Welcome to the 11th Annual Geoscience Exploration Seminar (AGES), which once again showcases the rich mineral potential that the Northern Territory has to offer.

AGES is a key part of the Northern Territory Geological Survey’s strategy to communicate the results and significance of its industry-focussed geoscience programs and collaborations. It is also becoming an increasingly important forum for the exploration industry to report on recent exploration highlights.

Mining remains the Northern Territory’s most important industry, and underpins much of our economic and regional development. AGES is now well-established as the premier networking conference for the local mineral exploration industry, and forms an important element of the Government’s strategy to grow and develop the Territory’s exploration and mining sector.

The past year has been an exciting one for the Territory’s minerals exploration industry, with expenditure on exploration at record levels and continuing to grow, whilst exploration in the rest of Australia has suffered the effects of the global financial crisis. This is leading to the revitalisation of many regional areas such as Tennant Creek, and resulting in new discoveries which promise to sustain the industry into the future.

The Territory Government remains committed to growing and strengthening the mineral exploration and mining industry in the Territory. Through the Bringing Forward Discovery initiative, the Territory has embarked on major new geoscience programs to stimulate exploration, and has now funded two rounds of collaborative exploration drilling and geophysics. The Territory also has dedicated strategies to assist explorers in attracting international investment into their exploration projects, particularly from the major markets in Asia. This strategy is bearing fruit, and for the second year in succession a large delegation from China will be attending AGES to meet local companies and discuss investment opportunities. In short, it is a key reason as to why the Territory continues to lead the nation when it comes to the growth of exploration expenditure.

Thank you for travelling to Alice Springs for this event. I hope you enjoy your stay in Central Australia. I trust that you find AGES stimulating and enjoyable, and that it will assist in bringing forward your next discovery in the Territory.

Hon. Kon Vatskalis MLA
Minister for Primary Industry, Fisheries and Resources

DEPARTMENT OF RESOURCES
MINISTER: Hon. Kon Vatskalis, MLA
CHIEF EXECUTIVE: Richard Galton
Northern Territory Geological Survey
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EDITORS: TJ Munson and KJ Johnston

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

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

For further information contact:
Minerals and Energy Information Centre
Phone +61 8 8999 6443
Website: www.minerals.nt.gov.au/ntgs
Email: geoscience.info@nt.gov.au

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15:30–15:50  Jo Whelan  NTGS  Geochemical and isotopic constraints on mafic magmatism in the Irindina Province, eastern Arunta Region: implications for mineral prospectivity
15:50–16:10  Eloise Beyer  NTGS  Regional geology and prospectivity of the Aileron Province in the Alcoota 1:250 000 map sheet area
16:10–16:30  Paul Burton  TNG Ltd  TNG Ltd – outlook for 2010

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19:00–late  Dinner speaker: Mike Etheridge, Chairman, ABM Resources

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9:20–9:40  Russell Birrell  Redbank Mining  Redbank Copper – moving to production
9:40–10:00  Tracey Rogers  NTGS  NTGS data and services – what’s new and what it can do for you
10:00–10:40  Morning tea

Session 2
10:40–11:00  Marina Costelloe  Geoscience Australia  Reducing exploration risk and promoting exploration with results from the Pine Creek airborne electromagnetic survey, Northern Territory
11:00–11:20  Brian Richardson  Thundelarra Exploration  Hayes Creek – a new uranium field?
11:20–11:40  Karin Orth  CODES/NTGS  Coronation Hill: a complex long-lived U+Au+Pt+Pd system
11:55–13:00  Lunch

Session 3
13:00–13:30  James Cleverley  CSIRO  Using geochemistry to map upflow in the Ranger U mineral system and using this data for exploration
13:30–13:50  Rick Valenta  Bondi Mining  Overview of NT exploration projects
13:50–14:00  Ian Scrimgeour  NTGS  Closing remarks

END AGES 2010
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**BRINGING FORWARD DISCOVERY: UNDERPINNING THE TERRITORY’S EXPLORATION BOOM**

Ian R Scrimgeour

Since early 2008, the Territory has been enjoying a boom in exploration that has seen a consistent increase in its share of Australia’s total mineral exploration expenditure. Whereas the rest of Australia has seen a significant downturn in exploration due to the effect of the Global Financial Crisis, the Territory has bucked the national trend and maintained record levels of exploration. In the 2008/09 financial year, a record $146.2 million was spent on mineral exploration (up by 10% over 2007/08’s record of $132.7 million). The Northern Territory was the only jurisdiction to increase its expenditure in 2008/09 relative to the previous year. Over the same period, expenditure in Queensland was down 12% and in South Australia it was down 38%.

This trend continued into the second half of 2009, with the Territory recording record expenditure of over $49 million in the September quarter, exceeding expenditure in both South Australia and New South Wales for the first time in six years.

This strong exploration expenditure has been reflected on the ground as a resurgence in exploration in a number of areas, including several promising new discoveries (see Dunster et al 2010). This includes the dramatic revitalisation of the Tennant Creek region, highly promising greenfields uranium exploration in the Top End, Murphy Inlier region and central Australia, and the opening up of the eastern Arunta Region as a significant copper and nickel greenfields exploration province.

This boom in exploration in the Territory has coincided with a range of initiatives to stimulate exploration in the Territory through the NT Government’s four-year (2007–2011) $14.4 million Bringing Forward Discovery initiative. Bringing Forward Discovery is designed to improve the Territory’s competitiveness as a destination for exploration investment, and to increase the likelihood of new mineral discoveries. Bringing Forward Discovery is delivering collaborative funding for exploration drilling and geophysical surveys in greenfields regions, and vastly improved coverage of regional gravity data across the Territory. The initiative is also funding continuing high-quality geoscience and prospectivity assessment studies by the Northern Territory Geological Survey (NTGS), along with strategies to assist companies in attracting international investment in their exploration programs. A summary of the outputs and achievements from the first two years of Bringing Forward Discovery is now available for download on the NTGS website.

Under the initiative, NTGS has embarked on a major campaign of regional gravity acquisition, to complement the Territory’s near-complete magnetic and radiometric coverage. In the first two years, this involved the acquisition of over 20,000 new gravity stations across the Territory. The past year has seen the acquisition and release of the 2009 Barkly gravity survey, covering a vast area east of Tennant Creek and north to the southern McArthur Basin and Murphy Inlier (Figure 1). The next gravity survey, to be undertaken in 2010, will be the West Arunta survey, which will complete coverage of the Arunta Region at a station spacing of 4 km or less.

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1 Director, Northern Territory Geological Survey, PO Box 3000, Darwin, NT 0801, Australia. Email: ian.scrimgeour@nt.gov.au.
NTGS has also continued a campaign of regional geoscientific programs to enhance the geological understanding and prospectivity of underexplored areas of the Territory. Highlights of these programs include the following:

- Significant breakthroughs have been made in understanding the geology and prospectivity of the Arunta Region, which is emerging as a major greenfields mineral province.
- New copper-gold and nickel-copper prospects have been discovered by NTGS in the Harts Range area, along with evidence of a link between copper-gold mineral systems and 1780–1760 million year old granites in central Australia.
- A deep seismic survey has been completed across central Australia in collaboration with Geoscience Australia, to assess the hydrocarbon and mineral potential of the southern Georgina Basin and mineralisation pathways in the Arunta Region.
- The discovery of widespread Archaean basement in western Arnhem Land has provided new insights into the link between Archaean inliers and major uranium deposits.
- A major breakthrough in understanding the Pine Creek Orogen has led to the identification of distinct domains with differing prospectivity and commodities, and suggests that the Alligator Rivers Uranium Field is geologically different to the rest of the Territory.
- Re-mapping of the northern Georgina Basin is now complete, with four new maps released to complement new gravity coverage over the area.
- The Northern Territory’s flagship geoscience publication, “The Geology and Mineral Resources of the NT”, is now in an advanced draft form with publication planned for 2010.
- The first edition of the Metallogenic Map of the NT has been released.

The Government is also stimulating greenfields exploration through the three-year, $2.4 million Geophysics and Drilling Collaborations program. The program aims to increase the intensity of exploration in under-explored greenfields regions of the Territory, by providing 50% of costs (up to $100 000) for selected projects to assist companies with the costs of exploration geophysics or drilling in remote areas. Information gained from these collaborative drilling programs is being made open file three months after completion, in order to increase the knowledge base of the Territory’s geology and resources and help with future exploration. More detail on this program, including results and outcomes from the first two rounds of the program, is provided by Close (2010). Applications for Round 3 of the Collaborations program are now open and close in mid-April 2010.

NTGS plans to value add to drill core acquired through the Collaborations program, as well as its historical drill core collection, by scanning it through the newly acquired HyLogger™ instrument, built by CSIRO. This is a rapid spectroscopic logging and imaging system that uses continuous visible and infrared spectroscopy and digital imaging to examine core and identify mineralogy in a non-destructive way. NTGS has recently commenced operation of the HyLogger™ at the Darwin core facility, as part of the AuScope National Virtual Core Library.

Another critical factor in stimulating exploration in the Territory is ensuring that companies have sufficient funds to adequately explore greenfields projects. Under Bringing Forward Discovery, the Government is undertaking major investment attraction strategies in China and Japan. This has directly contributed to the flow of tens of millions of dollars into the exploration industry in the Territory, through a range of joint ventures between local companies and Chinese and Japanese corporations. An example is the $17 million joint venture negotiated between Western Desert Resources and Japan’s Itochu Corporation, which has allowed the Roper Bar iron field to be aggressively explored, resulting in the discovery of new high-grade iron ore resources.

Exploration in the Territory is entering a new and exciting phase. Significant potential exists for greenfields discoveries, as a result of high geological prospectivity, combined with a relatively low density of past exploration. In particular, vast areas of the Territory are not exposed, with prospective basement remaining untested, but at exploreable depths. Planned future work by NTGS includes a focus on understanding the basement to the widespread shallow sedimentary basins, such as the Georgina and Wiso Basin, that cover vast areas of the Territory. Recent undercover exploration successes, such as in the Rover field beneath the Wiso Basin, are testament to the prospectivity of this buried basement. Furthermore, recent new discoveries of outcropping copper, nickel-copper and uranium mineralisation in central Australia indicates that discoveries can still be made in outcropping areas of the Territory. The Territory Government, through the Geological Survey, is committed to continuing to work with industry to ensure that new mineral discoveries are made, in order to maintain and grow the Territory’s mining industry into the future.

