) has explored beneath the east and west flanks of the old Cosmo open pit. Best results included 4.1 m at 10.1 g/t Au from 622 m downhole and 4.7 m at 7.1 g/t Au from 358 m downhole in the Eastern Lodes. In the Western Lodes, results included 7.5 m at 2.0 g/t Au from 176 m downhole and 3.9 m at 6.3 g/t Au from 99 m downhole. Cosmo Deep has an indicated plus inferred resource of 9.7 Mt at 4.05 g/t Au (1.24 Moz Au).
• Other successful drilling programs in the Pine Creek Orogen have resulted in a 22% increase in the Zapopan underground gold mine reserve to 247 300 t at 13.1 g/t for 103 700 oz Au. Zapopan is held by GBS Gold Australia Pty Ltd, who also own the nearby Union Reefs Mill and other prospects in the Pine Creek Orogen including Moline and Maud Creek.
• Mount Porter, held by Aratuna Resources, is located in the Pine Creek Orogen about 10 km northeast of the Union Reefs Mill. Mount Porter has an indicated resource of 300 000 t at 3.1 g/t Au and an inferred resource of 55 000 t at 2.6 g/t Au, calculated using a 1.7 g/t Au cut-off. The total contained gold is 34 200 oz. The total identified mineral resource using a 0.5 g/t Au cut-off is 87 000 t at 1.9 g/t Au or 53 100 oz. The project is approaching the ready-to-mine stage.
• Also in the Pine Creek Orogen, Renison Consolidated Mines NL completed financing arrangements for the development of the Tombs Gully mine and mining commenced in October 2005. The project will be a 45 000 oz per annum underground mine, with the first ore expected to be mined in January 2006. A CIL plant is currently being refurbished and is expected to be recommissioned by March 2006. Development and operation of the mine is to be by PT Petrosa Tbk, a subsidiary of Clough Ltd.
• Ord River Developments have reported some good grades at gold prospects in their Supplejack Project in the northern Tanami Region. The project area includes nine prospects; Tregony, Thomas, Boco, Donald, Far South East, Crusade South, Normandy Hill, PhD and Burnt Ridge. Best intercepts at the notoriously nuggety Tregony prospect include, in separate holes, 6 m at 28.7 g/t Au, including 1 m at 144.5 g/t; and 6 m at 18.14 g/t and in the same hole 3 m at 69.18 g/t. In 2001, Tregony was estimated to contain an indicated and inferred hard-rock resource of 1.1 Mt at 1.47 g/t Au for 55 300 oz using a 0.3 g/t cutoff. Preliminary evaluation suggests that the resource at Tregony could be more than previously estimated.
• At the end of 2005, Centrational Minerals Ltd (formerly Giants Reef) had a substantial landholding in the Tennant Region. Underground mining at Charriot ceased on 26 November 2005; the mine is on care and maintenance and the plant has been decommissioned.

Copper-gold
• Drilling at Adelaide Resources Ltd’s Rover copper-gold project in the Tennant Region has confirmed the potential of the system. The Rover 12 prospect has returned an intersection of 55 m at 0.31% copper and 0.02 g/t gold, including 15.1 m at 0.57% copper and 0.03 g/t gold from 465.3 m. The area is also prospective for base metals. Competitor Navarre Resources/Westgold Resources NL holds other tenements in the Rover area.

Copper-cobalt-nickel
• The Redbank copper project in the McArthur Basin was acquired by the newly renamed Redbank Mines Limited. The deposit has a JORC-compliant resource of 4.2 Mt at 1.5% Cu. SRK valued the project at $14.5 million.
• Intersections of 20 m at 2.07% Cu, 0.30% Co and 0.37% Ni, and 12 m at 2.17% Cu, 0.03% Co and 0.09% Ni were reported by Compass Resources NL, from its Browns East oxide prospect, 80 km south of Darwin in the Pine Creek Orogen. This oxidised copper-cobalt-nickel mineralisation is the weathered near-surface expression of the Browns East deposit (resource of 30.5 Mt at 1.29% Cu, 1.28% Pb, 0.13% Co and 0.13% Ni).
• Compass Resources NL have other multi-commodity targets in the Batchelor area including the Mouth Fitch oxide deposit. Recent intersections include 18 m at 2.06% Cu, 0.12% Co and 0.15% Ni. The Mount Fitch copper orebody remains open to the north and is adjacent to a uranium prospect of the same name.
• Discovery Nickel defined two Sally Malay-type nickel targets, **Cobia** and **Barra**, in their Litchfield Project. Drilling was planned for late 2005.

• Arafura Resources and Mithril Resources have teamed up to explore the **Hammer Hill** area of the eastern Arunta Region for nickel, cobalt and chromium. Previous exploration indicates percent levels of nickel and over ten percent chromium.

• Mithril Resources announced promising Ni-Cu grades over narrow zones at its **Barrow Creek** Project in the Arunta Region. Four out of five holes intersected sulfides. The best grades were 6.8 m at 0.27% Ni and 1.24% Cu from 133.8 m including 35 cm at 1.22% Ni and 8.27% Cu. Mithril has interpreted the results as a thin dyke and had planned to follow up with a geophysical survey.

• AusQuest Limited has used a Noril’sk Ni-Cu-PGE model, based on basalt lithogeochemical similarity, to explore the Cambrian Kalkarindji Flood Basalt Province. Work on their **Antrim** project is focused along the Neave Fault, which is thought to be a major basalt feeder. Only limited drilling has been undertaken to date.

**Lead-zinc-silver**

• Reward Minerals Australia Pty Ltd obtained further significant results from the most recent RC drilling program at the **Jervois** project in the eastern Arunta Region, including 6 m at 5.2% copper from 65.0 m in hole RJ 29 at Bellbird and 14 m at 9.9% lead, 2.8% zinc, 89 g/t silver from 32 m in hole RJ 41 at Green Parrot.

• Tennant Creek Gold worked on the **Manbarrum** lead-zinc project (formerly Sandy Creek or Legune) in the onshore Bonaparte Basin. Mississippi Valley-type (MVT) lead-zinc mineralisation was outlined in previous exploration during the 1970s. Title has now been granted over two tenements covering a 20 km strike length of identified, shallow, potentially open-pit mineralisation in several locations. The company will undertake drilling to upgrade the resource base to JORC compliance as rapidly as possible.

**Molybdenum-tungsten-tin**

• Thor Mining PLC/Sunsphere’s **Molyhil** Project is located 220 km northeast of Alice Springs, within the Arunta Region. A sampling program, which commenced in July 2005, included the sinking of three shafts to extract bulk samples from the orebody. The average combined grade over the 26.1 m of the first cross-cut is 1.01%, which is well in excess of the current combined JORC grade. The Molyhil Project currently has an indicated resource of 1.53 Mt at 0.32% WO₃ and 0.19% MoS₂ (combined grade 0.51%) and an inferred resource of 500 000 t at 0.25% WO₃ and 0.15% MoS₂ (combined grade 0.40%).

• Segue Resources acquired the **Coronet Hill** project in the Pine Creek Orogen from Arafura Resources. The historical copper and silver field will be explored for tungsten and tin, with a program forecast to cost $1.6 million.

**Iron ore**

• Territory Iron Limited has 13 tenements in the **Frances Creek** area 23 km north of Pine Creek. Iron ore was produced and exported from 1967 up until 1974, when Cyclone Tracy flooded pits and damaged port infrastructure, forcing closure. There are 55 known deposits in the area. The company has acquired geophysical surveys and is drilling to raise the resource status to JORC compliance. Cumulative resources for eight deposits have been upgraded to 5.77 Mt at 60.0% Fe from the previously reported 2.42 Mt at 60.7% Fe. This does not include Helene 6/7 previously reported at 1.0 Mt at 63.4% Fe. An overall reserve statement and feasibility study are anticipated early next year.
Mineral sands

• Matilda Minerals Limited has mining leases over the zircon-rich Andranangoo and Lethbridge Bay mineral sands deposits on the Tiwi Islands, some 60 km north of Darwin. The ore reserve is 4.9 million tonnes grading 4.5% heavy minerals. Construction of the gravity processing plant for the Tiwi Islands is on schedule and within budget. Matilda has an off-take agreement with Astron Limited to purchase the entire production from the project.

Diamonds

• Gravity Diamonds Limited has begun testing the ABN021 Abner Range kimberlite pipe in the McArthur Basin. The pipe, estimated to cover 1.3 hectares with a separate satellite lobe of 0.3 hectares, was discovered by following an anomaly identified in a Falcon® airborne gravity gradiometry survey. Both the main pipe and the satellite are diamond-bearing. One macrodiamond of 0.147 ct and two other diamonds greater than 0.3 mm diameter have been recovered from limited drilling. Previously announced drilling returned a total of 147 microdiamonds and two small macrodiamonds.

• North Australian Diamonds Ltd (formerly Striker Resources NL) began reprocessing sorthouse tailings at its Merlin mine in the McArthur Basin in the middle of the year. Production now exceeds 140 000 stones for 12 000 ct at over 460 ct per hundred tonnes. A total of 331 stones larger than 1 ct have been recovered. The company also reported the discovery of a 14.21 ct gem-quality clear white diamond, a 10.27 ct light brown gem-quality fragment from a larger stone and a 10.97 ct brown near-gem. Stage 2 of the development involves the processing of the remaining tailings, remnant ore from previously mined pits and ore mappable because of re-optimised pit designs. Bulk samples have been excavated from the Kaye and Ywain pits for processing. A valuation of Merlin diamonds achieved an average of US$1454 per ct; the most valuable “fancy yellow” type was valued at US$4500 per ct and a large white 14.21 ct stone was valued at $1815 per ct or US$25 791.

• Tawana Resources NL total diamond recovery from the TC-01 Timber Creek kimberlite in the Victoria Basin now stands at 17 387 diamonds weighing 839 ct from 3802 t, representing an overall grade of 22 ct per hundred tonnes. Tawana has entered into an alliance with de Beers to form Newco.

The current resurgence in uranium exploration has seen over twenty companies become involved in exploration in the NT

Rare earths

• As a result of an 8752 m drilling campaign in July 2005, Arafura Resources NL has trebled the resource at Nolans Bore to 18.6 Mt at 3.1% REO, 14% P₂O₅ and 0.47 lb/tonne U₃O₈. The company now predicts that Nolans Bore will have a mine life of at least 30 years. The resource estimate will lead into a feasibility study due to start in early 2006.

Manganese

• OM Holdings subsidiary, Bootu Creek Resources, has secured funding for the development of its Bootu Creek manganese project, 110 km north of Tennant Creek. The current reserve is 5.6 Mt at 26% manganese with resources of 11.1 Mt at 28% manganese. The mine is expected to produce 550 000–600 000 tonnes of manganese per annum, comprising 75% lump and 25% fines. Commissioning of the plant is scheduled for March/April 2006. The total project cost has been put at $41.2 million.

Uranium

The current resurgence in uranium exploration has seen over twenty companies become involved in exploration in the NT. Batavia Mining, Billiton Minerals, Crescent Gold, Deep Yellow, Energy Metals, Fast Scout, Laramide Resources, Marengo Mining, Nova Energy, Polaris Metals/Washington Resources JV, Scimitar Resources, Uranium Exploration Australia, Uranex NL and Valhall Uranium are among the new or spin-off companies with a portfolio that includes the NT. They join Cameco who has been the mainstay of uranium exploration in the NT for several years, and ERA who operates the Ranger Mine.