References


MINERAL EXPLORATION AND MINING OVERVIEW 2009

John N Dunster1, 2, Ian R Scrimgeour and Timothy J Hutchins3

Economic Necessity

Mining and energy were worth a record $6.7B to the Northern Territory during 2008/09 (Figure 1). This is more than all wholesale, retail, primary production and tourism combined. Mining and energy account for 23.6% of the Gross State Product, which is over three times the national average of 7.6%. Mining is also a major contributor to indigenous engagement and regional development in the Northern Territory. The continued prosperity and development of the Northern Territory depends on an active mining industry and ongoing exploration to provide the mines of the future. This document reviews Northern Territory exploration and mining activity for calendar 2009.

Exploration expenditure

As a consequence of the Global Financial Crisis, both global and Australian 2009 mineral exploration expenditure fell significantly from 2008 record highs. Australian mineral exploration expenditure dropped by 9.7% from a record $2.461B in 2007/08 to $2.223B during 2008/09. In contrast, the Northern Territory’s 2008/09 expenditure was $146.2M, up 10% on the previous year (Figure 2). The Northern Territory was the only Australian jurisdiction to increase its exploration expenditure in 2008/09 relative to the previous year. The next best performing state was Western Australia (down 1% despite strong iron exploration), followed by New South Wales (down 8%), Queensland (down 12%), Victoria (down 34%), Tasmania (down 38%) and South Australia (down 38%). The Northern Territory’s share of Australian exploration expenditure increased from 5.3% to 6.6%, maintaining the increasing trend since 2003/04 (Figure 3). Some of this success can be attributed to the Government’s investment in the Bringing Forward Discovery initiative funding of $14.4M over four years, designed to attract new exploration investment and bring forward the next generation of major resource discoveries in the Territory. The international promotion of the Northern Territory to explorers and investors, particularly in China and Japan, has resulted in the attraction of tens of millions of dollars of funds into Northern Territory exploration and mining.

Much of Australia’s and the Northern Territory’s recent exploration expenditure is brownfields (in and around an existing orebody). In Australia, the proportion of greenfields to brownfields exploration fell to a low of 36% in 2006/07 and was only slightly higher at 38% in 2008/09. This was also reflected in the metres drilled nationally, where only about half is greenfields. Greenfields exploration in the Northern Territory during 2007/08 accounted for 40% of the total expenditure. This increased to 47% during 2008/09 and is better than the national average. This is a testament to the industry’s appreciation of the greenfields potential of the Northern Territory, where so much prospective ground has not been tested by modern exploration techniques and/or is under shallow cover. In an effort to further stimulate greenfields exploration in the Northern Territory, the Government introduced a Geophysics and Drilling Collaboration through the Bringing Forward Discovery program (see Close, this volume).

In terms of Northern Territory exploration expenditure on targeted minerals, 2007/08 had almost equal shares expended on gold and “other minerals”, $15.4M and $15.0M respectively, and $10.7M on selected base metals. This balance changed significantly during 2008/09, with “other minerals” at $41.6M dominating gold at $26.7M and selected base metals at $11.4M.

Titles situation

At the end of 2009, there were 1166 granted non-extractive exploration licences and 1089 exploration applications. During 2009, 511 applications were received and 262 were granted. These numbers are similar to the previous year,

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1 Northern Territory Geological Survey, PO Box 3000, Darwin, NT 0801, Australia.
2 Email: john.dunster@nt.gov.au.
despite an overall increase in turn-over of ground during 2009 (Figure 4).

Exploration and mining update

The status of exploration and mining for calendar year 2009 is described below, by commodity.

Bauxite and alumina

The aluminium price peaked in 2008, fell to half that, and then climbed back above US$1/lb despite a >4 fold increase in the global inventory.

Bauxite and alumina have been the economic mainstays of Northern Territory mineral production for decades. World-class bauxite deposits were discovered in weathered Mesozoic rocks at Gove in the 1950s; mining commenced in 1971 and the alumina plant was commissioned in 1972. During 2008/09, Rio Tinto Alcan’s Gove bauxite mine and refinery was responsible for bauxite production worth $296.8M and alumina worth $566.4M. With substantial resources already proven (Proved Resource of 111 Mt at 49.5% Al₂O₃ and Probable of 64 Mt at 49% Al₂O₃ as of the end of 2008), there was little need for further exploration around the known Gove bauxite deposits and much of this land remains in moratorium. However, Rio Tinto Exploration Pty Ltd continued to explore elsewhere, including drilling on the Cato Plateau in partnership with BHP Minerals Pty Ltd. Territory Uranium Company Ltd and Rio Tinto Exploration Pty Ltd signed an agreement to acquire ELA 25395 in northeastern Arnhem Land, which is thought to be prospective for bauxite.

Coal and coal derivatives

Petroleum studies of the Pedirka Basin by NTGS initially led to several companies acquiring licences to explore for coal. These companies sought to evaluate the potential of the Permian Purni Formation variously for hard rock coal mining, for coal seam methane and for in situ gasification. As part of their evaluation in conjunction with petroleum exploration, Central Petroleum Ltd intersected coal in several drillholes. Coal occurs within a ca 200 m interval, typically below 400 m deep. Net thicknesses of seams over a metre thick range from 7 m to over 140 m. For example, drillhole CBM93-004 intersected a net thickness of 144 m of coal between 540 m and 950 m depth. Central Petroleum claims a trillion tonne underground coal gasification/coal seam gas potential. The “high” and “low” estimate cases are 13 900 TCF and 11 100 TCF gas, respectively. The Tri-Star Energy Company is also targeting Purni coal, favouring the central and western parts of the Pedirka Basin. Tri-Star recorded Mini-Sosie seismic in the Northern Territory during 2009.
Figure 4. Exploration titles that were granted or relinquished during the 2009 calendar year, indicating the relatively high turnover of ground.
Copper

Redbank Copper Ltd has a substantial land holding in the McArthur Basin near the Queensland border. The company is targeting, and sporadically mining copper mineralisation hosted in breccia pipes. Total Indicated and Inferred JORC resources for the Redbank Project area are 6.24 Mt at 1.5% Cu for 95 900 t of Cu. During 2009, the company secured $6M in finance and undertook a scoping study for the re-commencement of copper mining operations. An oxide processing project is set to commence in 2010 and sulfide processing should be resumed in 2012. Proposed copper cathode output is 2100 to 2500 tpa. The initial rate of copper concentrate production proposed for 2012 is 20 000 tpa at 27.5% copper from 300 000 t of sulfide ore, increasing to 30 000 tpa from 500 000 t of sulfide ore in subsequent years. This study was based on a copper price of $US3.20/lb. Redbank also signed an exploration joint venture with Glencore International (earning 50%). Drilling continued on several prospects in the Redbank project during 2009. Ten holes for 1632 m completed at Punchbowl contained a best intercept of 99 m at 1.90% Cu from 159 m, including 32 m at 3.4% Cu, from hole PBRC09. Redbank subsequently announced increased resources for the project, including Punchbowl, totalling 6.24 Mt at 1.5% Cu. Five holes for 756 m were completed at Quartzite, and the best result was 9 m at 4.0% Cu from 197 m. The best result at Bluff was 64 m at 4.0% Cu from 146 m, including 28 m at 6.0% Cu from BLRC09-001. Five holes for 978 m were completed at the Roman Nose prospect, with a best intercept of 50 m at 3.0% from 193 m, including 11 m at 7.0% Cu from RNRC09-005. Best results received from Camp Valley were 22 m at 2.05% Cu from 100 m, including 8 m at 3.05% Cu from CVRC09-001.

In the Pine Creek Orogen, carbonaceous shale within the Whites Formation, close to the contact with the underlying Coomalie Dolostone, hosts several prospects and orebodies variously including Cu, Pb, Zn, U, Cu, Co and Ni. The polymetallic Browns orebody lies at the southwestern extremity of a shear zone connecting the Dysons, Whites, Whites East and Intermediate orebodies. Lead isotope data indicate that base metal mineralisation dates to 1520 Ma. Compass Resources NL/HNC (Australia) Resources Pty Ltd (HAR)’s Browns oxide project in the Pine Creek Orogen has a past production of 1523 t Cu cathode from a resource of 9.4 Mt at 0.82% Cu, 0.14% Co and 0.14% Ni. Their Browns Sulphide project has a resource of 45.1 Mt at 0.35% Cu, 3.74% Pb, 0.73% Zn, 0.09% Co and 0.07% Ni and is undergoing feasibility studies. The sulfide mineralisation at Browns contains potentially economic concentrations of Cu, Pb, Zn, Co, Ni and Ag. These metals are strongly zoned, so that high grades of each metal may be spatially mutually exclusive, diluting the overall grade of each metal when expressed as a global resource. To better reflect the economic potential of the orebody, the resource can also be expressed as a recovered metal equivalent. Thus, the Browns Sulphide resource can be expressed as either 45.1 Mt at 1.9% Cu (recovered copper equivalent) or as 45.1 Mt at 9.2% Pb (recovered lead equivalent). Mount Fitch Copper prospect lies to the east of the uranium-rich orebody of the same name (see uranium). The Cu-Pb-Co-Ni mineralisation is at the base of Whites Formation. Compass Resources NL estimated the JORC-compliant resource as 5.3 Mt averaging 0.36% Cu, 0.09% Co and 0.12% Ni. Mineralisation is hosted within the Coomalie Dolostone, rather than at the contact between the Coomalie Dolostone and Whites Formation.

Reward Minerals Ltd/Inka Minerals Ltd hold the Jervois copper-lead-zinc-silver project in the Aileron Province of the Arunta Region. The project contains the Jervois, Marshall-Reward, Green Parrot, Coxs Find, Rockface, Killeen and Bellbird prospects. Mineralisation is hosted in the Boyina Schist, which consists of lenses of garnet magnetite quartzite and calc-silicate skarn rocks within a thick succession of sericite quartz schists. The mineralisation was discovered in 1929 and was mined sporadically until 1961. In 1980, a 125 000 tpa plant was constructed to exploit high-grade Ag-Pb-Zn ore at the Green Parrot prospect. Following the mining of approximately 40 000 t, operations were suspended in 1983, due to falling metal prices. Jervois has a 2003 Measured, Indicated and Inferred Resource of 6.14 Mt at 2.1% Cu, comprising 130 000 t of contained metal. During 2009, over 3000 m of drilling was completed at the Jervois Project. Best intercepts at Marshall-Reward included drillhole RJ146 with 10 m at 4.68% Cu from 163 m. Drillhole RJ157 at Bellbird North contained 2 m at 3.06% Cu, 5.08% Pb, 7.21% Zn, and 72 g/t Ag.