• In December 2005, Energy Metals announced that drilling had commenced at its 53.3% owned Bigrlyi uranium project in the Ngalla Basin. The Bigrlyi project is a joint venture with Valhall Uranium (41.7%) and Southern Cross Exploration (5%). The area was subjected to significant exploration activity in the period 1974 to 1982, including percussion and diamond drilling, resource calculations and metallurgical testing. A non-JORC-compliant overall resource of 808 000 t of ore at an average grade of 3.43 kg/t U₃O₈, equivalent to 2770 tonnes of contained U₃O₈, was established in the late 1980s. Anomaly 15 lies at the eastern end of the deposit and an independent consultant calculated a (pre-JORC) resource of 623 400 t at 3.21 kg/t U₃O₈. ‘Energy Metals’ current’ drilling program will test a radon geochemical anomaly, located 200 m east of the Anomaly 15 deposit. This drilling is the first part of a major campaign designed to infill and extend known uranium mineralisation, as well as locate new deposits buried under shallow sand cover. Assay results from the drilling and resampling program should be available in January 2006.
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Deep Yellow had looked to be set to be the first to a post-Federal intervention JORC-compliant uranium resource in the NT. Deep Yellow acquired their Ngalia Basin Napperby (aka New Well) calcrete uranium deposit from Paladin Resources. The shallow and thin deposit was previously drilled by Uranerz between 1977 and 1981. Uranerz carried out an economic orientation study, based on a range of 5700–6200 t contained $UO_2$ within a grade range of 0.036–0.038%. Deep Yellow undertook an air-core drilling program to bring it up to JORC compliance and independent specialists Hellman and Schofield were commissioned to do the resource statement. After a problem with an analytic standard sample was resolved, there was still an apparent discrepancy between recent assays and the original Uranerz data. This was attributed to poor recovery by air-core in the main mineralised zone and the choice of 1 m composites (Uranerz had used 0.5 m) through the narrow mineralised intervals. Further drilling will be required.

- Deep Yellow also acquired the uranium rights to all of Tanami Gold’s tenements in the Tanami-Arunta Province, covering 60 000 km² in both the Northern Territory and Western Australia. The Tanami-Arunta Province presents a range of uranium targets. Unconformity-related deposits, such as those at Lake Mackay, Browns Range Dome and adjacent areas, are of particular interest within the area. The tenement package also covers known deposits at Don and Deva in Western Australia.

- Drilling at Mount Fitch uranium prospect confirmed the presence of uranium mineralisation, as previously identified by drilling in the 1960s by the Australian Atomic Energy Commission. Some grades initially reported to the ASX by Compass Resources were later revised down because of “a transcription error.” Corrected figures include 66 m at 1.42 lb/tonne $UO_2$ from 19 m downhole, including 6 m at 3.74 lb/tonne. The uranium mineralisation is less than 100 m from, and in the same host rocks as a copper prospect, also called Mount Fitch, but the two do not appear to be genetically related.

- Laramide Resources entered into an agreement with Arafura Resources to explore the Lagoon Creek uranium prospect and surrounds in the Westmoreland Conglomerate (Murphy Inlier), near the Queensland border.

- An increased uranium spot price has allowed ERA to increase its reserves and resources, and extend the mine life of the Ranger mine by a further three years. The cut-off grade has been reduced from 0.12% to 0.08% uranium oxide, resulting in a 6285 t increase in reserves to 45 285 t and an increase in resources by 14 923 t to 42 992 t. The Ranger mine has operated for 25 years and is the second largest uranium mine in the world, providing 11% of world global output.

**Abrasives**

- Olympia Resources Ltd has signed a heads-of-agreement with Bravest Pty Ltd to assist in the production and marketing development of the Harts Range abrasives project in the Arunta Region. The project is located 180 km northeast of Alice Springs and contains 2.7 Mt of garnet and 6.2 Mt of alumino magnesio hornblende (AMH) within 71 Mt of ore reserves. The project is expected to produce 300 000 tpa of abrasive product.

**Coal**


- Conarco Minerals Pty Ltd holds ELs 23904 and 23906 on the coastal plains of the southwestern Gulf of Carpentaria region, near the town of Borroloola. Research for petroleum discovered a driller’s report of coal being intersected in a 1992 water bore near Manangoora Station. However, no other direct evidence of the existence of coal in the area is known. Following granting of the ELs, Conarco subsequently farmed-out.

**Titles and exploration expenditure update**

Forty-three percent of the NT is considered prospective and explorable for mineral resources. At the end of 2005, 31% was under application, a significant increase over the previous three
The Tennant Region hosts a large number of small to medium, high-grade, iron-oxide, gold-copper deposits. Many of these deposits have been mined during the last 50 years and the region is currently being actively explored for new resources. A large amount of geological information is available on the deposits and their local geological environments, but due to limited surface exposure, the more regional geological context of the region is poorly understood. Modern systematic aeromagnetic data covering the entire Tennant Region has been used by NTGS for the production of an excellent interpreted solid geology map (Johnstone and Donnellan 2004), but much of this interpretation is untested and the likely three-dimensional distribution of rock units is not defined. Some of the ambiguity in the geological interpretation can be reduced, if geological, magnetic and gravity data can be integrated. NTGS has recently acquired systematic gravity coverage over the Tennant Region and these data, together with data from Geoscience Australia and open-file company data, provide important additional information on the likely sub-surface distribution of major rock units. A combination of constrained 2.5-D forward modeling and unconstrained 3-D inversion has been employed to help define the likely sub-surface distribution of major rock units.

Although a large volume of petrophysical information is available on the ore bodies and their immediate environment, there is only a limited petrophysical database for other units and the properties on many major rock suites are unknown or poorly constrained. Additional petrophysical data were acquired on exploration drill core samples held by NTGS, but these holes intersected only a limited portion of the overall stratigraphy. An additional complication in the interpretation of the geophysical data is that there is significant spread in petrophysical properties for individual rock units and considerable overlap between units. This means that unambiguous identification of individual rock units, based on their gravity and magnetic signatures, is not usually possible. This variability in properties together with the limited geological data available from outcrop and clustered drillholes makes tightly constrained regional forward modeling or inversion a difficult and ambiguous process.

In response to the inherent ambiguity in physical properties at Tennant Region, a new methodology for interpretation of unconstrained inversion volumes has been developed and trialed. The method attempts to take into account the statistical variability in petrophysical properties of the major rock units. It does so by expressing the likelihood that each cell in the model belongs to a particular geological unit in terms of a membership function that is defined from the statistical variability of selected training areas. The approach that has been adopted is similar to the classification approach commonly applied to satellite or other remote sensing data, but in this case, it has been applied to a three-dimensional volume. Training areas for the density and susceptibility volumes for each major geological class were defined in regions where the geology was well understood and likely to be relatively homogenous. Each cell in the final 3-D model is assigned to the most likely geological class, but the membership information is also preserved for each cell for each class in the model. This new approach recognizes and explicitly records the inherent ambiguity in the interpretation of the gravity and magnetic datasets.

For the Tennant Region, the subsurface distribution of granitic rock units is well defined in the models although it is not generally possible to distinguish between different suites of granitic rocks on the basis of their regional geophysical characteristics. However there is considerable uncertainty associated with the interpretation of the distribution of other rock suites, such as elements of the Warramunga Formation and Ooradidgee Group, due to their overlapping physical property signatures. The final models provide a realistically imprecise depiction of the likely three-dimensional distribution of rock units. They also provide an ideal basis for more detailed investigations of the subsurface geology of the Tennant Creek area. The final physical property models can be used directly in the future for regional-residual separation of gravity and magnetic data for more detailed local modeling or inversion studies.

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New insights into the Jervois mineral field
Max Frater

The Jervois copper-lead-zinc prospect occurs in Palaeoproterozoic Bonya Schist (1807 Ma depositional age), approximately 360 km by road northeast from Alice Springs. The outcrop of resistant hills that contains the mineralised horizon is folded in a ‘J’-shape synform in aerial photographs and satellite images. The ‘J’ fold roughly defines the limits of outcrop. After initial discovery in the 1920s and some small-scale mining of oxide ore, the first modern exploration program was undertaken by New Consolidated Goldfields in the period 1961–1965. Three zones of mineralisation (Reward, Green Parrot and Bellbird) were outlined over a distance of 5 km. This phase of exploration defined a combined ore reserve of 2.4 Mt at 2% copper to a depth of 95 m. Subsequent exploration by Petrocarb (1969–1973), Union Corporation (1973–1974) and Plenty River Mining (1980–1983) added substantially to the metal tenor and tonnage. Petrocarb established a ‘reserve’ of 3 Mt at 2.5% copper and 50 g/t silver to a maximum depth of 130 m. In addition, a further 300 000 t at 9% lead, 3% zinc and 170 g/t silver were estimated for Green Parrot.

Plenty River Mining commissioned a treatment plant and mine infrastructure to treat lead-zinc-copper-silver ore from the Green Parrot orebody in 1982 at a total cost of A$15 million. The plant produced 500 t of concentrate in 3 months to June 1982, before being placed on care and maintenance for the company to go public with a share float in March 1983. The plant was again commissioned on Green Parrot oxidised ore in August 1983, but following a sharp decline in metal prices, was again placed on care and maintenance in December 1983. In the 5 months of production, the plant produced 2000 t of concentrate grading 50.4% lead, 5.4% zinc, 0.6% copper and 680 g/t silver. Following the cessation of production, Plenty River Mining continued to explore in joint ventures with Anaconda (1983–1984) and Normandy Poseidon (1991–1996) in geophysical and drilling exploration programs.

Britannia Gold NL acquired the Jervois tenements in 1987. Britannia entered into a joint venture agreement with MIM Exploration in 1999, with MIMEX managers. MIMEX applied high-resolution geophysical techniques and a deep diamond-drilling program to map and test the lode horizon at depth and along strike from the Reward-Marshal, Green Parrot and Bellbird mineralisation. In all, 36 RC and diamond holes were drilled, with generally encouraging results. An important development was the recognition of gold mineralisation associated with copper in primary ore. Virtually all holes on the lode horizon intersected mineralisation, some of the best intersections being: 42.5 m @ 1.77% Cu, 0.24 g/t Au, 120 g/t Ag (DDH J13); 28 m @ 2.47% Cu, 0.59 g/t Au, 25 g/t Ag (DDH J15); 12 m @ 1.54% Cu, 0.54 g/t Au, 16 g/t Ag (DDH J22); 6.2 m @ 3.29% Cu, 0.09 g/t Au, 37 g/t Ag (DDH J26); 30 m @ 1.05% Cu, 0.08% Au, 5 g/t Ag and 9.1 m @ 3.21% Cu, 0.24 g/t Au, 17 g/t Ag (DDH J33).

MIMEX withdrew from the joint venture in late 2001, having concluded that the mineralisation was depth limited and that mineable widths were discontinuous in the mineralised zones. Drilling had indicated that mineralisation occurred in discontinuous pods controlled by structure and stratigraphy, and neither was particularly well understood. MIMEX concluded that the mineralisation would not provide a producing mine of an attractive size to MIM.

The recently formed Reward Minerals purchased the Jervois tenements from Britannia in late 2003. The company carried out a diamond- and RAB-drilling program in 2004–2005 to fill in gaps in the drilling record at shallow levels. Some of the better down-hole intersections reported by Reward Minerals included, for Bellbird: 4 m @ 7.93% Cu, 6 m @ 5.2% Cu and 12 m @ 2.85% Cu; and for Green Parrot: 7 m @ 14.2% Pb, 7.6% Zn, 1.8% Cu, 415 g/t Ag, 14 m @ 9.9% Pb, 2.82% Zn, 89 g/t Ag, 5 m @ 11.3% Pb, 2.9% Zn, 356 g/t Ag and 10 m @ 3.3% Pb, 2.26% Zn, 100 g/t Ag and 4.9 g/t Au.