As part of the work on its Huckitta project during 2009, Mithril Resources Ltd discovered a greenfields copper prospect called Basil. Surface samples of up to 6.3% Cu identified a mineralised trend over 10 km long, with a co-incident EM anomaly. Initial drilling of a small portion of this trend returned a best intercept of 41 m at 0.6% Cu and 432 ppm Co from 74 m from drillhole LBRC12. This includes 3 m at 1.4% Cu and 9 m at 1.0% Cu. A parallel trend, named Polly, also contains significant copper mineralisation at surface and remains undrilled.

As part of their exploration for uranium at the unconformity between the Westmoreland Conglomerate and underlying reduced rocks of the Murphy Metamorphics, Bondi Mining Ltd drilled MURD002 in the U19 U-Cu target. This hole, part of a wider drilling program co-funded by NTGS under the Geophysics and Drilling Collaborations program, contained up to 1.04% Cu with anomalous uranium. Further drilling in this target intersected the altered mafic intrusive host at 402.7 m. It gave a best result of 2 m at 0.16% Cu from 455 m (see Uranium).
**Diamonds**

Despite predictions that global diamond demand will exceed supply in the next eight years, 2009 was not a good year for diamond exploration or mining in the Northern Territory. Exploration expenditure fell from $5.6M in 2007/08 to $0.6M in 2008/09 and there was no production from any diamond mine. Companies with diamond exploration permits included: Acacia Minerals Pty Ltd, Astro Diamond Mines NL/Legend International Holdings Inc, Crossland Diamonds Pty Ltd, Daylight Jack Minerals (Anthony Martin), Gravity Diamonds Ltd, Rio Tinto Ltd and North Australian Diamonds Ltd. Several of these companies lost momentum because of corporate dealings. North Australian Diamonds Ltd holds tenure over the Merlin Project in the McArthur Basin. The Merlin Project comprises 14 kimberlite pipes, of which nine were subject to open-pit mining over a five year period commencing in 1998. Operations ceased in 2003, having produced 507 000 ct of diamonds. During its short operational life, the Merlin Project was renowned for the production of top quality white diamond and large specials, the largest being Australia’s biggest diamond at 104.73 ct, found in 2002. North Australian Diamonds had previously undertaken resource definition drilling resulting in the identification of a sufficient resource to underpin a reinvigorated >10-year mining project. In keeping with its staged approach to the project, pre-production trials have commenced. North Australian Diamonds also undertook diamond exploration drilling at the nearby Lancelot prospect.

Tawana Resources NL surrendered its title over the Timber Creek kimberlite pipes, where previous bulk sampling of TC-01 was conducted in 2002. The statutory reports for this project were publicly released in 2009. A total of 17 387 diamonds weighing 839 ct were recovered by extracting and processing 3802 t of raw kimberlite, representing an overall grade of 22 cph (carats per hundred tonnes). The deepest section of the pipe sampled, at 8 m below surface, had a grade of 25 cph. Just over 10 500 +1.0 mm diamonds were valued by Independent Diamond Valuers Pty Ltd at an average of US$14.04 per carat. Whilst many of the diamonds were pale brown in colour, numerous white and a few pink diamonds were also recovered. No systematic sampling or evaluation work has thus far been carried out on the TC-02 to TC-04 pipes, which previous explorers regarded as uneconomic.

The ABN021 Abner Range kimberlite diamond pipe is 43 km southwest of the McArthur River base metals orebody and 49 km from Merlin. Gravity Diamonds Ltd/Mwana Africa Plc discovered the pipe by drilling an anomaly identified in a Falcon airborne gravity gradiometry survey, in an area where Ashton Mining Ltd had previously reported microdiamonds. The steeply dipping pipe is covered by lithified sediments 5 to 10 m thick and is weathered to at least 150 m subsurface. Shallow bulk testing of the top of the ABN021 pipe was carried out by Gravity Diamonds in 2006. The results continue to be accessed and remain confidential. Although further exploration of the main ABN021 pipe was planned, the company’s highest priority was exploration for further pipes in the Abner cluster. During 2009, Legend International Holdings Inc acquired the Gravity Diamonds Abner Range titles. There was no work during 2009 because of these corporate dealings and the difficulty in raising capital during the Global Financial Crisis.

**Gold**

Gold prices in $US increased significantly during 2009, peaked at above US$1200/oz in early December and closed the year above US$1100/oz. However, relative currency exchange rates disadvantaged the gold price in SA. Gold exploration expenditure in the Northern Territory rose from $15.4 M in 2007/08 to $26.7 M in 2008/09, but declined in proportion to other commodities.

**Pine Creek Orogen**

Crocodile Gold Australia Pty Ltd took over tenements in the Pine Creek area from GBS Gold Pty Ltd and is actively proving-up resources, mining and producing gold. Crocodile Gold continued to build resources and reserves in their Howley Project (former Chinese Project) which is focused on a “big pit” mine concept. The project now has an Indicated Resource of 11.448 Mt at 1.54 g/t Au using a 0.7 g/t cutoff. Crocodile Gold reported an intersection of 55.1 m at 3.2 g/t Au, 318 g/t Ag, 8.4% Zn, 0.3% Cu and 3.1% Pb from their Iron Blow polymetallic orebody. The gossan at Iron Blow was discovered in 1873 and first worked in 1886. The primary ore consists of massive, medium- to coarse-grained sulfide-carbonate-silicate with a bedding-parallel mineral foliation. It is hosted in a mixture of lithologies in the lower Mount Bonnie Formation. The Canadian National Instrument 43-101-compliant Inferred Resource estimate on the Iron Blow project is 3.175 Mt grading 2.08 g/t Au, 100.9 g/t Ag, 0.76% Pb, 3.28% Zn and 0.19% Cu. The contained gold content of the resource is 210 000 oz. Toms Gully orebody is relatively high grade (typically 7 to 8 g/t Au) compared to others in the Pine Creek Orogen. The orebody is a 1 m-thick quartz-sulfide vein within a fault, which has been interpreted as a thrust. The host rocks are regionally metamorphosed, lower greenschist facies, folded carbonaceous siltstone and mudstone of the Wildman Siltstone. During 2009, drilling at Toms Gully underground mine intersected up to 27.24 g/t gold over 1.8 m and 6.9 g/t over 13.2 m.

Most gold at the Pine Creek Orogen Batman orebody (also known as Yimuyen Manjerr) at Mount Todd is in a stockwork of quartz veins and their margins, with only a minor amount extending into the wall rock. The veins
are hosted in metamorphosed interbedded siltstone, shale and minor tuff of the Burrell Creek Formation. Two thin lamprophyre dykes have been mapped in the mine pit. Ore was mined between 1993 and 2000. When production ceased, the mine had produced 347 484 oz (10 816 kg) gold. Gold recovery averaged 62% from the oxidised ore (0.88 g/t Au) and 58 to 60% from the transition ore. Early in 2009, Vista Gold Corporation announced an updated resource for Batman, modelled at various cutoff grades. The estimated combined Measured and Indicated gold resource at a cutoff grade of 0.5 g/t is 151 Mt at 0.94 g/t for 4.6 Moz of gold. The Inferred Resource was estimated to be 66.7 Mt at 0.86 g/t for 1.8 Moz of gold at a 0.5 g/t cutoff. Vista Gold has begun a further $5M drilling campaign at Batman and regional exploration to test en echelon structural offsets of the Batman-Driffield structural trend.

Tennant Creek Region

The typical Tennant Creek IOCG orebody is believed to have resulted from mineralised hydrothermal fluids passing along shear zones and reacting with Proterozoic iron-rich sediments of the Warramunga Formation, resulting in what are now steeply plunging, zoned, high-grade, small-tonnage Au-Cu-Bi sulfide orebodies. The region historically produced over 5 Moz of gold and 500 000 t of copper. During 2009, Emmerson Resources Ltd and partner Ivanhoe Australia Ltd pursued existing prospects at Traminer, Analytic and Trinity-Troika, and also drilled numerous greenfields targets in the Tennant Creek area. Emmerson Resources Ltd reported encouraging drill results from 8556 m of reverse circulation and diamond drilling at the Pinnacles North prospect, where 2 m at 50.6 g/t Au was intersected. Early-stage testing was conducted on several high-priority targets including Vivid, Olympos, Macedon, Delphi and Rising Star. A high-grade copper intersection of 1.9 m at 6.49% Cu, including 0.6 m at 18.3% Cu, was reported from 201 m at Rising Star. This mineralisation is hosted within a thick zone of haematite-dolomite-chlorite alteration that contains bornite and chalcopyrite.

Between them, Westgold Resources Ltd and Adelaide Resources Ltd are reinvigorating the Rover field west of Tennant Creek. Adelaide Resources Ltd reported intersecting two intervals of high-grade ironstone-hosted mineralisation at Rover 1. The first interval was a copper-rich upper zone that assayed 55 m at 3.36% Cu including 9 m at 8.00% Cu. A lower gold-copper zone contained 31 m at 2.16 g/t Au and 2.23% Cu, including 2 m at 23.24 g/t Au and 1.87% Cu. Later results included 47 m at 1.51 g/t Au in the alteration zone below the ironstone body hosting the 55 m intersection above, and 1 m at 21.1 g/t Au. At Rover 4, further significant intersections included 21 m at 2.33% Cu and 0.94 g/t Au; 27 m at 1.20% Cu; and 17 m at 1.81% Cu, including 7 m at 3.07% Cu. Westgold Resources Ltd reported encouraging new drill results from their Rover 1 Western Zone. This is adjacent to the area drilled by Adelaide Resources. Westgold reported intersections including: 128 m at 1.2% Cu, 1.2 g/t Au, 2.0 g/t Ag, 0.07% Bi and 0.05% Co from 402 m; 13 m at 3.7% Cu, 0.13 g/t Au, 1.6 g/t Ag and 0.13% Co from 433 m; 7 m at 4.1% Cu, 4.4 g/t Au, 7.9 g/t Ag, 0.40% Bi and 0.11% Co from 494 m and 7 m at 185.0 g/t Au, 0.2% Cu, 4.4 g/t Ag, 1.65% Bi and 0.01% Co from 542 m.