Acid volcanic rocks of rhyolitic composition occur at the base of the district stratigraphy. The volcanics are deformed and internal textures destroyed, but at their thickest, they consist of both fine- and coarse-grained siliceous rocks, which are massive or coarsely bedded and which contain rounded bombs or clasts of the same composition. These coarse-grained to massive volcanics are interpreted in outcrop as having a high thickness to length ratio that varies considerably laterally. The absence of fine- to medium bedding suggests that they are either lavas or laharc deposits. They are overlain and may lens laterally into quartzite and calc-silicate beds that suggest a shallow-marine environment. The Jervois mineralisation is interpreted to occur at this level, though distal to the rhyolite/laharic bodies. The latter are represented in the ‘J’ fold by diamictite, containing rounded pebbles of acid volcanic in a slate matrix. The mineralisation itself occurs in slate, andalusite-quartz-mica schist and calc-silicate rocks. Thick blastic andalusite schist occurs above the mineralised horizon. This unit narrows and blast become less abundant to the north of Reward and northeast from Bellbird, on the eastern side of the ‘J’. Slate,
meta-siltstone, fine-grained psammite and calc-silicate rocks occur above the blastic andalusite schist. To the west of Jervois (west of Bonya Bore), this succession passes upward into a thick meta-dolerite sill. Isolated outcrops of meta-basalt intruded by dolerite, 10 km southeast of Jervois, are interpreted as lying above the sedimentary succession. Both meta-dolerite and at least two generations of pegmatite intrude the stratigraphy in the ‘J’ fold. Pegmatites are common in mineralised rocks in the Reward-Green Parrot zone, whereas meta-dolerites are not recognised in the workings and are rarely intersected in drilling. Pervasive magnetite extends the length of the ‘J’ fold and to the east and north. Magnetite appears to occur in both S₁ and S₂ foliations, and it preferentially replaces bedded calc-silicate rocks to produce massive ironstone. Haematite occurs only as a trace replacing magnetite (martitisation), but haematite and goethite impregnate and form veins in brecciated granite to the north of the ‘J’ fold.

Three major deformation events are evident. D₃ is recognised in regional flat-lying isoclinal folds (F₃) that result in close repetition of sedimentary units at Jervois. D₃ is expressed in moderately tight to tight folds (F₃), with variable fold axes that plunge from shallow to vertical. Granites and pegmatites of at least two generations (deformed and undeformed) are present in the region. The ‘J’ fold (F_3) is interpreted as a drag feature to a regional fault that passes to the west of Jervois, hidden beneath Adelaidian-aged Georgina Basin sediments. The regional fault is recognised to the southwest of Bellbird in tall ridges of brecciated and altered granite, and can be traced in aeromagnetic images under the Jervois Range.

Mineralisation in the Jervois prospects occurs late in ‘en echelon’ shears, presumably related to D₃. There is no close relationship between sulfides and magnetite, whereas magnetite is abundant and widespread in the mineralised horizon; the better-developed sulfide occurrences are restricted to brecciated and mylonitised rocks, which may be skarn, slate or andalusite schist. In diamond drill core from the MIMEX drilling program, it is apparent that there is a relationship, although inconsistent, between metasomatised country rock adjacent to pegmatite and increased levels of magnetite and sulfides. Interpretations of textures and fabrics indicate that the initial influx of magnetite was associated with D₃ and probably associated with early granite emplacement. The intimate relationship between sulfides and magnetite in skarn rocks point towards S being present (at least locally) in the hydrothermal system, during, or in the later stages of magnetite mineralisation (D₃). Later folding (F₄) and shear deformation (D₄) resulted in vein and breccia structures that remobilised both magnetite and sulfides. During D₄, open space within en echelon shear zones formed the sites for base-metal/magnetite mineralisation. Cu is the dominant base metal and there is almost as much chalcopyrite as pyrite in sulfide intersections in drill core. MIMEX intersected a Cu-Au-(Ag) mineral association in deep holes in the Reward/Marshall zone in 2001 and Reward Minerals reported Ag-Au and Pb-Ag-Au mineralisation at Green Parrot in their 2005 drilling program. Pb-Zn-Ag mineralisation is generally confined to Ca-Mn garnet-rich skarn, which is interpreted as having replaced calc-silicate. The absence of Pb-Zn mineralisation at Bellbird appears to be related to the absence of skarns in the prospect. The flushing of many elements, including REE and HFSE, from magnetite-rich zones suggests a high fluid/rock ratio in the hydrothermal system. The dominant gangue mineral assemblage to magnetite and sulfide mineralisation is chlorite, quartz and white mica (H₂ alteration), with subordinate biotite. In skarn mineralisation, gangue minerals commonly include garnet, chlorite, quartz (and carbonate).

The Jervois mineralisation has many of the characteristics of an IOCG system: a large volume of magnetite, elevated Ag, Co, U, P (and Au) and prominent structural control. There has been no regional geochemistry that might prove or disprove the presence of extensive alkali-rich alteration, as is typical of IOCG systems. The highly oxidised Fe-rich (S-poor) ore fluids that were responsible for abundant magnetite in the district were probably magmatic (granite) and basin derived, the Fe⁴⁺ was probably derived from abundant meta-dolerite and gabbro that

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Macmahon’s Open Cut Division continues to expand its operations across Australia with a string of new and potential contracts.

In June 2005, Macmahon announced it had expanded its open cut operations into the Northern Territory with the award of a three-year contract with Boodeena Resources to develop the new Bootu Creek Manganese Mine. The mine is located approximately 100km north of Tennant Creek and the contract involves mining and processing manganese ore. The initial production rate is 600,000 tonnes per year of manganese product.

"Manganese will be transported from the mine by road to a rail siding where it will be loaded onto trains for transport to Darwin for shipping," Macmahon Open Cut General Manager Damien O'Reilly said.

Most recently, Macmahon was notified it was the preferred proponent for the two year mining and processing contract at the existing BHP Billiton Jimblebar iron ore mine in Western Australia.

The Jimblebar mine is approximately 60 kilometres east of Newman and has an average annual production of seven million tonnes of ore.

"The booming iron ore sector continues to provide us with contract opportunities," Mr O'Reilly said.

"The news of the Jimblebar contract comes after Macmahon was awarded a mining and crushing contract for BHP Billiton's new Orebody 18 open cut iron ore mine in December."

The Orebody 18 contract, with a value of approximately $250 million, was the single largest contract, in terms of value, ever awarded to Macmahon.

"Macmahon's operations at Orebody 18 will involve the full range of mining services including drilling, blasting, loading and hauling of iron ore and waste materials. The ore processing services will include crushing and train loading of iron ore, in addition to the maintenance of the BHP Billiton owned ore processing infrastructure," Mr O'Reilly said.

"The booming iron ore sector continues to provide us with contract opportunities."

When fully operational, the new mine is expected to employ close to 140 people and produce up to eight million tonnes per annum of iron ore for the duration of the contract.

"Macmahon continues to strengthen our working relationship with BHP Billiton. This work complements our open cut contract mining work at the Mt Whaleback iron ore mine, in Newman, where we have been since November 2003," he said.

A buoyant resources sector has created further open cut opportunities across Australia. Last year, Macmahon also extended long-term contracts at Dampier Port Bulking and Argyle Diamonds, both in Western Australia. Macmahon has worked at the Dampier iron ore port since July 1993 carrying out iron ore blending as part of scheduling to meet customer requirements.

The contract was extended for a further three years and the scope of work was expanded to include blending at both the Dampier and Cape Lambert ports.

Macmahon started work at the Argyle Diamond mine in Western Australia's Kimberley region in 1990. The contract, which involves tailings dam construction, was extended until December 2007.

"We are also developing our fleet at Eaglefield coal mine in Queensland to continue meeting our client’s needs on this long-term contract," Mr O'Reilly said.

"Macmahon recently purchased an Hitachi EX5500 which has already started work at Eaglefield. The fleet at Eaglefield will be further supplemented during the year with several Komatsu 730E trucks with 180 tonne payloads."

Southeastern Arunta Region:

Subdivision and undercover disposition

Dorothy Close, Mark Duffett, Ian Scrimgeour, Kurt Worden and Ben Goscombe

Introduction

The East Arunta project incorporates ILLOGWA CREEK, HALE RIVER and HAY RIVER, and covers the Neoproterozoic to Palaeozoic Irindina Province and the Palaeoproterozoic Aileron Province of the Arunta Region. In 2005, the focus of the East Arunta project was twofold: firstly to acquire detailed field observational data and analytical results in the Palaeoproterozoic southeastern region of the Aileron Province; and secondly, to interrogate available geophysical and drilling datasets to provide an interpretation of the depth and nature of the Irindina and Aileron provinces that extend beneath the cover of Eromanga Basin and Cenozoic sediments.

Subdivision of the southeastern Palaeoproterozoic Aileron Province

An informal subdivision of the southeastern section of the Palaeoproterozoic Aileron Province of the Arunta Region, as described below, is defined on the basis of distinct lithological packages, peak metamorphic conditions, and preliminary U-Pb SHRIMP geochronological data.

Alooojarjara domain

The Alooojarjara domain comprises a package of upper amphibolite-to granulite-facies metapelites, metapsammites, abundant mafic
intrusive rocks, and lesser felsic intrusive rocks. These units were previously mapped as belonging to the Harts Range Group, as they occur structurally above the Bruna Detachment Zone. However, U-Pb SHRIMP dating of a quartzofeldspatic gneiss from the Aloojarjara metamorphics (Maidment 2005) yielded a magmatic age of 1760 ± 9 Ma, confirming that this succession is Palaeoproterozoic. Anomalous levels of Au and Cu within ultramafic units of the Alooarjara domain (originally identified by Agip Australia Pty Ltd in 1977) have been confirmed with follow-up sampling. A quartzofeldspatic vein or segregation within an ultramafic unit has yielded elevated Au (71 ppb), Cu (3.4%) and Cr (2150 ppm).

Albarta domain

The Albarta domain comprises amphibolite-facies metapelites, metapsammites, calcisilicates and minor quartz magnetite layers (Albarta Metamorphics) intruded by granites, granodiorites and lesser mafic units. Preliminary SHRIMP U-Pb geochronology of a metasediment with a possible volcaniclastic protolith from the Albarta Metamorphics suggests a potential correlation with 1770–1760 Ma protoliths of the Oonagalabi base metal deposit. U-Pb SHRIMP zircon dating of two granite samples within the Albarta domain have yielded preliminary magmatic ages similar to an age of 1762 ± 9 Ma that was obtained by Zhao and Bennett (1995) for a granite within the Atneequa Granite Complex. This suggests that the majority of felsic intrusive rocks distributed throughout the Albarta metamorphics are probably contemporaneous.

Casey Inlier

The Casey Inlier is a previously unmapped inlier of Palaeoproterozoic basement that is exposed within the northeastern Amadeus Basin in HALE RIVER. It can be subdivided into three fault-bounded zones based on lithological packages and metamorphic grade. The ‘eastern zone’ comprises metasediments that include metapelite, metapsammite, quartz-magnetite layers, and graphite-bearing calcisilicate rocks, together with mafic to ultramafic units and biotite granite. These lithologies have all been pervasively overprinted by an upper amphibolite-facies northwest–southeast-trending fabric. SHRIMP U-Pb zircon dating of the metasediments in this ‘eastern zone’ has yielded an interpreted maximum deposition age of 1845 ± 6 Ma, whereas dating of a representative sample of the felsic intrusives of this zone has yielded a magmatic age of 1817 ± 3.9 Ma. Sm-Nd isotopic analysis of the dated granite has yielded a model age of 2.32 Ga and an εNd value of -1.16. This dating suggests that the ‘eastern zone’ of the Casey Inlier contains units that are significantly older than the 1810–1780 Ma Strangways Metamorphic Complex to the north.

The ‘central zone’ comprises granulite-facies basement rocks and a greenschist-facies cover succession. Granulite-facies migmatitic metapsammite, lesser metapelite and felsic to mafic intrusive rocks form the basement. The cover succession is a succession of quartzite and porphyroblastic pelitic schist that unconformably underlies the Neoproterozoic basal Amadeus Basin. Deformation of this succession under peak upper greenschist-facies conditions is east-vergent. The eastern boundary of the central zone is defined by a multistage steep dextral strike-slip fault zone that was reactivated during the 400–300 Ma Alice Springs Orogeny to offset Amadeus Basin sediments. Abundant quartz-filled tension vein arrays within this cover succession suggest extensive fluid flow and the potential for gold mineralisation. The granulite-facies basement succession is retrogressed by the same regional amphibolite-facies NW-SE trending fabric that is seen in the ‘eastern zone’.