Excalibur Mining Ltd holds tenure over the historic Nobles Nob and Juno mines and their surrounds. These mines were, in their day, some of the richest gold mines in Australia. Nobles Nob is located 13 km southeast of Tennant Creek and was discovered in 1933. Production commenced in 1939. It was mined until the 1980s and produced more than 1 Moz of gold at 17 g/t. Supergene enrichment grades in excess of 1550 g/t Au were mined between the 30 m and 60 m levels. The Juno mine, located about 8 km southeast of Tennant Creek, was operated by Peko Mines in the 1960s and 1970s. At its peak, it produced more than 800 000 oz Au at an average grade of 56 g/t. Overall, Juno has produced 26.13 t Au, 1440 t Cu, 2295 t Bi and 2.752 t Ag from 455 000 t of ore. Excalibur undertook a $10M fund raising campaign during 2009 to cover work on these projects. Following on from extensive drilling in 2008, Excalibur drill tested up-dip extensions at Juno. Recent best intercepts included 13 m at 42.84 g/t Au from 160 m, including 5 m at 102.38 g/t Au, 14 m at 1.24% Cu from 236 m and 5 m at 23.78 g/t Au from 191 m. Excalibur’s M10 prospect or Juno Deep, is approximately 100 m below the former Juno mine. The company’s assets also include shallow oxide prospects located adjacent to the Nobles Nob mine. The most prospective of these are Rising Sun, Weavers Find, Nobles Nob West, and NM4. Drilling at Weavers Find resulted in significant intersections including 9 m at 9.84 g/t from 64 m, including 2 m at 35.80 g/t Au, 1 m at 1.24% Cu from 236 m and 5 m at 23.78 g/t Au from 191 m. Excalibur’s 2009 resources statement comprised 1.117 Moz of gold from 3.6 Mt at a grade of 10.16 g/t. Successful drilling, the remodelling of existing data and a company restructure expedited mining scoping studies. Preliminary metallurgical test work was completed on reverse circulation drill samples from Nobles Nob West and Rising Sun. The results were encouraging with generally good recoveries of 88% and 99% achieved, along with low reagent consumption and rapid leach cycles. Emphasis is now on reopening Juno as an open pit, rather than an underground mine, and examining the viability of shallow oxide resources adjacent to Nobles Nob.

Truscott Mining Corporation Ltd raised $550 000 towards a 26-hole 2925 m drilling program at their Westminster Project, which covers 5.96 km² just west of Tennant Creek township, targeting high-grade shoots along the Big Ben–Peter Pan–Wheat Doria trend. Best intercepts included drillhole 09WMRC031 with 2 m at 26.28 g/t Au from 46 m, 5 m at 23.53 g/t Au from 83 m and 1 m at 13.05 g/t Au from
105 m. Continuous mineralisation from 09WMRC041 in the number four ore body bulked to 28 m at 4.94 g/t Au from 79 m, including 5 m at 23.5 g/t Au.

A Territory Uranium Ltd–Panoramic Resources Ltd joint venture drilled three holes to test postulated IOCG targets at their Bluebush project, located 30 km southwest of Tennant Creek, between the main Tennant Creek orebodies and the Rover Field. Drilling, co-funded under NTGS’s Geophysics and Drilling Collaborations program, confirmed the presence of potential Cu-Au host rocks, including sediments and basalts beneath the Palaeozoic cover, where sparse historical drilling had previously intersected barren granite. Geochemically anomalous grades from prioritised samples included 1 m at 0.14 g/t Au from 293 m in TDD1. The anomaly is associated with a sheeted quartz vein set and is within a zone of mineral alteration. Further assays are underway.

Sipa Resources Ltd announced in December 2009 that drilling in its West Warrego farm-in had intersected anomalous levels of gold, bismuth and molybdenum that they believed indicated a “near-ore environment”. Hole WWD 04 intersected 73 m (from 126 to 199 m) of Tennant Creek-style magnetite ironstone, with strong chlorite alteration and up to 87 ppb Au, up to 23 ppm Bi and up to 112 ppm Mo. Holes WWD 01, 02 and 03 all intersected magnetite bodies with associated chlorite-haematite alteration. This program was also co-funded by NTGS.

**Tanami-Arunta regions**

The Tanami gold province straddles the Northern Territory–Western Australia border. Gold was discovered in the region by Alan Davidson in 1900, but the first large-scale mining didn’t take place until 1986. The Northern Territory contains 121 known gold occurrences and prospects in the Tanami Region. These are dominated by Callie, where high-grade Au-quartz veins occur in folded carbonaceous siltstone in the lower part of the Dead Bullock Formation. Callie was discovered in 1991 and open-cut mining commenced in 1995. More than 12% of all gold ever mined in the Northern Territory has come from this mine. As of 31 December 2009, the Probable Resource was 10.4 Mt at 4.43 g/t Au for 46.07 t Au; the Inferred Resource was 10.7 Mt at 5.52 g/t Au for 59.06 t Au. Drilling has indicated that significant mineralisation extends below 1000 m. Newmont Asia Pacific/Newmont Mining Corporation’s Tanami operations, including the Callie underground mine and working the Callie stockpile, has produced 2.073 Mt at 3.76 g/t for 233 000 oz of gold. This was the 6th highest annual production from any Australian mine and the greatest outside Western Australia. Newmont undertook some mine-scale drilling during 2009, but apart from exploration drilling of conceptual targets on MLS 154, which tested the Wilson, Central, Jenna, Auron and Colliewobble systems, little greenfields exploration has been undertaken.

In August 2009, ABM Resources NL announced a proposed acquisition of Tanami Exploration NL’s highly prospective, but largely greenfields Northern Territory tenements, including the prospective Lake Mackay area containing the Tekapo Au-Cu prospect, and the Reynolds Range area containing the Sabre and Falchion prospects. The acquisition includes a commitment to a $10M exploration program over two years. In a separate deal, protracted negotiations during 2009 culminated in Tanami Gold NL and ABM Resources NL securing the Groundrush gold project from Newmont Asia Pacific for AS$22M. The project area contains numerous prospects such as Twin Bonanza, Old Pirate, Hyperion, and Grange as well as the abandoned Goldrush mine. The area has a JORC Resource totalling 5.86 Mt at 2.7 g/t for 516 000 oz, a 1.25 Mtpa treatment plant, all associated support infrastructure including offices, workshops, airstrip, 140-person accommodation village, borefield and communication facilities, as well as an extensive package of Mineral Leases (21 Leases with a total area of 125 km²) and Exploration Licences (16 Licences with a total area of 1945 km²). This package provides enormous scope for both greenfields and brownfields exploration. ABM intends to drill the Old Pirate prospect during 2010. This area historically had spectacular grades with assays up to 152 g/t Au. A scoping study to estimate the timing and cost of re-starting the Groundrush treatment plant has been completed and planning has begun to re-optimise all of the 43 open pits and other unmined orebodies in the project area.

In other promising news for Northern Territory Tanami gold exploration, Excalibur Mining Ltd and Palace Resources Ltd announced a joint 2010 reconnaissance RAB drilling program of about 16 000 m over six targets.

**Iron**

The average iron ore price for January to November 2009, dropped about 26% from the 2008 average. Acrimonious price negotiations, falling demand and a pipeline of continuing oversupply were all contributing factors. In spite of these, many analysts remain bullish for 2010. In terms of contained iron, Australia has about 15% of the World’s Economic Demonstrated Resources, most of which is in Western Australia’s Pilbara Region. In 2008/09, Western Australia accounted for 93.7% of Australia’s iron ore exploration expenditure and also produced over 90% of Australia’s total iron ore. However, the last few years have seen a resurgence of interest in Northern Territory’s iron ore potential, albeit for what some regard as “boutique” orebodies.

Territory Resources Ltd operates a 2.0 Mtpa iron ore mine at Frances Creek. Iron ore was previously mined at the site until the pits were flooded and the ship loading facility was destroyed by Cyclone Tracy in 1974. Territory Resources
resumed mining in 2007. The iron mineralisation occurs in a fault breccia in the lower Wildman Siltstone and ranges in composition from haematite to goethite and limonite. There are over 50 named occurrences and prospects covering a distance of approximately 35 km. The southern end of the mineralised belt was exploited from 1967 to 1974, for a total production of around 6 Mt. As of September 2009, Frances Creek had total Probable Reserves of 4.7 Mt at 59.95% Fe and Indicated and Inferred Resources of 6.43 Mt at 58.66% Fe. Projected mine life based on this resource is 3 to 5 years. Optimisation of the mining and plant, including increased crushing capacity and a new wet processing facility, had reduced the cash operating cost to A$51/t FOB Darwin as of March 2009. Intensive brownfields drilling was undertaken during 2008/09, most recently including 547 reverse circulation holes for 33 023 m. Greenfields exploration by Territory Resources during 2008/09 focused on geophysical data acquisition and drilling at the Elizabeth Marion prospect (see Manganese).

The Roper Bar Sherwin Ironstone project in the McArthur Basin was first investigated by BHP between 1955 and 1961. Twenty-six iron ore prospects were designated letter and number names. The ore varies from massive to oolitic and pisolithic, and occurs within interbedded medium- to very coarse-grained ferruginous sandstone and siltstone of the Mesoproterozoic Sherwin Ironstone Member. A partnership between Western Desert Resources Ltd and IMEA Exploration and Development Australia Pty Ltd has exploration licences totalling almost 2300 km² covering much of the area previously held by BHP. Drilling has been undertaken during 2008 and 2009, and JORC Inferred Resources were given as: Area D: 90 Mt haematitic iron ore at 37.2% Fe; Area E: 12.3 Mt at 44% Fe. Recent intersections in Area F included: 7 m at 64.3% Fe, <0.01% P, 4.0% SiO₂, 2.1% Al₂O₃ and 1.4% LOI; 9 m at 62.7% Fe, <0.01% P, 4.3% SiO₂, 2.0% Al₂O₃ and 3.6% LOI, and 7 m at 66.2% Fe, <0.01% P, 3.1% SiO₂, 1.2% Al₂O₃ and 0.7% LOI. Late in the year, the company announced an Inferred Resource for Area F East of 14.2 Mt at 49.5% Fe, 22.0% SiO₂, 3.2% Al₂O₃, 0.01% P and 2.5% LOI, including a high-grade zone of 7.3 Mt at 59.3% Fe, 8.9% SiO₂, 2.8% Al₂O₃, 0.01% P and 2.2% LOI. Beneficiation testwork successfully upgraded material of moderate grade to 63–65% Fe, using low-cost gravity techniques.