The ‘western zone’ is a dominantly magmatic domain, with abundant muscovite-biotite leucogranite and lesser biotite porphyroblastic granite and mafic rock. No metasediments have been identified in the western zone. Peak metamorphic grade for this zone has been interpreted to be amphibolite facies, defining the regional northwest–southeast-trending fabric, as observed in the other two zones.
The principal previous magnetic interpretation in the region is Geophysical interpretation of the undercover enabled interpretation of cover thickness to extend through to the drill intersections in the immediate vicinity. The average difference data. ‘Basement’ (defined for this purpose as any pre-Alice Springs Commensurate corrections must therefore be made to inferences of Orogeny unit) intersections in water bores were interpreted largely so

Future isotopic analysis, using both U-Pb SHRIMP zircon and monazite dating, together with Sm-Nd analysis of the intrusive rocks in the central and western zones of the Casey Inlier, will provide insights to the nature of the underlying basement crust, and will allow further comparisons with adjacent Palaeoproterozoic domains.

Geophysical interpretation of the undercover Palaeoproterozoic Aileron Province and Neoproterozoic to Palaeozoic Irindina Province

Cover depth interpretation
Both the Aileron and Irindina provinces are interpreted to extend for considerable distances under cover of Eromanga Basin and Cenozoic sediments. The thickness of this cover has been defined and mapped using a synthesis of government stratigraphic drilling, water bore, exploration drilling, previous magnetic interpretations, seismic, new magnetic source depth interpretation and outcrop data. ‘Basement’ (defined for this purpose as any pre-Alice Springs Orogeny unit) intersections in water bores were interpreted largely from lithological descriptions given in driller and (occasionally) geological logs.

The principal previous magnetic interpretation in the region is that of a PhD thesis by Whiting (1987). These magnetic source depth estimates have been supplemented by new work and other interpretations contained in company reports. Interpreted magnetic source depths are generally at least 30 m deeper than outcrops and drill intersections in the immediate vicinity. The average difference is over 60 m, with up to 100 m apparent in some instances. This is interpreted to result from magnetite-destructive oxidative weathering. Commensurate corrections must therefore be made to inferences of cover thickness from magnetic source depth estimates, bearing in mind that some rock types may be more vulnerable than others.

The Tanami Deep Seismic Reflection Experiment: 2006 preliminary results

Leon Vandenbergen, Bruce Goleby, Leonie Jones, Leon Bagas, David Huston, Andrew Crispe, Patrick Lyons, Wade Johnston, Tim Smith and Tim Barton

Summary
The Tanami seismic reflection project is a joint project between Geoscience Australia, Geological Survey of Western Australia, Northern Territory Geological Survey, Newmont Australia and Tanami Gold NL. Data acquisition was completed in July 2005 and preliminary results indicate that the crustal architecture of the Tanami and Arunta regions appears to have been imaged, including several structural anomalies that may control known gold mineralisation. The main crustal-scale features include a major southeast-dipping suture that extends from the surface to the Moho (possibly the boundary between the Tanami and Arunta regions); a partitioning of the crust into a less reflective upper crust and a more reflective middle to lower crust; a series of southeast-, northeast- and northwest-dipping shallow reflectors within the Tanami Region that are interpreted as thrusts; shallow and relatively thin granitic bodies that are less than 10 km thick; and a strong association between ore deposits and prospects and the location of crustal structural anomalies, including shallowly-dipping thrusts, pop-up structures and ramp anticlines.

Seismic data from petroleum exploration in the Eromanga and Pedirka basins (1960s to 1980s) extends to within a few kilometres of shallow magnetic basement southeast of the Casey Inlier and in central SIMPSON DESERT NORTH. This has enabled interpretation of cover thickness to extend through to the southeastern corner of the NT, where it is tied to several petroleum wells. One of these, Beachcomber-1, in eastern SIMPSON DESERT SOUTH, intersected metasediments with possible affinity to the Irindina Province at 1786.5 m. Cover thicknesses throughout

ILLOGWA CREEK, HAY RIVER and much of northern HALE RIVER are much shallower than this, not exceeding 250 m and typically less than 150 m. The relief on the basement unconformity surface appears to be not dissimilar to its exposed westward equivalents, with variations exceeding 100 m over short distances. Some distinct Cretaceous and/or Cenozoic sub-basins are apparent adjacent to outcropping Arunta Region rocks in central ILLOGWA CREEK and western HAY RIVER.

Basement interpretation
Observed magnetic signatures can be classified into several distinct groups, most of which are directly correlatable to outcropping geological units. Highly magnetic (exceeding 10000 x 10^-5 SI apparent bulk magnetic susceptibility), convoluted signatures correspond to granulites of the Palaeoproterozoic Strangways Metamorphic Complex. Rocks of the adjacent Irindina Province (Neoproterozoic to Palaeozoic protoliths) are generally much less magnetic (typically less than 500 x 10^-5 SI apparent bulk magnetic susceptibility), but nonetheless, exhibit east-southeast-trending magnetic bands, consistent with isoclinal folding through much of the terrane, occasionally disrupted by faults at very low angles to this trend. Dips are difficult to discern, with few ideally isolated anomalies, but a range appears to be present, with none predominant. The Alooarjara domain magnetic signature is enigmatically intermediate between that of the Irindina and Strangways complexes. East of 137°E, an open-folded magnetic marker unit appears to be associated with a particular horizon within a largely concealed Neoproterozoic succession, contiguous with the Georgina Basin to the north. Nowhere else in the Georgina Basin does the section contain such a magnetic unit.

References
Newmont is working hard to uncover the wealth of the remote Tanami Desert in the Northern Territory. In order to optimise gold recovery, Newmont is continually developing and applying leading-edge technology and adopting best practice in all aspects of its business. The objective is to ensure long-term success by increased returns to shareholders and our host communities and governments, through improved infrastructure, employment and business opportunities, economic growth, and fulfilling our environmental and social responsibilities.
Introduction

The Tanami Deep Seismic Reflection Survey is a collaborative research project involving Geoscience Australia (GA), the Northern Territory Geological Survey (NTGS), the Geological Survey of Western Australia (GSWA), Newmont Exploration Pty Ltd and Tanami Gold NL. The main objectives of the seismic reflection survey are to investigate the crustal architecture of the Tanami Region and identify the geological features and settings that have led to gold mineralisation in the area.

To achieve these objectives, the seismic reflection survey was designed to:

- image the geometry of the main faults
- determine a deformation sequence for these faults
- identify through-going crustal structures
- determine stratigraphic thicknesses of the Tanami Group and granite body geometries
- determine the relationships of the various stratigraphic packages to controlling structures
- investigate the relationship of mineralised domains to crustal-scale structures
- identify Archaean basement and its relationship to overlying Tanami Group stratigraphy
- investigate the character of the Tanami–Arunta boundary.

Tanami geology

The Tanami Region is approximately 600 km northwest of Alice Springs and straddles the NT–WA border (Figure 1). The region has gold resources and production in excess of 10 million ounces, and hosts the Callie, Tanami, Granites and Groundrush mine sites, and the Coyote and Bald Hill deposits. The region is considered highly prospective for further large gold deposits.

The oldest rocks in the region are Archaean-aged metasedimentary and meta-igneous rocks (2510 Ma: Page et al 1995), and these are basement to the overlying Tanami Group. The Tanami Group (1850–1830 Ma) is predominantly turbiditic and consists of the Dead Bullock and Killi Killi formations (Cross and Crispe in press, Crispe et al in press). The Tanami Group hosts most of the regions 1800 Ma gold deposits (Cross et al 2005). Tanami Group sedimentation was terminated by the
Tanami Event, the first major deformation and metamorphic event in the Tanami Region at around 1830 Ma. Sediments and volcanics of the Ware Group and Mount Charles Formation were deposited at 1825–1810 Ma and 1800 Ma, respectively. The period between 1825 and 1790 Ma was characterised by several periods of deformation and granite intrusion. These rocks are overlain by younger rocks of the Pargee Sandstone (<1765 Ma) and Birrindudu Group. The results of geochronological studies in the region indicate that correlates of the Tanami Group extend into the northern Arunta Region to the south (A Cross and J Claoué-Long, GA unpublished data).

Seismic acquisition

Under the supervision of ANSIR (Australian National Seismic Imaging Resource) and through its facilities manager, Terrex Seismic Pty Ltd, the seismic reflection acquisition program ran from May to July 2005. During this period, 720 line kilometres of seismic reflection data were acquired for a total budget of $1.2 million. The data were acquired using ANSIR’s seismic reflection system, consisting of a 240 channel ARAM24 (24 bit) seismic reflection recording system with 10 Hz geophones and 3 x IVI 60 000 lb Vibrators operating at all times.

The Tanami seismic survey consisted of four regional deep seismic traverses, 05GA-T1 through to 05GA-T4 (Figure 2). Traverse 05GA-T1 is a northwest–southeast regional transect whilst Traverses 05GA-T2, 05GA-T3 and 05GA-T4 provide orthogonal three-dimensional control on the geometry of the region’s main fault systems. The seismic traverses passed close to, or over the Tanami, Groundrush, Callie and The Granites mine sites and the Coyote and Bald Hill deposits, in order to provide crustal-scale information on the geological settings of these mineral-rich areas.

In conjunction with the seismic reflection acquisition program, the Northern Territory Geological Survey collected 400 m-spaced gravity data along each of the seismic traverses. Geoscience Australia, through ANSIR, also collected wide-angle velocity data along regional traverse 05GA-T1 to provide additional velocity constraints on the upper crust.

Processing and interpretation

Processing commenced in June 2005 and is due for completion by June 2006. Processing utilises the DISCO/FOCUS seismic

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Newmont is one of Australia’s largest gold producers, with interests in five mining operations in Western Australia, Northern Territory, Queensland and New Zealand.

Newmont Tanami Operations, located 530 kilometres northwest of Alice Springs in the remote Tanami Desert of the Northern Territory, consists of a processing facility at The Granites, the Callie high-grade underground mine and open pits at Dead Bullock Soak, and the Tanami plant which processes Groundrush open pit ore.

Newmont plays a significant role in providing economic benefit to our host communities and governments, through direct and indirect employment, purchasing goods and services, and payment of taxes and royalties. We believe the equitable distribution of wealth generated from our operations should be leveraged into long-term value for host communities. Wherever we operate in the world we are committed to fulfilling our environmental and social responsibilities, leaving a legacy of increased prosperity, healthier, better-educated people with quality job skills and improved employment prospects, and improved local infrastructure.

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processing package. Major processing steps identified as being most critical in improving the quality of data include refraction statics corrections, velocity analysis and the correct migration of the data.

Geoscientists from GA, GSWA, NTGS, Tanami Gold NL and Newmont Exploration Pty Ltd met in October/November 2005 to begin interpreting the seismic data. The next joint interpretation workshop is planned for early March 2006, and final results from the project (including data and interpretations) are to be released to the public at a Tanami Seismic Workshop, scheduled for June 2006.

Tanami seismic survey preliminary results

Initial assessment of the seismic data indicates that the quality is very good and that the majority of the survey objectives appear to be achievable.

Large-scale features interpreted from the seismic include the following:

- The Moho appears to have been imaged on all sections, and ranges in depth from 35–50 km.
- Changes in Moho topography appear to be coincident with significant changes observed in other geophysical data, in particular, regional gravity.
- Many large crustal structures appear to extend from the surface to the Moho boundary. Several are interpreted to be of fundamental significance to the architecture of the crust.
- There appears to be a broad correlation of known mineralised domains and the position of secondary structures associated with larger-scale features.
- Domains with previously unrecognised complexities in the crustal architecture appear to have been imaged. Several of these domains appear to have considerable mineralisation potential, and have been subjected to only limited previous exploration.
- Several granite bodies in close proximity to known mineralisation appear to have been successfully imaged. The granite bodies are relatively thin (<10 km). No significant granite bodies were imaged in the middle to lower crust.
- A broad correlation appears to exist between the geological relationships in these initial seismic interpretations to those modelled in the Tanami 3D web-model (Vandenberg and Meixner 2004). Significant refinement and improvement to the 3D web-model are anticipated following incorporation of the new seismic data.
- In light of our preliminary interpretations, it is anticipated that the seismic data will have a significant impact on current and future exploration strategies in the Tanami Region.

Conclusions

The Tanami Seismic Collaborative Research Project, with its 354 km-long ‘backbone’ traverse 05GA-T1, and the three cross-lines 05GA-T2, 05GA-T3, and 05GA-T4 are providing a better understanding of the three-dimensional structure of the Tanami Region. The project is providing results that will assist mineral explorers in a region that has known gold resources, but where exploration strategies in the Tanami Region.

Acknowledgments

The seismic data were acquired for the project by ANSIR: the National Research Facility for Earth Sounding. We thank them for their efforts and expertise. We thank Geoscience Australia, the Geological Survey of Western Australia, the Northern Territory Geological Survey, Newmont Exploration Pty Ltd and Tanami Gold NL for assistance during the field operations and input during the interpretation of the data. Geoscience Australia provided staff to process the seismic data.

References


Results of recent stratigraphic drilling in the southwestern Amadeus Basin and implications for petroleum and minerals exploration

Greg Ambrose

Two stratigraphic drillholes were drilled in late 2005 in the far southwestern Amadeus Basin. They provide much needed stratigraphic control in this area, with implications for petroleum and minerals explorers. Full details will be published shortly and the main conclusions are available on the NTGS website.

The stratigraphic section encountered in drillhole LA05DD01, located 270 km southwest of the Mereenie oil and gas field, spans 621 m of the Cambro–Ordovician Pertaorta Group. The lowermost part of the drillhole comprises microbial laminated, pale grey quartzite (Arumbera Sandstone) in sharp contact below with 202 m of red-brown to olive green mottled, dolomitic siltstone/mudstone. The additional presence of overlying enterolithic folding, diapiric breccia, chert and evaporites in this section supports a correlation with the Early Cambrian ?Giles Creek Dolostone. The Chandler Formation is disconformably? overlain by an upward-coarsening alluvial succession about 300 m thick (Petermann Sandstone). The latter is dominated in the lower part by a prograding, upward-coarsening, partly channelised alluvial succession, capped by more massive, lithic sandstone deposited on a braidplain as sediment was swept off the Musgrave Province to the south. The sandstone is texturally and mineralogically immature, and has not been metamorphosed. The uppermost sandstone records sulphides (chalcopyrite and ?bornite) disseminated along crossbeds and subvertical fractures in the interval 271–276 m. This may be classic red-bed-style Cu mineralisation, which was focused along relatively permeable zones, including fractures.

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which has a sharp (disconformable?) contact with the underlying Petermann Sandstone. Limonite staining after pyrite is common and the sandstone has poor to very good visual porosity.

About 10 km southwest of the initial drillhole, a second stratigraphic drillhole, BR05DD01, intersected 1225 m of Neoproterozoic section. The deepest intersection, the Loves Creek Member of the Bitter Springs Formation, is 700+ m thick and comprises mainly dolostone (silty and occasionally oolitic packstone and wackestone) with occasional black shale, chert and sandstone in the upper section; evaporites become more common with depth. Some vuggy carbonates below 900 m have fair visual porosity, but substantial source rocks are lacking. Unconformably overlying the Bitter Springs Formation is 48 m of massive diamictite belonging to the Areyonga Formation. The upper few metres of this succession is shaly and conglomeratic, and grades into silty mudstone of the Pertatataka Formation, which is 480+ m thick. Black shale of the Aralka Formation is missing in this well. The lower Pertatataka Formation comprises pale-dark grey and chocolate-brown silty mudstone interspersed with thin, upward-fining, occasionally sandy layers, interpreted as turbidites, which are 2–10 m thick but have very poor visual porosity. The top 150 m of the intersected section comprises mainly chocolate-brown silty mudstone and evaporites.

Geochemical analysis of the Pertatataka Formation failed to reveal Total Organic Carbon contents above 1%, as is the case in other parts of the basin, and these may represent depleted source rocks. Further work is required to resolve this and also the nature and source of a small, live oil bleed located in the lower Pertatataka Formation.

It is relevant that the most important Neoproterozoic petroleum system in the basin, the Gillen Member of the Bitter Springs Formation, has not been intersected in the western portion of the basin and the extent and significance of this petroleum system remains unknown.

### Northern Territory regolith project:
**A successful completion**

Mike Craig

This abstract outlines the aims, deliverables, scope, major activities, products, achievements and impacts of the recently completed and highly successful collaborative project on the Regolith-Landscape Framework of the Northern Territory. Staff from the Northern Territory Geological Survey (NTGS) and the Cooperative Research Centre for Mineral Exploration and Landscape Environments (CRC LEME) began a seemingly mammoth collaborative task of documenting and describing the character, distribution and variability of regolith throughout the Northern Territory, on a regional scale not previously undertaken. It has taken twenty-seven months for the team to reach the goals it set in mid 2003.

**Aims**

The Northern Territory (NT) Regolith Project was designed to establish a regolith-landforms map (1:2.5 million scale), to be supported by a Regolith Materials Atlas, describing how regolith materials vary in appearance, where they can be expected to occur and what their broader identifying characteristics might be. A wide variety of local regolith materials, suitable for addressing the diverse needs of mineral exploration and land management, were to be characterised, and if possible, major landscape domains and their associated weathering history and evolution were to be fitted into the emerging broader geochronological framework of the Australian regolith.

### Major project activities and products

1. The generation of a regolith-landforms map of the Northern Territory at 1:2,500,000 scale (Figure 1).

2. The conducting of a trans-NT regolith traverse, to set the scene for a more detailed investigation of the nature and distribution of regolith and associated landforms throughout the NT (Figure 1).
3. The study of major regolith terrains to better characterise the regolith and landform variations throughout the NT (Figure 3).

4. The conducting of a regolith materials and mapping workshop, in Darwin, following on from the NTGS “Gabfest” (18–21 January 2004), to an audience of NTGS staff and invited industry representatives. The workshop focused on regolith materials and mapping techniques, and was presented by Mike Craig, Ravi Anand and David Gray.

5. The distilling of a wide range of regolith information from within the project activities, sufficient to construct an atlas of NT regolith materials (Figures 4 and 5).

6. Using palaeomagnetism in a pilot study, begin to establish a geochronology of oxidation events using surface and mine exposures of the NT regolith and fitting this information into the emerging wider Australian regolith geochronology (Figures 6 and 7).

7. Providing, at project closure to NTGS, a copy of the detailed Geographic Information System (GIS) of regolith-landforms and material attributes constructed.

8. Providing a summary project report.
Project achievements

Formal project work has now ended. The team has achieved the following significant milestones:

1. The NT regolith project has produced a regolith-landforms map (1:2.5 million scale) of the entire Northern Territory (generated from a more comprehensive working GIS detailing the Northern Territory regolith). The hard-copy map is a much needed companion to other Territory-wide maps at 1:2.5 million scale. Note that much more detail can be extracted from the project’s working GIS.

2. The regolith atlas is now complete and is a key milestone in providing critical information in support of the NT regolith-landforms map and the detailed NT regolith GIS. It conveys information to explorers, land use managers and others about the nature and distribution of the NT regolith; how the wide assortment of regolith materials varies in appearance; and broader identifying characteristics, including geochemistry. The atlas will become an indispensable field reference for those needing to know about the Northern Territory regolith.

3. A pilot palaeomagnetics sample program was successfully conducted to help address the issue of a lack of age control in NT regolith materials and landforms. Overall palaeomagnetic ages range from 2 Ma in a weathering profile along the Darwin foreshore to 295 Ma in a road cutting at Tennant Creek. A small cluster of ages occurs around 5–10 Ma, from samples taken from the hinterland of the Darwin coastal plain. A single age of 47 Ma comes from near Glen Helen Gorge west of Alice Springs. Project results generally fall within three major age clusters determined from a very much larger range of samples being amassed by Brad Pillans (pers comm). In view of the results of our pilot program, a much clearer understanding of the timing of NT regolith, weathering and landscape development can be derived from a more focused palaeomagnetic age determination program across the Territory, and would be a welcome addition to the understanding of the NT regolith.

Impacts

The project’s products provide the Northern Territory with the first comprehensive, structured regional account of:

- regolith-landforms, in terms of variability and distribution, from 1:300 k to 1:2.5 million scales
- regolith material characteristics from mesoscale through to microscale
• broader regolith geochemistry
• the beginnings of a systematic oxidation event geochronology.

The detailed regolith-landforms GIS and the pictorial atlas of regolith materials represent a valuable new source of information that will help foster mineral exploration and land management decisions within the Territory by providing a better understanding of its regolith. This work contributes significantly to building a better integrated and more substantial underpinning for geoscientific work in the Territory.

Staff

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References


New geochronological data from the Tennant Region

David Maidment, Lex Lambeck, David Huston and Nigel Donnellan

The Tennant Region consists of three provinces that record a sedimentary, igneous and deformational history spanning the interval 1.86–1.71 Ga (Donnellan 2005). The central Warramunga Province (formerly Tennant Creek Block) is bounded to the north by the Ashburton Province and to the south by the Davenport Province. SHRIMP U-Pb zircon geochronological data have been collected from the Warramunga and Davenport provinces as part of a larger project to better constrain the timing of sedimentation, tectonism and mineralisation, and establish correlations with other elements of northern Australia (Claoué-Long et al 2005).
Warramunga Province

The Warramunga Province consists of a thick turbidite succession, the Warramunga Formation, which is overlain by sedimentary and felsic volcanic rocks of the Flynn Subgroup. The Warramunga Formation contains numerous ironstone-hosted Au-Cu-Bi deposits that produced 160 t of gold until 2000. Previous geochronology indicates that the Warramunga Formation was deposited at about 1.86 Ga, and intruded by granite and felsic porphyry at about 1.85 Ga (Compston 1995). Sedimentation, magmatism and deformation of the succession are considered to be coeval with a long-lived phase of tectonism, termed the Tennant Event. SHRIMP zircon geochronology has been carried out on sedimentary rocks of the Warramunga Formation and associated intrusive rocks to further constrain the timing of sedimentation, ironstone formation and mineralisation.

Two samples of the Warramunga Formation have been dated by detrital zircon geochronology; one from the Explorer 28 prospect and one from the White Devil mine. The detrital zircon age spectra obtained for both samples are very similar, with a dominant cluster of ages at about 1.86 Ga and a scattering of ages as old as 2.6 Ga. Both samples show evidence of near-zero-age Pb loss, and the youngest group of concordant analyses at 1860 Ma defines the maximum depositional age. Felsic volcanic rocks in the Junalki Formation (1862 ± 4 Ma; Smith 2000) are a potential local source for the 1860 Ma zircons. However, these zircons may have also been derived from the Pine Creek Province to the north, where significant felsic magmatism occurred at this time (Carson et al 2005). Metamorphism of the Pine Creek Orogen about at 1855 Ma (Carson et al 2006) might have been linked with regional uplift, and may have provided a source for sediments in the Warramunga Province. A minimum age for the Warramunga Formation has been obtained by dating the Tennant Creek Granite, 27 km northeast of Tennant Creek, which yielded an age of 1850 ± 4 Ma. This age is indistinguishable from the 1849 ± 3 Ma age of the Quarry porphyry (Donnellan et al 1999). SHRIMP ages at about 1.86 Ga and 1.85 Ga, during a phase of active tectonism in northern Australia.