Australian Ilmenite Resources Pty Ltd’s Roper Heavy Mineral project is targeting ilmenite-bearing Derim Derim dolerite sills in the Roper Group and associated placer deposits. Australian Ilmenite’s project has a Measured Resource of over 300 000 t ilmenite with a further 4 Mt either Indicated or Inferred. The ilmenite is very low in deleterious minerals such as Cr₂O₃, U and Th, and is suitable for the production of both synthetic rutile and titanium sponge. During 2009, work continued on the southern tenements, where it is believed that further ilmenite is present in the top 1 m of soils. Over 6000 auger holes have been drilled and in excess of 20 000 samples taken and analysed. Batavia Mining Ltd recently entered into an option over this area, which it sees an extension of its Roper River Iron Ore Project. Batavia announced a $1.5M exploration budget and will have until 29 July 2010 to determine whether to exercise the option. The easternmost tenement, EL 26412, abuts Western Desert–IMEA’s Roper Bar Iron Ore Project. The western ELs 24101 and 24102 contain prospects designated Areas T, U, V, W, X and Y by BHP. BHP drilling and bulk sampling indicated grades of between 43% and 63% Fe from prospects T–Y and there is potential for large tonnages of both direct shipping and upgradeable iron ore to be confirmed. The remaining of Batavia’s named prospects all lie within EL 24102 and have been subjected to relatively little work.

TNG Ltd has an iron ore prospect, now called Legune. It is one of several ferruginous gossans in the Burt Range Formation and associated stratigraphic units in the onshore Bonaparte Basin. Prospect names in this region are confusing. The main iron occurrence was formerly called Ochre Mine or Wicklow Claim and was mined as a source of ochre for tinting paint and concrete. However, Ochre Mine and Legune were also the former names of a nearby zinc-lead prospect which became Sandy Creek orebody at Manbarrum, also held by TNG (see Lead-Zinc-Silver).

Surface sampling at Legune iron ore prospect included samples with >50% Fe and low levels of phosphorous, silica and aluminium. During 2009, a Mineral Rights Agreement was signed with Chinese-backed Teng Fei Mining Ltd. The agreement provides for the 100% sale by TNG of the rights to explore and advance the Legune iron ore prospect.

The Peko Rehabilitation Project Pty Ltd involves the potential to sell 3.9 Mt of Tennant Creek tailings and waste stockpiles at 80% magnetite to the coal washing industry. The area has past production of 19 226 t magnetite at 69% Fe. The company is currently seeking a joint venture partner.

Territory Resources Ltd/Aarad Metals Ltd Warrego tailings project is located 36 km northwest of the township of Tennant Creek. The project comprises five tailings dams that were used in the processing of iron-rich copper- and gold-bearing material since the 1970s. No formal resource estimates have been reported for the Warrego tailings project. However, an exploration target based on a surface survey of the volume of the dumps and an estimate of density from earlier samples indicated that approximately 12 Mt of tailings material may be amenable to the production of a magnetite concentrate, with copper and gold as by-products. Historical test work indicated that a magnetite concentrate of about 62.3% Fe could be produced from the tailings. In addition, potential recovery could include 0.34 g/t
to 1.6 g/t Au at varying recovery levels, with the highest recovery level being 92.5%. Average grades of 0.18% Cu and 0.3% Co were also recovered from samples.

Lead-Zinc-Silver

At TNG Ltd’s Manbarrum Project, independent consultants have concluded that high-grade reverse circulation drilling results from the Mississippi Valley-type Sandy Creek zinc-lead-silver orebody should be included in the resource estimate. Their study found that previous diamond drilling may have suffered zinc loss, possibly due to the drilling process. Higher-grade reverse circulation drilling results, previously considered unreliable when compared with earlier diamond drilling, are now valid. A new resource estimate in progress will update the JORC Mineral Resource inventory for the Manbarrum project from the present combined polymetallic resource of 35.9 Mt of Pb, Zn and Ag. Also at Manbarrum, analytical results from scout diamond drilling have confirmed broad-scale zinc and lead mineralisation at Browns Prospect, 6 km northeast of Sandy Creek.

The McArthur River Mine, one of the world’s largest zinc, lead and silver mines, is situated about 70 km southwest of Borroloola, in the McArthur Basin. It is operated by McArthur River Mining (MRM), a subsidiary of Xstrata Plc. It opened as an underground mine in 1995 and has now been converted to open-cut. An 18% reduction in operating cost was achieved in 2009. Total production from the mining operation to June 2008 was 1.7 Mt Zn, 0.42 Mt Pb and 16 Moz Ag. As of 30 June 2007, McArthur River had a total resource of 144 Mt at 11.2% Zn, 4.8% Pb and 48 g/t Ag; Total reserves were recorded as 46.3 Mt at 9.6% Zn, 4.2% Pb and 43 g/t Ag. The very fine-grained thinly bedded sulphide ore is hosted in the HYC Pyritic Shale Member of the Barney Creek Formation. There are eight stacked, structurally deformed ore lenses. The pyritic shale facies are believed to be restricted to depositional sub-basins and much of the recent exploration in the eastern McArthur Basin has used airborne electromagnetics.

Rox Resources Ltd announced the results of drilling to test the open pit potential of their Myrtle prospect in the Northern Territory, 20 km south of the McArthur River mine. Myrtle contains near-surface zinc-lead mineralisation with a strike length of at least 700 m along the Main Zone of mineralisation and remains open in all directions. Although both Myrtle and McArthur River are both hosted in the HYC Pyritic Shale Member, Myrtle sulphides are >100 μm in contrast to the ultra-fine grain size of McArthur River. This indicates that metallurgical recoveries at Myrtle should be better than at McArthur River and initial metallurgical testwork was encouraging, with recoveries of 90% Zn and 74% Pb achieved. Myrtle has an Inferred Resource of 38 Mt at 4.2% Zn, 1.0% Pb (5.2% combined Zn+Pb) at a 3% Zn+Pb cutoff. At a higher cutoff grade of 5% Zn+Pb, the resource includes 15 Mt at 5.5% Zn, 1.5% Pb (7.0% combined Zn+Pb). Recent drilling results included 9 m at 3.44% Zn and 1.28% Pb from 41 m (including 2 m at 5.87% Zn, 2.67% Pb) and 10 m at 3.23% Zn, 1.32% Pb. Updated resource estimates will be completed during the March 2010 quarter. A new discovery of mineralisation at the Eastern Zone, which lies about 1 km east of the Main Zone, is at least 600 m long and extends 200 m down dip. Intercepts include 5 m grading 3.87% Zn, 1.83% Pb (5.70% Zn+Pb) from 66 m and 8 m at 3.41% Zn, 1.42% Pb (4.83% Zn+Pb) from 62 m. It appears that the mineralisation at the Eastern Zone is dipping towards the south at an angle of about 20°. The mineralisation is open in both directions along strike as well as down dip, and follow-up drilling is clearly warranted.

Lead-zinc mineralisation was discovered at Bulman (previously known as Hill 131 and Wilton Crossing) in the McArthur Basin in the late 1880s or early 1900s, and a number of small-scale mining operations ran until 1911 and then briefly again in 1925. Mining was then abandoned due to the rapidly decreasing Pb values with depth. At that time, there was no interest in the zinc content. The carbonate-hosted stratabound mineralisation occurs at ten localities (Bulman 1–10) and typically has similarities to Mississippi Valley-type ore bodies. Elsewhere, mineralisation also appears to be partly structurally controlled, partly localised by the metamorphic contact between the Derim Derim dolerite and Dook Creek Formation dolostone, and partly hosted in carbonateous Dook Creek Formation. The Bulman prospect is currently held by Admiralty Resources NL/ Bulman Resources Pty Ltd. During 2009, these companies completed airborne magnetic and radiometric surveys, geochemical sampling and reverse circulation drilling (15 holes for 415 m) around the Bulman 1 prospect. The best intercept was 3 m at 5.0% Pb and 11.6% Zn from 15 m. There is no JORC-compliant resource as yet.

Magnesium

The price for dead burnt magnesite fell over 30% from the start of 2009 until late November. The price then rallied and has stabilised at about US$300/t FOB China.

Australia has only about 5% of the world’s Economic Demonstrated Resources of magnesite, but the Kunwarara orebody in Queensland is the world’s largest known resource of cryptocrystalline nodular magnesite, a high-quality ore. Numerous occurrences and prospects have been documented in the Northern Territory’s Pine Creek Orogen and some of these appear to be high grade. During 2009, Korab Resources Ltd began a review of the Winchester magnesite orebody near Batchelor. Magnesite is hosted in the Coomalie Dolostone. It is claimed to be particularly
high-grade magnesium, grading on average 91% magnesite (MgCO3). Its JORC-compliant resource is 16.6 Mt averaging 43.23% MgO. This resource was considered sufficient for over 25 years production at a rate of 50,000 tpa magnesium metal.

**Manganese**

Australia has 13% of the world’s Economic Demonstrated Resources of manganese ore. The price increased >4 fold from November 2007 to mid 2008, fell to a low in mid 2009, and then climbed slowly again to the end of the year. Partly because of this price spike, the value of Northern Territory manganese production went from 24% to 71% of the total mineral production over three years. During 2008/09, the Northern Territory produced $1455M worth of manganese. This is eight times the value of gold production in the Northern Territory produced $1455M worth of manganese.

Manganese exploration was also undertaken at Fenn Gap prospect in the Amadeus Basin and Masterton 2 in the McArthur Basin. These two historical prospects are held by Genesis Resources. The manganese mineralisation at Fenn Gap occurs as a stratabound, dolostone-hosted manganese-rich zone over several kilometres in length, with manganese grades up to 50.9% Mn (averaging 39% Mn). Geological mapping conducted by Genesis has delineated over 9.9 km of outcropping goethite mineralisation (between 43% and 53% Fe) with moderate-grade manganese assays (33.2% Mn) obtained from the Table Prospect area. Surface rockchip sampling conducted over the Masterton 2 prospect and surrounding areas included ore-grade values of manganese varying from 43.5% to 53.1% Mn.

Territory Resources Ltd is investigating a potential sales program for high-manganese iron ore within the Frances Creek area. This specifically targets the Millers prospect. The former Mount Miller mine had historic production in excess of 20,000 t of manganese. Snowden Mining Industry Consultants Pty Ltd completed a new resource model using the original drilling, more recent exploration drilling and infill drilling conducted during 2007/08. The total JORC-compliant Indicated and Inferred Resource is 1.28 Mt at 4.55% Mn, 1.53% Fe, 0.15% Al2O3, 0.11% P, 4.55% Mn, 8.30% LOI, using a 50% Fe cutoff. The area north of Elizabeth Marion prospect was sampled. Surface-enriched rock-chip samples contained up to 41.8% Mn.