A porphyry dyke from the White Devil mine has been dated to constrain the timing of formation of the ironstone that hosts Au-Cu-Bi mineralisation. The dyke cross-cuts the ironstone, but is interpreted to predate mineralisation. Zircon from the porphyry yielded an age of 1847 ± 3 Ma, similar to that obtained by Compston (1995), and confirm that the Warramunga Formation was deposited between 1.86 and 1.85 Ga, during a phase of active tectonism in northern Australia.

The Hill of Leaders Granite outcrops in the northern part of the Davenport Province, where it intrudes folded turbiditic sedimentary rocks that have been correlated with the Warramunga Formation. The turbidites are separated from overlying shallow-marine rocks of the 1840–1815 Ma Ooradidgee Group by a major angular unconformity. The essentially undeformed Hill of Leaders Granite contains deformed metasedimentary xenoliths and is nowhere seen in contact with the Ooradidgee Group. The granite is interpreted to have been intruded towards the end of deformation associated with the Tennant Event, which is considered responsible for folding, uplift and erosion of the Warramunga Formation (Donnellan 2000). SHRIMP U-Pb dating of zircon from the granite has yielded a concordant 206Pb/238U age of 1848 ± 3 Ma, consistent with an unpublished SHRIMP U-Pb age for the granite of 1848 ± 7 Ma (Page 1995). The ages obtained for the granite indicate that deformation associated with the Tennant Event ceased after 1846 ± 3 Ma, and was followed by the eruption of widespread felsic volcanic rocks and later felsic and mafic intrusive rocks has provided relatively tight constraints on the timing of sedimentation, tectonism and mineralisation, providing a reference point for the Palaeoproterozoic evolution of northern Australia.

Davenport Province

The Davenport Province consists of a succession of sedimentary and bimodal volcanic rocks that were deposited between 1840 and 1.790 Ma: the Ooradidgee and Hatches Creek groups (Donnellan 2005, Clauéou-Long et al 2005). The province preserves a record of shallow-marine to terrestrial sedimentation that records the effects of tectonism through this period. Dating of widespread felsic volcanic rocks and later felsic and mafic intrusive rocks has provided relatively tight constraints on the timing of sedimentation, tectonism and mineralisation, providing a reference point for the Palaeoproterozoic evolution of northern Australia.
of the 1840 ± 4 Ma Epenarra Volcanics, which unconformably overlie the lower succession (Claoué-Long et al. 2005).

Relatively small lode Au deposits and prospects occur in the Davenport Province, primarily in the Kunrilli area. Gold-bearing quartz veins cross-cut sedimentary rocks of the lower part of the Ooradidgee Group and associated dolerite intrusives. The age of this mineralisation is poorly known, with the 1840 Ma age of the Epenarra Volcanics (Claoué-Long et al. 2005) providing a maximum age constraint. Dolerite intruding the Rooneys Formation in the Kunrilli area has been dated to better constrain the development of the Territory and to provide opportunities for both organisations to enhance their activities.

Volcanics, might represent the extrusive equivalent of the dolerite, forming part of a bimodal magmatic suite. Bimodal magmatism also occurs lower in the succession, where felsic lavas and pyroclastic rocks of the 1840 ± 4 Ma Epenarra Volcanics are broadly coeval with basalt of the Edmerringee Volcanics. This implies that the Ooradidgee Group and the overlying Wauchope Subgroup were deposited within an extensional tectonic setting in the interval 1840–1815 Ma. Unconformities within this succession could conceivably be related to uplift associated with extension, or may be due to short periods of contraction that separated extensional phases.

Numerous small tungsten deposits occur in the Davenport Province and have yielded 4500 T W concentrate (65% WO₃) between 1913 and the early 1970s (Blake et al. 1987). In some areas (eg, the Wauchope tungsten field and the Juggler mine in the Elkedra area), mineralisation is spatially associated with outcropping granites of the Devils Suite (Budd et al. 2001), a group of several, extremely fractionated I-type granites that were apparently intruded after the major folding events in the province. Other deposits, such as those in the Hatches Creek tungsten field, are interpreted to be related to unexposed granites (Blake et al. 1987). Budd et al. (2001) classified the tungsten mineralisation into two types: 1) W-Cu-Bi-Mo-Au-Sn, and 2) W-Sn on related to Treasure Suite volcanic rocks and the Devils Suite, respectively. However, the multi-element group forms veins that cross-cut volcanic rocks of the Treasure Suite and it thus seems probable that all the tungsten mineralisation is related to emplacement of the Devils Suite. The age of the Devils Suite is relatively poorly known. SHRIMP U-Pb zircon dating of the Elkedra Granite has yielded a concordant group of analyses at 1720 ± 6 Ma and a single concordant analysis at 1633 ± 20 Ma, and the Devils Marbles Granite has yielded an age of 1711 ± 4 Ma, based on 4 analyses of 2 zircons (Page 1995). The informally named Kaidwalla granite forms part of the Devils Suite and outcrops 15 km north-northeast of Murray Downs Homestead in the western part of the province. SHRIMP U-Pb dating of zircon from the granite as part of this study has yielded an age of 1707 ± 4 Ma, including a range of inherited grains between 1.78 and 2.08 Ga. This is similar to ages of about 1700 Ma, obtained from muscovite selvages on mineralised veins in the Hatches Creek field (Fraser 2004), further supporting the connection between the Devils Suite granitoids and tungsten mineralisation.

A lamprophyre dyke from the Mosquito Creek tungsten field has previously yielded an age similar to that of the Devils Suite, with SHRIMP U-Pb zircon age groupings of 1715 ± 11 Ma and 1690 ± 18 Ma (Page 1995). The same dyke within the Hill of Leaders Granite was re-sampled and yielded a SHRIMP U-Pb zircon age of 1711 ± 2 Ma, which is interpreted as the crystallisation age of the lamprophyre. The lamprophyre dykes in the Davenport Province appear to be part of a larger suite of dykes that occurs over a wide area of the Warramunga Province (Duggan and Jaques 1996), which have yielded K-Ar and Rb-Sr (minimum) ages between 1700 Ma and 1660 Ma (Black 1975, Compston and McDougall 1994). These lamprophyres were interpreted by Duggan and Jaques (1996) to have been sourced from sub-lithospheric mantle that had been modified by addition of a crustal component by subduction, and by later mantle metasomatism. The geochemo evidence for subduction prior to 1711 Ma is consistent with the arc-like composition of magmas emplaced at 1.76 Ga along the southern margin of the Arunta Province (Zhao and McCulloch 1995). If this interpretation is correct, north-directed subduction along the southern margin of the North Australian Craton might have been the driver for deformation, magmatism and mineralisation, which extended as far north as the Warramunga Province, between 1.8 and 1.7 Ga.

**Acknowledgements**

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**References**


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Over the last six years, geoscientists from Geoscience Australia (GA), the Northern Territory Geological Survey (NTGS), and, more recently, the Geological Survey of Western Australia (GSWA) have collected over 130 new lead-isotope analyses from the Tanami, Tennant, and Arunta (Aileron Province and Warumpi Province) regions. These new data, in combination with early data from these regions and data collected by NTGS geologists in the Daly River area of the Pine Creek Orogen (P Ferenczi, NTGS, in litt 2004), allow for the first time a synthesis of lead-isotope variations across the North Australian Craton. These data also provide insights into the origin of certain base metal and gold deposits in the craton.

Lead-isotope data suggest systematic variations across the North Australian Craton from north to south. The northern part of the craton (Pine Creek, Halls Creek and Tanami regions) appears to be characterised by relatively uniform lead-isotope growth, with virtually all data plotting along the lead-isotope growth curve defined by the CSIRO-AGSO evolution model for shale-hosted Zn-Pb deposits of the Mount Isa and McArthur regions (Sun et al 1996). However, in the southern part of the craton, lead-isotope growth is heterogeneous in space and time, with the southern- and easternmost parts having progressively more primitive lead.

Values of μ (238U/204Pb integrated to present day) decrease from 12.94–13.04 in the Pine Creek, Halls Creek and Tanami regions; 12.86–12.92 in the Tennant region and northern Aileron Province; 12.76–12.85 in the southeastern Aileron Province; 12.72–12.76 in the Inkaumulla Package; and then to 12.62–12.72 in the Warumpi Province (values calculated using the CSIRO-AGSO model; Sun et al 1996). These results are consistent with variations in Nd isotopes, and could be explained as the result of more primitive crust formed in a convergent margin on the southern flank of the North Australian Craton. However, these values are significantly higher than values typical of deposits in similar-aged arc environments (μ = 12.49 at the 1730 Ma United Verde volcanic-hosted massive sulfide deposit, Arizona). These results suggest that potential for Broken Hill-type and volcanic-hosted massive sulfide deposits increases to the south and east. It is interesting to note that lead in the Warumpi Province shares some similarities with Broken Hill-type deposits.

In detail, lead-isotopes suggest a local source of lead in gold deposits of the Tanami Region; they indicate that gold mineralisation at the Dodger prospect in the northwestern Aileron Province is of broadly similar age to lode gold deposits in the Tanami Region; and they suggest that the Browns deposit, which lies to the south of the Rum Jungle area of the Pine Creek Orogen is epigenetic. In the Tanami Region, analyses of arsenopyrite, whole rock, and pyrite from different lode gold deposits yield different arrays on 206Pb/204Pb versus 207Pb/204Pb diagrams, suggesting that in each of the deposits considered, lead had a slightly different source. The data are interpreted to indicate that the lead was sourced locally, and not from a regional fluid which would have homogeneous lead-isotopic characteristics.

Lead-rich samples from the Dodger prospect in the northwestern Aileron Province yield lead model ages of 1774-1792 Ma using the CSIRO-AGSO model of Sun et al (1996). Although this model is not locally controlled in this area, the Dodger data plot close to the CSIRO-AGSO growth curve, indicating that the model age should be relatively robust. If so, the age of the Dodger prospect is similar to the age of the Tanami gold deposits (cf Cross et al 2005).

Lead-isotope data from the Browns deposit (McCready et al 2004) yield CSIRO-AGSO model ages consistently between 1632 and 1624 Ma. The age of the host to this deposit, the Whites Formation, is constrained to greater than 2025 Ma, as it underlies the 2025 +8/-5 Ma Wildman Siltstone (Worden et al 2004). As the accuracy of well determined, locally controlled lead-isotope model ages is, at very worst, 100 million years, the discrepancy between the galena model age and the host unit strongly implies that the lead in this deposit is epigenetic and not diagenetic, as suggested by McCready et al (2004).

The Litchfield Province (Pietsch and Edgoose 1988) is located along the western perimeter of the Palaeoproterozoic Pine Creek Orogen (PCO). It is a longitudinal domain of mid- to high-grade metasedimentary rocks, extensively intruded by Palaeoproterozoic granites and mafic bodies. A lack of contiguous outcrop across the Litchfield Province hampers lithostratigraphic correlation both within the province, and with the low-grade central Pine Creek Orogen to the east and the Halls Creek Orogen to southwest. This has restricted the development of comprehensive regional tectonic models. Given that the Halls Creek and Pine Creek orogens are both well-endowed with diverse mineral deposits, such correlations are crucial in assessing the prospectivity of the Litchfield Province. This contribution presents recent field-based observations, P-T estimates and SHRIMP in situ.

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monazite geochronological data on metasedimentary units from the Litchfield Province, and presents a preliminary discussion on potential correlations and plausible regional tectonic scenarios.

The Litchfield Province contains three medium- to high-grade metamorphic units, namely the Hermit Creek, Welltree and Fog Bay metamorphics, and these are the primary foci for this study. The Fog Bay Metamorphics are known only from drillcore, and are characterised by graphitic pelite, psammitite and mafic volcanogenic sedimentary rocks. They are located in the northwest Litchfield Province, and are inferred to be faulted against the Welltree Metamorphics along the north-trending Tom Turner Fault. The Welltree Metamorphics are comprised of poorly exposed biotite-feldspar gneiss, schist and amphibolite. The Hermit Creek Metamorphics, located in the Daly River region in the southern Litchfield Province, can be further subdivided into undeformed granulite-facies migmatic pelite and psammitite, and highly deformed medium-grade pelitic and psammitic ferruginous schist, amphibolite and subordinate calc-silicate rocks.

Structure

Structural observations presented here were obtained from the middle amphibolite-facies muscovite-biotite schist of the Hermit Creek Metamorphics, located in the southern Litchfield Province (Daly River). A northeast-trending upright S1 foliation contains a moderately developed sub-horizontal mineral extension lineation, L1. Tight to isoclinal upright co-linear F1 folds are common. A well developed upright S2 fabric locally transposes the S1 fabric and structures into narrow northwest-trending D2 shear zones. Within D2 domains, S2 contains a variable, but generally strong lineation (L2), plunging moderately (about 40–45°) to the northwest. Several sets of F2 folds, with variable axial plane orientations, have fold hinges co-linear with the L2 lineation. D2 is best observed within mid-grade pelites of the Hermit Creek Metamorphics, but also strongly affected the Fish Billabong Adamellite, which displays intense L2 development.

The regional effects of the transposition of D1 into northwest-trending D2 shear zones can be observed in 1st VD magnetic images, where magnetic trendlines are re-orientated into northwest-oriented corridors. Based on drag folding visible in the magnetic images, and assuming a sub-horizontal transport direction, D2 shear sense appears to be sinistral. The Wangi Basics do not display any evidence of having been affected by either structural event, either due to its emplacement postdating the D1 and D2 events, or due to rheological rigidity limiting structural reworking, with fabrics Anastomosing around rigid mafic bodies.

Assessment of the structural evolution of the Welltree and Fog Bay metamorphics is hampered by limited outcrop. Thin sections of the Fog Bay Metamorphics do not indicate any significant penetrative deformation. In contrast, the Welltree Metamorphics exhibit a well developed fabric defined by biotite and sillimanite; however, the relationship of this fabric to S1 and S2 observed in the southern Litchfield Province is difficult to assess.

Metamorphic conditions

Metamorphic conditions experienced by the Litchfield Province were varied, ranging between lower amphibolite and granulite facies. Peak P-T conditions experienced by the high-grade migmatic Hermit Creek Metamorphics, reached at least 742°C (± 44) at 5.4 kbar (± 0.5), with the development of garnet-cordierite-K-feldspar-biotite-quartz-plagioclase-(sillimanite, thomsonite) assemblages (all calculations via THERMOCALC 3.23). The notable feature of this subunit is that metamorphism appears to have proceeded statically, with little evidence of penetrative deformation. Primary bedding is remarkably well preserved and graded beds are visible. These observations contrast markedly with the pervasive S1 and S2 development experienced by middle amphibolite-facies muscovite-biotite schist of the Hermit Creek Metamorphics elsewhere in the southern Litchfield Province. No P-T estimates were obtained from this middle amphibolite-facies schist due to insufficient suitable phases.
P-T estimates from the Fog Bay Metamorphics yield temperatures of about 596–617°C at pressures of about 4.6–5.1 kbar, for spessartine-rich garnet (X_{spss} = 20–25 mol%)-sillimanite-plagioclase-muscovite-biotite-quartz (H_{2}O-saturated). Estimates from the Welltree Metamorphics on garnet-sillimanite-plagioclase-K-feldspar-biotite-quartz assemblages yield temperatures of about 727°C and pressure of about 5.9 kbar. Textural observations indicate that muscovite + quartz is not stable (ie the reaction musc + qtz = kspar + sill has been crossed), but K-feldspar-biotite-sillimanite is stable, thus conditions remained below the point of biotite + sillimanite breakdown (which marks the onset of granulite-facies conditions).

Retrograde conditions from all units are difficult to establish. P-T estimates from the high-grade Hermit Creek Metamorphics and the Welltree Metamorphics, using garnet rims affected by retrograde diffusive exchange, indicate a cooling-dominated post-peak path, but this is not quantitatively well constrained.

**Geochronology**

SHRIMP II in situ monazite isotopic data was collected on the Welltree, Fog Bay and high-grade Hermit Creek Metamorphics in November 2005 at the Research School of Earth Sciences in collaboration with Geoscience Australia. In situ U-Pb dating of monazite has recently become fashionable for determining the timing of metamorphic events affecting psammitic and pelitic metamorphic rocks, as monazite appears to be more responsive to metamorphic processes than zircon. A critical advantage of the in situ methodology is that the monazite petrological context is preserved with respect to major metamorphic phases and fabrics, enabling enhanced confidence when interpreting geochronological results within the context of specific metamorphic textures and fabrics.

In all samples, two principle textural locations were targeted, specifically monazite inclusions within garnet porphyroblasts (to assess the possibility of preserved older populations within garnet), and monazite residing in the matrix. The Fog Bay Metamorphics yielded an age of 1853 ± 3 Ma (FB03IRS002B), and two samples of the high-grade migmatitic Hermit Creek Metamorphics yielded ages of 1854 ± 4 Ma (FE05JC001) and 1856 ± 2 Ma (FE03IRS001). These dates are statistically identical. There is no statistical difference recognized by discriminating analyses on the basis of textural location of the monazite (ie garnet inclusion or matrix), or compositional differences within an individual monazite. The monazite data in each sample is therefore interpreted to represent a single population reflecting the timing of peak (or near-peak) metamorphism at about 1855 Ma.

The Welltree Metamorphics, in contrast, yielded a single population of monazite analyses at 1812 ± 3 Ma, significantly younger than results obtained from the Fog Bay and Hermit Creek Metamorphics. In this case, we interpret 1812 Ma to represent the timing of tectono-metamorphism in the Welltree Metamorphics. This is based on the occurrence of monazites aligned in the penetrative fabric, as well as monazite inclusions present within garnet porphyroblasts, all of which are chronologically indistinguishable.

SHRIMP monazite ages presented here are significantly older (by about 50–60 Ma) than previously reported electron microprobe (EMP) ages from the same samples; the same monazite grains were analysed, and in many cases the SHRIMP site was superimposed on the EMP site; eg Carson et al (2005). The newly acquired SHRIMP II data presented here supersedes this previously acquired EMP data, which will not be considered further.

**Tectonic implications**

Although it is clear that further investigation is required to better understand the tectonic evolution of the Litchfield Province and its relationships with adjacent terrains, the data presented here provides some important constraints and directions for further study. Several important observations can be stressed.

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Patrick are further expanding their involvement in the mining sector with the recent appointment as materials handling contractors in Darwin for OM Minerals Bootu Creek manganese project. In addition to our traditional stevedoring operations in loading the product, Patrick Darwin will manage the train unloading, stockpile management operations and transport of the product to the Port of Darwin shiploader.

Patrick presence in the mining industry in both Geraldton and Darwin is an important strategic development in our ongoing expansion.

The apparent absence of pervasive deformation in the Fog Bay Metamorphics and, in particular, the high-grade migmatitic Hermit Creek Metamorphics implies, at least, a passive perturbation of the geothermal regime of the crust at about 1855 Ma. An advective heat source is required and a likely candidate, at least in the Daly River region, is the Wangi Basics. The timing of emplacement of the Wangi Basics is presently unknown (samples are currently being processed by KW), but emplacement is likely to be synchronous with the timing of peak metamorphism in the high-grade Hermit Creek Metamorphics at about 1855 Ma.

The Palaeoproterozoic Halls Creek Orogen (HCO) in Western Australia has been subdivided into three geologically distinct fault-bounded northeast-trending linear belts, the Western, Central and Eastern zones (Blake et al 2000). One popular tectonic model for the HCO broadly involves closure of an oceanic basin between the Kimberley Craton and the NAC (eg Sheppard et al 1999). Current regional interpretations suggest that the Litchfield Province represents a plausible geological extension of the HCO. The newly acquired geochronological data permits some reappraisal of this intuitive, but nevertheless, inadequately constrained geological association.

Preliminary geochronological data presented here suggest that the Litchfield Province shares several important affinities with the Western Zone of the Halls Creek Orogen. Notably, the western zone of the HCO is characterised by the emplacement of layered mafic-ultramafic intrusions aged about 1855 Ma (eg Toby: 1855 ± 2 Ma, Springvale: 1857 ± 2 Ma; Page and Hoatson 2000). These ages correlate with the timing of metamorphism in the Fog Bay and Hermit Creek Metamorphics at 1855 Ma in the Litchfield Province. Peak metamorphism in these units is estimated to correlate with the timing of emplacement of the Wangi Basics. Similarly, the Whitewater Volcanics, Greenvale Porphyry and Paperbark supersuite of the Bow River Batholith, all situated in the western zone of the HCO, are dated at about 1855 Ma and are similar in age to granites from the Litchfield Province (1850–1860 Ma).
Ma: Page et al. 1985, KW unpublished data). These data suggest that metamorphism and bimodal magmatism at 1855 Ma is a significant characteristic of both the western zone of the HCO (eg Page and Hoatson 2000) and the Litchfield Province, and provides a basis for regional correlation models. Whilst there are some similarities between protoliths and protolith ages in the eastern zone and the Litchfield Province (Blake et al. 2000), there is no evidence of the main phase of metamorphism and deformation at about 1835 Ma (Halls Creek Orogeny) that affected the central and eastern zones of the HCO. There therefore appears to be, at this stage, no strong correlation between the Litchfield Province with the Central and Eastern zones of the HCO.

Correlation between the Litchfield Province and the Western Zone of the HCO is supported by the available data, but is clearly tentative at this stage. Bimodal magmatism and a lack of observed pervasive deformation during medium- to high-grade metamorphism in the Litchfield Province at about 1855 Ma is broadly consistent with an extensional setting with invasion of the crust by mafic magmas (eg Wangi Basics). It would appear that any viable tectonic model of the Litchfield Province and the Western Zone of the HCO necessitates an episode of crustal extension, regardless of the nature of the broader regional-scale setting.

In the subduction model, the Western Zone of the HCO, and by the association inferred here, the Litchfield Province represent the eastern leading edge of the Kimberley Craton, which, following destruction of the intervening oceanic basin, collided with the NAC. This scenario implies that the boundary between the Litchfield Province and the central PCO region is a fundamental continental suture between the Kimberley Craton and the NAC, a suggestion that is not favoured by the available field evidence. According to Sheppard et al. (1999), the eastern margin of the Kimberley Craton may have undergone crustal extension as an ensialic marginal basin, prior to terminal collision with the NAC, as a means of formation for the protoliths of the Tickalara Metamorphics, a characteristic unit of the Central Zone of the HCO. A similar style of ensialic rift formation may have also occurred in the Litchfield Province, permitting initial bimodal magmatism and static metamorphism of the Litchfield Province sedimentary protoliths; however, in the subduction model, it is a challenge to account for the favourable attributes of the extensional marginal basin formation and avoid the effects of a terminal collision with the NAC at about 1835 Ma (eg Sheppard et al. 1999).

An alternative tectonic model for the evolution of the HCO is an intraplate extensional model, which has been historically applied to much of Proterozoic Australia (eg Etheridge et al. 1987). In this model, limited crustal extension and rifting, in this case, at 1855 Ma, proceeded without the development or subsequent destruction of an oceanic basin, in the Western Zone and the Litchfield Province. Two principle advantages of this model are that the presence of rocks from an arc and subduction environment are not required (and are notably absent in the Litchfield Province and central PCO region) and it is not necessary for the boundary between the Litchfield Province and the central PCO to represent a continent–continent suture. However, this model implies that the Litchfield Province and the PCO is, in some fashion, part of the Kimberley Craton, rather than the western margin of the NAC, which is a potentially challenging scenario.

At this stage, it is not possible to fully characterise the nature of the tectonic relationship of the Litchfield Province with adjacent terranes and the relationship is clearly more complex than a simple extension of the HCO. The present geometry of the Litchfield Province, central PCO and the internal zones of the HCO is further complicated by the subsequent development of upper crustal strike-slip fault systems and questions remain as to the nature and location of the boundary between the NAC and the Kimberley Craton.