**Molybdenum–Tungsten**

Continuing depressed molybdenum and tungsten prices and the strength of the Australian dollar against the US dollar, further delayed the development of Thor Mining Plc’s Molyhil. Although the price of roasted molybdenum concentrates had increased to US$15.25/lb, and the selling price of tungsten had increased and tightened to between US$195/mtu (metric tonne unit) and US$250/mtu, Thor considers these are substantially below levels required for development with confidence. During 2009, the Molyhil resource model was re-optimised by independent geological consultants, taking into account the revised cost model and revised commodity prices. The resource estimate has been marginally upgraded to 3.75 Mt at 0.19% Mo, 0.32% W and 28% Fe. No exploration activities were conducted during 2009.

**Nickel**

Over recent years, Mithril Resources Ltd’s Huckitta–Harts Range joint venture has discovered Ni-Cu-PGE mineralisation at several locations (Blackadder, Baldrick, Blackadder, Baldrick, Maroon, Frances, Millers, 2 prospect and 2 prospect). Surface-enriched rock-chip samples contained up to 41.8% Mn.
Edmund and Miggins) in the Arunta Region. Drilling results included 9 m averaging 0.48% Ni and 0.37% Cu, comprising both oxidised and sulfide mineralisation, from Baldrick, and 3 m averaging 0.14% Ni from Blackadder. Also during 2009, the Huckitta–Sammy joint venture drilled five reverse circulation holes for a total of 535 m beneath a mineralised outcropping gabbroic body at Mithril’s Kevin Darling Prospect. Elevated Ni-Cu-PGE in drillhole SARC-002 included 491 ppm Ni, 572 ppm Cu and 115 ppm Pt+Pd+Au over 2 m intervals.

Drilling was conducted at the Hammer Hill project, in which Mithril Resources Ltd and BHP Billiton are earning up to 70% from Arafura Resources Ltd. A 52 hole air core drilling program intersected ultramafic rocks, a favourable host for nickel sulfide mineralisation. However, there was no significant Ni-Cu mineralisation. Investigations are now underway to determine if the ultramafic rocks intersected in the Hammer Hill project area are related to mineralised intrusions 30 km to the south at the Blackadder and Baldrick prospects.

Several companies, recently including Proto Resources and Investments Ltd, have targeted Norilsk-style magmatic nickel copper-PGE mineralisation, which they hope will be associated with continental flood basalts of the Antrim Plateau Volcanics. There have been no significant intersections of the target minerals to date.

**Rare earths**

Australia’s Economic Demonstrated Resources of rare earths amounted to 1.65 Mt. China has over 30% of the world’s Economic Demonstrated Resources of rare earths and supplies 95% of the market, but China is restricting supply through industry consolidation, quotas and tariffs. There are now several other emerging suppliers. Although the demand for some rare earths will continue to be met by supply; Nd, Tb, Dy and Y are predicted to be in short supply through industry consolidation, quotas and tariffs. There are now several other emerging suppliers. Although the demand for some rare earths will continue to be met by supply; Nd, Tb, Dy and Y are predicted to be in short supply through industry consolidation, quotas and tariffs.

Arafura Resources Ltd’s Nolans (formerly Nolans Bore) rare earth elements-phosphate-uranium-thorium orebody is located in the Reynolds Range, 135 km northwest of Alice Springs. About one third of the rare earths are in phosphate-rich apatite and two thirds in cheralite (a phosphate mineral). Nolans is enriched in higher-value rare earths. Measured, Indicated and Inferred Resources total 30.3 Mt to a depth of 130 m, with grades of 2.8% rare earth oxides, 12.9% P₂O₅, 0.44 lb/t U₃O₈, and 0.27% Th. In terms of mass, the orebody contains 848 000 t of rare earth oxides, 3.9 Mt of phosphate as P₂O₅, and 13.3 Mb (6031 t) of U₃O₈. This should be sufficient to sustain a mine life of more than 20 years.

According to Arafura, the distribution of the light rare earth elements currently being considered for extraction, (La, Ce, Pr, and Nd) amount to 95%, whereas the heavy rare earths (Sm, Eu, Gd, Tb, Dy) amount to 4.23%. It is envisaged that about 850 000 t of ore a year will be mined in an open pit to a depth of about 75 m, of which about 300 000 t a year will be separated as waste during primary treatment at the mine site. A rare earth elements processing plant, possibly to be located in Darwin, will extract rare earths, phosphate, uranium and by-product calcium chloride; aiming at production in 2012. Arafura have entered into an agreement with Jiangsu Eastern China Non-Ferrous Metals Investment Holding Co Ltd (ECE) a subsidiary of the East China Mineral Exploration and Development Bureau, in which ECE acquired up to 25% of the issued capital of Arafura.

Rum Jungle Uranium Ltd has targeted uranium-rare earth elements mineralisation along the western margin of Mount Goyder. A reverse circulation drilling program of 26 holes for 1824 m was undertaken in late 2008. Results reported in 2009, indicate that polymetallic skarn mineralisation was intersected in eight holes. Mineralisation includes low-grade U, Cu and Fe, with anomalous rare earth oxides, Co, Au and Ag. The best result in terms of rare earth elements is 3 m at 0.97% rare earth oxides, 215 ppm U₃O₈, 158 ppm Co, 0.27% Cu and 35.2% Fe from 27 m in MGRC003. Mineralisation is located in a hornfels zone of the Wildman Siltstone. Follow-up is planned as part of a Joint Venture Agreement with Territory Resources Ltd, where Rum Jungle Uranium Ltd has mineral rights to all non-ferrous metals.

**Phosphate**

Phosphate rock prices rose strongly during 2008 and peaked at US$450/t in mid 2008, as a result of an increasing global demand for fertiliser for food production and for biofuel crops. By early 2009, the price had fallen to US$110/t, but this is still double the long-term average price. The dramatic decrease was a result of the Global Financial Crisis, which had a significant influence on phosphate demand and pricing, particularly for mono/diammonium phosphate (DAP) fertiliser. The largest producers dramatically cut production, as DAP prices fell from US$1230/t FOB in May 2008 to US$390/t by early 2009, and to a low of US$270/t by late May 2009; a 4.5-fold drop in a year. About 83% of Australia’s inferred phosphate resources, which total 1574 Mt, occur as sedimentary phosphorite in the Georgina Basin. These resources are distributed between Queensland and the Northern Territory. Several companies are re-examining known deposits and exploring for new phosphate prospects in the Northern Territory Georgina Basin.

The Wonarah phosphate deposit was discovered in 1967 by IMC Development Corporation. It was then explored by a Rio Tinto–Australian Kimberley Diamonds joint
venture before being taken up by the current tenement holder, Minemakers Ltd. The phosphate occurs in the Cambrian upper Gum Ridge Formation or basal Wonarab Formation. The 2009 JORC Inferred Resource was 1105 Mt at 18% P2O5, which made Wonarab Australia’s largest JORC-compliant rock phosphate deposit. A 2010 update puts the global resource at 1258 Mt at 12% P2O5 and 0% P2O5 cutoff. Within that, the Main Zone deposit has an estimated Indicated plus Inferred Resource of 66 Mt at 28% P2O5 at a 25% cutoff, whereas the high-grade core of the nearby Arrawarra deposit has Indicated and Inferred Resources of 4.7 Mt at 30.2% P2O5, using a 15% cutoff. Minemakers is currently developing the deposit. Trial mining has been undertaken and production is planned for 2010.

Phosphate Australia Ltd has the Highland Plains deposit which abuts the Northern Territory/Queensland border. This deposit was discovered in the 1960s. Phosphate occurs in the Cambrian Border Waterhole Formation. It has a total JORC Inferred Resource of 56 Mt at 16% P2O5, with a lower cutoff grade of 10% P2O5. The company also announced an increased resource of 14 Mt at 20% P2O5 in the Western Mine Target Zone of the deposit. Drill intersections included: 10 m at 24.7% P2O5 from 8 m, including 4 m at 31.1% P2O5 from 11 m, and 5 m at 24.7% P2O5 from 34 m. Phosphate Australia has been undertaking metallurgical test work and is investigating the viability of a slurry pipeline to transport up to 3 Mtpa to the coast of the Gulf of Carpentaria.

Other companies undertaking phosphate exploration in the Georgina Basin include Aragon Resources Ltd/Territory Phosphate Pty Ltd who drilled the historic Ammaroo prospect, Australis Exploration Ltd, FSL World Holdings Pty Ltd, Bondi Mining Ltd, Mantle Mining Corporation Ltd, South Boulder Mines Ltd, Uramet Minerals Ltd and Vale Australia EA Pty Ltd. Consolidated Global Investments Ltd has ground in both the Daly and Georgina basins.

Aragon Resources Ltd/Territory Phosphate Pty Ltd has the historic Lady Judith prospect in the Wiso Basin. The phosphate is in Hooker Formation mudstone and silty limestone. Phosphate assays of up to 31% P2O5 over 6 m have been reported. Waterbore RN020989 located within the tenement contains 28.2% P2O5 over 3 m from a depth of 15 m.

The Geolsec phosphate prospect was discovered during the 1960s by a ground radiometric survey targeting uranium mineralisation. Fluorapatite is hosted in the poorly understood Geolsec Formation in Mesoproterozoic rocks of the Pine Creek Orogen. The deposit is now held by Korab Resources Ltd/Geolsec Phosphate Operations Pty Ltd. It contains approximately 1.3 Mt of rock phosphate grading up to 39% P2O5 with an average grade of 12% P2O5. Korab announced that it has been able to reduce the start-up and projected operating costs of the GeolSec project in the Northern Territory by 38% from the original estimate. The project is fully funded to production following the successful completion of fund raising in September 2009.

The eastern McArthur Basin contains massive to flaggy phosphate beds with grades in the range 5–24% P2O5 and stromatolitic phosphorite, with uniform grades of 29–34%, occurs in the basal unconformity-bounded Palaeoproterozoic Karns Dolostone in the Selby area. Phosphate occurrences are also known from the underlying unit. McArthur Basin phosphate had been targeted by Legend International Holdings Inc and others, often as part of multi-commodity exploration programs. A lack of success during 2007–2008 saw exploration momentum decline during 2009.

The multi-commodity Nolans orebody (see rare earths) has Measured, Indicated and Inferred Resources totalling 30.3 Mt to a depth of 130 m which includes 12.9% P2O5.

**Tin-Tungsten-Tantalum-Lithium**

The tin price peaked at US$24/t in May 2008, fell back to less than half in March 2009 and closed the year at US$15.5/t. Despite an increasing market for use in batteries (particularly in electric vehicles), lithium demand actually declined through the third quarter of 2009. Globally, lithium is in oversupply and this may persist until 2013. Lithium prices were generally stagnant through most of 2009, but some suppliers announced 20% price reductions in September.

Tin-tungsten-tantalum-bearing pegmatites and quartz veins were discovered in 1879 at Mount Wells and in the Bynoe Harbour area shortly afterwards. Mineralisation is typically hosted within the Burrell Creek Formation in the contact aureole of granites. At Mount Wells Sn-Cu-W-Au orebody, Outback Metals Ltd has been re-assaying many of the samples from their 2008 drilling program after it appeared that a dubious laboratory standard caused a bias in the original results. An updated resource is expected shortly.

Tin-tantalum-bearing pegmatites are present in a north-trending 10 km-wide belt extending from Bynoe Harbour to the Wingate Mountains. The host rocks are generally metamorphosed Burrell Creek Formation. Named prospects, orebodies and historical mines include Mount Finiss, Goodwill Extended, Hang Gong, Sues Pegmatite, Annie group, Leviathan, Saffums and Observation Hill. Another cluster of pegmatites is present in the Mount Shoobridge area. Haddington Resources Ltd/Altura Mining Ltd/Australian Tantalum Pty Ltd reviewed the tin potential of Leviathan, Sues Pegmatite, Saffums 3 and the River Annie Group during 2009. The company has become interested in the lithium potential of the Sn-Ta pegmatites in the Pine Creek Orogen and reviewed data on the abandoned Ah Bung mine, and on the Lianas, Jennys, Clarks, Black Jade and Mugs Find prospects. A field program is being prepared to assess the prospectivity of a number of these pegmatites at Finiss Range, where rockchip assays of up to 1.46% lithium oxide have been recorded.
Uranium

The uranium spot price remained volatile during 2009. On average, it rose progressively from US$20/lb $U_3O_8$ in January 2005 to a peak of US$138/lb in July 2007 and closed 2009 at US$44.5/lb. The long-term uranium contract price fell from a high of about US$95/lb to $US61/lb during 2009. Long-term contracting volumes were at a five-year low. Global demand was easily met, especially with the emergence on the market of material released from US Government stockpiles. Australia has the world’s largest Economic Demonstrated Resources of uranium. This is dominated by Olympic Dam in South Australia, which alone may be approximately 30% of the world’s total. Excluding that, the Northern Territory has the largest share of the remainder, including examples of all known types of economic mineralisation. The most significant orebodies, including Ranger, Jabiluka and Koongarra, are in the Alligator Rivers region.

During 2009, Energy Resources of Australia Ltd’s (ERA) Ranger Mine produced 5497 t uranium oxide (cf 2008: 5272 t), the third highest in ERA’s history. Ranger ore is in metapelite of the lower Cailhill Formation, close to the contact with the underlying Nanambu Complex. In the No 1 ore body, which was mined until 1994, host rocks are brecciated and occur within a synform. Current production is from the No 3 orebody. The host rocks there are a monotonous succession of thinly laminated quartz-chlorite schist, containing a few thin (<1 m-thick) chert bands. The primary uranium minerals in both orebodies are uraninite or pitchblende, with some coffinite and minor brannerite and curite. Revenue from the sale of uranium oxide for the year was a record $767.8M (cf 2008: $495.6M). Work continued on a feasibility study for a proposed heap leach facility at the Ranger mine, for the extraction of 15 000 to 20 000 t of uranium oxide contained in low-grade mineralised material within the current pit and on existing stockpiles. Separate studies are advancing regarding the Ranger 3 Deeps mineral resource, including the development of an exploration decline to allow closely spaced underground drilling. These studies are expected to be completed during the middle of 2010, with a decision on the development of the exploration decline to be taken thereafter. ERA spent $5M on exploration during 2009, mostly on resource drilling at Ranger 3 Deeps. Overall, uranium exploration expenditure in the Northern Territory increased from $48.7M in 2007/08 to $54.5M in 2008/09.

During 2009, Thundelarra Exploration Ltd drilled at its Thunderball prospect, a grassroots discovery near Hayes Creek in the Pine Creek region. Uranium mineralisation occurs in a sheared and tightly folded succession of metasedimentary rocks and tuffaceous units of the Gerowie Tuff near the contact with the overlying Mount Bonnie Formation. Mineralisation appears to consist of uraninite, both in structurally controlled veins and disseminated through the host rocks. The best drill intersection was 15 m at 1.5% $U_3O_8$, including 1 m at 20.3% $U_3O_8$ in reverse circulation drillhole TPCRC019. Another noteworthy intercept was 11 m at 3.4% $U_3O_8$ including 4.6 m at 8.0% $U_3O_8$ in diamond drillhole TCPDD026. At the Corkscrew prospect, 3.5 km away, limonitic surface boulders have assayed up to 2.3% $U_3O_8$. To date, the source of the highly mineralised boulders has not been located.

Rum Jungle Uranium Ltd identified roll-front-type uranium mineralisation associated with oxide copper on its Mount Bundy project, 90 km southeast of Darwin. The Anniversary Breccia prospect is located 10 km northwest of Toms Gully gold mine and U-Cu mineralisation was intersected, with best results including: 1 m at 1769 ppm $U_3O_8$ and 3.87% Cu within an interval of 5 m at 570 ppm $U_3O_8$ and 1.12% Cu. A large low-grade intersection of 53 m at 250 ppm $U_3O_8$ from 45 to 98 m included 26 m at 339 ppm $U_3O_8$ and 2557 ppm Cu.

The Territory Uranium Company Ltd discovered a new low-grade surface uranium occurrence in the Daly River area which is now their Energy prospect. Continuous flat-lying uranium mineralisation up to 10 m wide occurs from surface to the base of a brecciated sandstone, which is probably part of the Tolmer Group. Highest grades appear to be associated with the contact between the sandstone breccia and a clay/mudstone and weakly pyritic carbonaceous shale. Twenty reverse circulation holes were drilled for 1147 m. The best intersection was 7 m at 567 ppm $U_3O_8$ from surface in drillhole TURC74. This includes 2 m at 973 ppm $U_3O_8$ from 4 m depth. Two other holes confirm that mineralisation extends for 2.5 km laterally. Reverse circulation drilling by Uranium Exploration Australia Ltd at its Crystal Creek Project showed that the mineralisation extends to depth, particularly in the western 1 km of the outcropping structure. In July 2009, the company announced the discovery of another nearby zone of uranium mineralisation which outcrops intermittently over a strike distance in excess of 3000 m (radiometric Anomaly B). This mineralisation appears to be associated with the Mesoproterozoic Yarunganyi Granite of the Southwark Granite Suite. Rock chip and field XRF determinations indicated $U_3O_8$ concentrations of up to 4120 ppm. Anomaly B and adjacent outcrops were drilled in late November. Over half of the holes drilled at Anomaly B contained anomalous uranium values >100 ppm $U_3O_8$, the best drill intercept being 346 ppm $U_3O_8$ over 3 m downhole thickness from 64 m depth.

Crossland Uranium Mines Ltd has announced promising surface sample results from their Cockroach Dam prospect within the highly radioactive Teapot Granite in the Warumpi Province. Follow-up of radiometric anomalies with rockchip sampling produced anomalous results, with a maximum value of 5364 ppm $U_3O_8$, and an arithmetic average of all 186 outcrop samples of 439 ppm $U_3O_8$. 

[15]
Bondi Mining Ltd undertook reconnaissance drilling exploring for uranium at the unconformity between sandy phases of the Westmoreland Conglomerate and the underlying reduced rocks of the Murphy Metamorphics. One drill sample from within 1 m of the unconformity contained 44.3 ppm U$_3$O$_8$ along with elevated Pb, Zn, As, Ni and P. Anomalous uranium in drillhole MURD002 in the U19 U-Cu target was followed up with two other reverse circulation/diamond holes. MURD015 intersected the altered mafic intrusive host at 402.7 m. It gave a best result of 2 m at 0.16% Cu from 455 m. The Westmoreland Sandstone was weakly anomalous in uranium, the best interval being 1 m at 29 ppm U$_3$O$_8$ from 274 m. Bondi’s Murphy project is the subject of a Letter of Agreement with Japan Oil, Gas and Metals National Corporation (JOGMEC), wherein JOGMEC can earn 61% interest by funding $3M in exploration over four years. The project has also received two co-funded drilling grants under the Bringing Forward Discovery program.

An Energy Metals Ltd-led joint venture has been evaluating the historic Bigrlyi uranium orebody in the Mount Eclipse Sandstone of the northern Ngalia Basin. At a cutoff grade of 500 ppm U$_3$O$_8$, the Bigrlyi resource totals 20.6 Mlb (9444 t) of U$_3$O$_8$ and 38.6 Mlb (17 509 t) of V$_2$O$_5$. Significantly, 45% of the contained uranium metal (or 4190 t U$_3$O$_8$) now reports to the Indicated Resource category, compared with 39% in the previous (March 2008) OK resource estimate. At a 250 ppm cutoff, the MIK resource increases to 29.4 Mlb (13 336 t), with most of this resource within 200 m of the surface and potentially amenable to open cut mining. At both the 500 ppm and 250 ppm cutoff grades, approximately 55% of the contained uranium metal reports to the Indicated Resource category. The Bigrlyi mineralisation remains open at depth and along strike. The ore is reported to have excellent metallurgical properties. Base case acid leach tests recorded extraction rates of 98% uranium and 59% vanadium, with 94–95% of uranium extracted within 8 hours at optimum leach conditions (pH 1.8, 50°C, ORP=450 mV, coarse grind size). Reverse circulation drilling of 44 holes for 5559 m at Bigrlyi during 2009 returned encouraging shallow intercepts from untested zones and a new mineralised position at Bigrlyi of 4 m at 0.27% U$_3$O$_8$, including 1 m at 0.74% from 77 m, and other intercepts of 2 m at 0.13% U$_3$O$_8$ and 2 m at 0.05% U$_3$O$_8$.

Energy Metals also have a palaeochannel uranium prospect called Cappers near the southern Ngalia Basin margin. During 2009, drilling of 310 aircore holes for 3070 m confirmed previously encouraging results and gave a best intercept of 570 ppm eU$_3$O$_8$ (uranium equivalent) by gamma probe over 4.40 m from 3.35 m depth. In the final quarter of 2009, China Guangdong Nuclear Power, a subsidiary of China Uranium Development Company, made a proportional take over bid for Energy Metals.