The Welltree Metamorphics record an episode of tectono-metamorphism at about 1812 Ma, significantly younger than the 1855 Ma recorded by the Fog Bay and high-grade Hermit Creek metamorphics, and this is markedly younger than currently
identified episodes of Palaeoproterozoic tectono-metamorphism in adjacent terranes. The 1812 Ma episode may correlate with the structural development of D1 and/or D2 in low-grade Hermit Creek Metamorphics in the southern Litchfield Province, but does not correlate with events in either the HCO or central PCO to the east. The minimum age for pervasive fabric and structural development in the low-grade central PCO region is provided by the emplacement of the post-tectonic Cullen Batholith at 1825–1835 Ma (Stuart-Smith et al 1993), clearly pre-dating the 1812 Ma fabric development in the Welltree Metamorphics. It is clear that further study is required to characterise the nature of the 1812 Ma event within the Litchfield Province and its relationship to other components of the NAC.

Economic potential of mafic intrusions in the Litchfield Province

Preliminary geophysical interpretation combined with drillhole data from the Litchfield Province suggests the existence of extensive non-outcropping areas of mafic to ultramafic varieties of the Murrenja Dolerite throughout the province, west of Tom Turners Fault. Geochemical assays of the Murrenja Dolerite were conducted on selected drillcore. The most primitive rocks with a ‘Mg number’ of 80–82 (Hoatson and Blake 2000, 322) exhibited concentrations of: 2000–3000 ppm Cr, 320–1000 ppm Ni, 13 ppb Pd, 20 ppb Pt, 34–62 ppm Cu and 78–100 ppm Co. These rocks are the closest in composition to their primary melt. The moderate abundance of PGEs may indicate that an early S-saturation event did not occur, enhancing the prospectivity for PGE and Ni mineralisation within the Murrenja Dolerite, west of Tom Turners Fault.

Furthermore, on the basis of correlations presented above, the Wangi Basics are interpreted to be a northeastern extension of the western zone of 1860–1850 Ma mafic magmatism in the Halls Creek Orogen, including the group II Springvale intrusion (1857 Ma), which hosts sub-economic levels of Cr-PGE-Ni-Cu. In the Halls Creek Orogen, intrusions are commonly characterized by Cr-PGE-Ni-Cu mineralisation, associated with stratabound chromitite (Type I intrusions of Hoatson 2000). Although no intrusions have yet been identified that are temporally related to the 1845 Ma Sally Malay intrusion, which hosts the Ni-Cu-Co deposit of the same name, given the scarcity of outcrop and data in the Litchfield Province, the potential for Sally Malay-style mineralisation remains significant. In outcrop, disseminated sulfides were observed in gabro and pyroxenite varieties of the Wangi Basics, which also locally display decimetre-scale weak compositional layering, possibly magmatic. The Ni-Cu-PGE potential of mafic rocks in the Litchfield Province is subject to ongoing studies, which will continue in 2006.

Summary

- Static medium- to high-grade metamorphism in the Litchfield Province (Hermit Creek and Fog Bay metamorphics) is now well constrained by monazite data at c.1856–1854 Ma.

- The Litchfield Province and the Western Zone of the HCO share a number of similar geological characteristics, including bimodal magmatism and metamorphism at ca. 1855 Ma.

- Crustal extension is a plausible mechanism for the evolution of the Litchfield Province at 1855 Ma.

- No evidence has been found for closure of an oceanic basin in the Litchfield Province as postulated in the Halls Creek Orogen.

- Based on the available data, there is no clear evidence for correlation of the Litchfield Province with the Central and Eastern zones of the HCO which experienced metamorphism and deformation at c.1835 Ma.

- A single monazite population with a mean age of c. 1812 Ma in the Welltree Metamorphics suggests the existence of previously unrecognized tectono-thermal event of this age.

- Extensive mafic intrusions within the Litchfield Province have largely untested potential for chromite- and/or sulfide-related mineralisation.

References


Vein-related mineralisation in the western part of the Pine Creek Orogen

AS Wygralak and TP Mernagh

Although the Palaeoproterozoic Pine Creek Orogen (PCO) represents a single geotectonic unit, significant geological differences exist between its central and western parts. The central part is characterised by predominantly greenschist-facies regional metamorphism and I-type felsic intrusions. It hosts significant gold and minor tin mineralisation. Most of the rocks in the western part are metamorphosed to amphibolite grade (Litchfield Province) and contain S-type felsic intrusions. The western part is dominated by tin mineralisation and minor gold occurrences.

The central part of the PCO has been extensively explored since the 1870s and most of the mineral deposits were discovered by the turn of 20th century. Early exploration there was aided by relatively easy access provided by the construction of the telegraph line and by the railway. Larger gold deposits in the central part of PCO (such as Enterprise, Cosmopolitan Howley, Union Reefs and Mount Todd) have been subjected to extensive geoscientific studies and there is currently a relatively good understanding of the nature of these mineral systems.

The western part of the PCO is much more remote. Difficult access hampered early exploration and, as a result, our understanding of factors controlling tin and gold mineralisation in this region is less clear. In 2005, NTGS commenced a project involving the study of mineral systems in this region. This work is in the early stages. It concentrates on the delineation of the physico-chemical character, origin and age of fluids responsible for tin and gold mineralisation. The preliminary results are presented in this abstract.

Tin-related pegmatitic veins are hosted almost exclusively by the Soldiers Creek and Allia Creek granites, whereas gold-bearing veins occur in clastic metasediments (mostly coarse greywacke) of the Burrell Creek Formation.

Fluid inclusion work has revealed that the only notable difference between tin- and gold-bearing fluids is the temperature. The former have a temperature range of 320–440°C and the latter 160–320°C. Other differences are less pronounced (Table 1).

In general, Sn-bearing fluids have less CO₂ and more CH₄, indicating their more reduced character compared with the Au-bearing fluids. Both fluids show evidence for boiling and separation of vapour phases.

Comparison with ore-stage gold-bearing fluid from the central part of the PCO (Woolwonga mine) shows a significantly lower

<table>
<thead>
<tr>
<th>Ore-stage fluid</th>
<th>Sn-bearing veins</th>
<th>Au-bearing veins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>320–440</td>
<td>160–320</td>
</tr>
<tr>
<td>Vapour phase CO₂ (mole%)</td>
<td>0–98</td>
<td>72–95</td>
</tr>
<tr>
<td>Vapour phase CH₄ (mole%)</td>
<td>1–98</td>
<td>2–24</td>
</tr>
<tr>
<td>Liquid phase Na/K</td>
<td>1.7–5.7</td>
<td>1.6–3.2</td>
</tr>
<tr>
<td>Liquid phase Na/Ca</td>
<td>1655–6172 (av. 1906)</td>
<td>808–3863 (av. 2483)</td>
</tr>
<tr>
<td>Calculated δ¹⁸O (%)</td>
<td>5.0–6.1</td>
<td>5.5–6.0</td>
</tr>
</tbody>
</table>

Table 1. Summary of physico-chemical parameters of tin- and gold-bearing fluids.
(>10 times) Na/Ca ratio. Such a difference probably reflects the presence of carbonates in the central part of the PCO (Koolpin Formation). This is an important observation, which indicates that the chemistry of fluids is altered by the surrounding rocks, reflecting the contact metamorphic nature of the gold-bearing fluids.

$^{40}$Ar/$^{39}$Ar ages of muscovite associated with tin- and gold-bearing veins (Table 2) fall in two distinct classes. Veins related to the Allia Creek Granite are older and in the range 1742–1726 Ma. Veins associated with the Soldiers Creek Granite are younger and in the range 1707–1703 Ma.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>$^{40}$Ar/$^{39}$Ar age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Related to Allia Granite</td>
<td>Related to Soldiers Creek Granite</td>
</tr>
<tr>
<td>12281</td>
<td>1730 ± 8</td>
</tr>
<tr>
<td>12284</td>
<td>1742 ± 5</td>
</tr>
<tr>
<td>12285</td>
<td>1742 ± 5</td>
</tr>
<tr>
<td>12287</td>
<td>1726 ± 6</td>
</tr>
<tr>
<td>12294</td>
<td>1730 ± 10</td>
</tr>
<tr>
<td>12301</td>
<td>1705 ± 5</td>
</tr>
<tr>
<td>12303</td>
<td>1705 ± 8</td>
</tr>
<tr>
<td>12304</td>
<td>1707 ± 8</td>
</tr>
<tr>
<td>12305</td>
<td>1703 ± 5</td>
</tr>
</tbody>
</table>

Table 2. $^{40}$Ar/$^{39}$Ar ages of vein-related muscovites.

The above data suggest that tin and gold mineralisation in the western part of the PCO has a strong spatial and temporal relation to reduced granitoids. The zonation from intrusion-proximal/high-temperature tin veins to distal lower-temperature gold-bearing veins is characteristic of intrusion-related gold deposits (Thompson and Newberry 2000). The main precipitation mechanism in both cases was the same and involved boiling. Reduction of gold-bearing fluid by organic matter in the Burrell Creek Formation could provide an additional mechanism for precipitation of gold.

Fluid inclusion work has revealed that a major difference between tin- and gold-bearing fluids is the temperature

Such a scenario has important exploration implications. Several poorly explored areas in the western part of the PCO are located within 1.5–2.0 km-wide contact metamorphic aureoles of felsic intrusions and they could provide promising exploration targets.

A separate generation of younger quartz veins with epizonal features exists in the Litchfield Province. These veins are second-order and are associated with regional-scale structures, such as the Henschke Fault. Preliminary sampling indicates that they also contain gold mineralisation. The best result obtained so far is 0.24 g/t Au, but much further work is needed to fully assess the gold potential of this generation of veining.

Reference
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Typically, an exploration company will provide Arnhem Exploration Services with project specifications, the project will be completed and data reported back promptly to the explorer. All the exploration company has to do is process the data afterwards without having to organise the field work.

Arnhem Exploration Services can be contacted on 08 8962 2337 or 0428 335 006. Their email address is arnhemex2002@yahoo.com.au
Hanson Training Services (Australia) Pty Ltd is a Registered Training Organisation based in Alice Springs, Northern Territory. HTS provides a range of nationally accredited training and assessment in areas such as Information Technology, business, Governance, horticulture, driver training (cars, 4WD, light-rigid, medium-rigid and heavy-rigid trucks), forklifts and a range of heavy equipment (such as grader, back hoe, skid steer and so on), as well as Senior First Aid.

HTS works with a range of companies who are experts in their field who can also deliver specific training in areas such as Search and Rescue and Occupational Health and Safety geared to the mining industry. Work in a range of mining environments during 2004-2005 in Mongolia was very well received and this work will now be an ongoing Project for HTS and its partners.

Training can be organised for a convenient time at any stage of the year and our experienced trainers and assessors are available to travel anywhere within Australia or internationally, at reasonably short notice. Recent international training experience during 2004, 2005 and 2006 has equipped our industry-qualified staff with a wealth of knowledge in working within a range of culturally diverse mining environments. Additionally, HTS Managing Director Sue Hanson is a qualified geologist who can add mining industry experience in the Australian context.

In addition to mining exposure, HTS also currently has contracts in China (English training and assessment) and France (Bush Foods export) and will be returning to both countries throughout 2006 and into the future to pursue and grow these projects.

Further information on training courses can be found on the company website www.hansontrainingservices.com.au or by telephoning the head office on 08 8953 3966 or on freecall number 1800 28 78 38.

HTS is a leader in the training area and this is evidenced by our recent win in the Telstra Small Business of the Year Award (2004) and then also winning the NT Training Provider of the Year Award in 2005. HTS’s philosophy of superior customer service, flexibility and exceeding the clients expectations in terms of training have held us in good stead to continue to grow and prosper.
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Australian Corporate Management Pty Ltd are proud to be associated with the 2006 NT AGES/MINING SERVICES EXPO and would like to thank all Companies that participated in the 2006 NT AGES/Mining Services Expo Program.

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