The Napperby (formerly New Well) orebody is near-surface uranium mineralisation occurring in a 20 km-long 1.5 km-wide Cenozoic palaeochannel. Carnotite mineralisation was discovered, 3 to 7 m below the surface, in the late 1970s. Since signing an option agreement with Deep Yellow Ltd in 2007, Toro Energy Ltd has undertaken resource definition and has increased the contained tonnes of uranium on a JORC basis. The March 2009 Inferred Resource was 9.34 Mt at 359 ppm (0.036%) U$_3$O$_8$ for 3351 t (7.39 Mlb) of contained uranium oxide, using a 200 ppm U$_3$O$_8$ cut off. Toro has undertaken metallurgical testing, which indicated that a 90°C alkaline leach produced 90% uranium extraction in 8 hours. Toro is currently undertaking a scoping study aimed at identifying the key economic factors toward development.

A Cameco Corporation and Paladin Energy Ltd joint venture was granted an exploration licence over the historical Angela-Pamela uranium orebody in February 2008. The orebody is in the northern Amadeus Basin, 25 km south of Alice Springs. Higher-grade mineralisation at Angela is defined by a linear zone, 70 to 250 m wide, within sandstone of the Undandita Member of the Late Devonian Brewer Conglomerate. Angela-Pamela was previously drilled in the 1970s and during the 1980s, a non-JORC-compliant maximum total resource for Angela was estimated to be 12 650 t of U$_3$O$_8$, grading 0.1% U$_3$O$_8$. Cameco have completed 27 000 m of resource definition drilling and is hoping to have a stock exchange-compliant resource estimate by April 2010 and to begin a scoping study by the end of 2010.

Cleos Uranium Project is located 36 km north-east of Pine Creek township between Kakadu National Park and the Rum Jungle Mineral Field, in the Pine Creek Orogen. Mineralisation is believed to be in the Masson Formation. The project has a near-surface Inferred Resource of 1.4 Mt at 304 ppm U$_3$O$_8$ at the Cleos, Twin and Dam prospects, which were discovered by Total Mining Australia Pty Ltd in 1983. The Cleos area is subject to a joint venture agreement between Atom Energy Ltd and Thundelarra Exploration Ltd. Referred to as the Allamber Project by Thundelarra, the tenements are located approximately 60 km east of their Thunderball project, described above. A 17 hole, 1593 m reverse circulation drill program has been completed at Allamber. Initial results were encouraging with nine holes returning anomalous intercepts including 10 m at 458 ppm U$_3$O$_8$ in hole TAL013RC and 5 m at 1016 ppm U$_3$O$_8$ in TAL011RC.

Mount Fitch uranium, held by Compass Resources NL, is mostly hosted in dolomitic rocks of the Whites Formation. The orebody has a total Measured, Indicated and Inferred Resource of 5.05 Mt at 0.8 lb/t uranium. Although approximately 90% of the resource estimate now falls in the Measured and Indicated categories, this
is a significant reduction in the previously reported global resource.

**Uranium-gold**

NuPower Resources Ltd hold titles over the historic Eva (or Pandanus Creek) and Cobar 2 (or Cobar II) uranium-gold mines in the Murphy Inlier close to the Queensland border. Most mineralisation at Eva is controlled by shears and fractures in intensely altered porphyritic acid volcanics of the Cliffdale Volcanics. Fifty vertical and inclined holes, which included 40 percussion holes, were completed for a total of 2388 m and 10 core holes for 466 m. NuPower reported intersections including 27 m at 0.77% U\textsubscript{3}O\textsubscript{8} and 5.10 g/t Au (including 4 m at 2.24% U\textsubscript{3}O\textsubscript{8} and 17.72 g/t Au), 20 m at 0.416% U\textsubscript{3}O\textsubscript{8} and 5.07 g/t Au, drillhole EV001 5 m at 0.15% U\textsubscript{3}O\textsubscript{8}, 1.67 g/t Au from surface, 7 m at 1.25% U\textsubscript{3}O\textsubscript{8}, 4.79 g/t Au; EV002 7 m at 0.79% U\textsubscript{3}O\textsubscript{8}, 5.69 g/t Au from 3 m; 7.5 m at 0.59% U\textsubscript{3}O\textsubscript{8}, 6.18 g/t Au from 11.5 m. Mineralisation intersected to date occurs over a strike length of 100 m and down dip for up to 100 m, to a depth of 65 m.

**Vanadium**

TNG Ltd’s Mount Peake project is a mafic rock-hosted vanadium-titanium-magnetite prospect in the northern Arunta Region, 60 km west-southwest of Barrow Creek. Drilling of the prospect has identified an extensive layer of magnetite within a large gabbro intrusion, with a mineralisation envelope that commences around 15 m below surface; this is up to 122 m thick and has a north–south strike length in excess of 1 km. Most of the 9 km-long magnetic anomaly associated with the prospect remains undrilled. On the basis of initial drilling, the domain was then investigated in the northeast corner, where the company discovered unmapped outcrops of vanadium mineralisation in an interpreted mafic intrusive complex. A total of 16 breccia samples contained average values of 0.74% V\textsubscript{2}O\textsubscript{5} and 27.7% Fe. Mapping outlined semi-continuous rubble and outcrop of the breccia over an approximate area of 900 m by 400 m.

Drilling by Arafura Resources Ltd at their Jervois project (not to be confused with the Jervois base metal orebody) has intersected several broad zones of strong primary magnetite-vanadium mineralisation, with relatively attractive metallurgical characteristics. Concentrate grades of up to 1.98% vanadium (V\textsubscript{2}O\textsubscript{5}) and 67.9% Fe have been achieved, with an average recovery of 76% V\textsubscript{2}O\textsubscript{5} to concentrate. In April 2009, Arafura and East China Exploration (ECE) signed a Letter of Intent for ECE to sole fund A$8M of exploration on the Jervois Project for an equity interest of 51%.

Several Northern Territory uranium orebodies contain by-product vanadium. For example, large diameter core drilling at Biglryi intersected 3.0 m at 1.57% V\textsubscript{2}O\textsubscript{5} from 34.0 m, associated with uranium mineralisation. The current resource at Biglryi contains 17 509 t of V\textsubscript{2}O\textsubscript{5}.

**References and useful sources of information**


Some material cited here has been sourced from company websites, news releases and Stock Exchange announcements by companies. The Northern Territory Department of Resources also maintains a database of Northern Territory exploration news which can be accessed from: [http://apps.minerals.nt.gov.au/explornews/](http://apps.minerals.nt.gov.au/explornews/).

All the above websites were accessed January 2010.

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UNLOCKING THE NEXT GENERATION OF DEPOSITS IN THE TENNANT CREEK MINERAL FIELD

Grant “Rocky” Osborne

Serious gold and copper production within the Tennant Creek Mineral Field (TCMF) extended continuously from 1950 until 1999, then again between 2002 and 2007. Early discoveries were localised around outcropping “ironstones” (hydrothermal iron-oxide concentrations), with the majority of later discoveries resulting from drill testing of magnetic anomalies. Discovery and production within the TCFM was clearly linked to the areas of outcrop and/or shallow cover existent in the southeastern part, with a notable lack of success westwards under deeper cover. For example, the cover existent in the southeastern part, with a notable lack of anomalies. Discovery and production within the TCMF was clearly linked to the areas of outcrop and/or shallow cover existent in the southeastern part, with a notable lack of success westwards under deeper cover. For example, the two most recently worked deposits along the Chariot Line, Chariot (2003–2005) and Malbec West (2005) lie 8 km and 9 km west of Tennant Creek, respectively. Clearly, the successful early model of drilling strong magnetic targets is less reliable in this area.

Emmerson Resources (ERM) strongly believes in the potential of the TCMF and recognises that future exploration success will need to be based on a different model to that used in the past. Such a model will need to make much greater use of independent datasets, such as geology, geochronology, geochemistry, alteration mapping, remote sensing and other geophysical techniques. With this in mind, ERM has been steadily acquiring new datasets and testing priority targets within the TCMF and has spent about $13M since listing in late 2007. This aggressive expenditure level is now underwritten by a $28M Joint Venture with Ivanhoe Australia.

This landmark JV not only provides ongoing funds for aggressive exploration, but is also a vote of confidence in Emmerson and its approach to building shareholder wealth through discovery. Moreover, ERM’s focus on discovery is underpinned by comparing historical production with the predicted Zipf’s power law distribution of finite resources. This suggests that rather than Warrego being the largest Au equivalent deposit, there could well be two Tier-one deposits (>1 Moz Au), as well as a string of smaller deposits (>0.3 Moz Au) yet to be discovered!

ERM are steadily developing a new geological model for IOCG (Iron Oxide Copper Gold) mineralization in the TCMF that integrates the historically accepted parameters within a regional temporal and structural framework. Drilling and gravity surveying have emphasized the link with the Tennant Creek Supersuite Felsic intrusives, validating suggestions by earlier workers. Drilling has also led to the discovery of a thick intermediate-mafic intrusive suite that is permissively coeval with the Tennant Creek Supersuite, both units being deformed during a major deformation event (the ca 1850 Ma Tennant Event?).

Given the problems imposed by overburden and weathering, ERM are also investing in the development and application of new geophysical processing techniques, as well as trialling alternate methods within the TCMF. An example of the former is Vector Residual Magnetic Intensity (VRMI), which offers the potential of screening lithological magnetic responses from hydrothermal magnetite, whereas examples of the latter include AMT and deep-penetrating IP surveys. Existing geochemical paradigms are also being revisited via 3D multi-element analysis and the alteration surrounding the mineralisation is being assessed via spectral surveys.

Four different styles of IOCG targets, located from north to south across the TCMF, will be discussed to illustrate these ideas and ERM’s exploration approach.

The Rising Star target is located 37 km north of Tennant Creek and 1.8 km east of the old Northern Star Mine on a prominent ENE-trending gravity ridge with weak magnetic anomalism. Spot historical drilling tested small outcropping “ironstones” that were found to be weakly anomalous in copper, but barren of gold, and the causative bodies of the gravity and magnetic sources remained unknown. ERM have completed semi-detailed gravity and three profiles of AMT/Deep IP surveys. These data show strong chargeability anomalies coincident with the gravity ridge that is bounded to the north and south by zones of high resistivity. It is interpreted that the chargeable gravity anomaly represents an haematite-dominant IOCG system overlying resistive granite at depth.

The Voltan target is located 31 km NNW of Tennant Creek in an area of negligible outcrop. The area lies 1.5 km west of a prominent magnetic iron-oxide ridge and represents a 3 km x 500 m gravity feature, with a weak bounding magnetic anomaly. Historical drilling at the nearby Golden Slipper deposit defined a small Au resource, but the majority of the gravity feature had never been drilled. ERM executed a reconnaissance RAB drill program (160 m x 40 m x 24–36 m depth) and have defined a coherent Au-Bi-Cu geochemical anomaly, extensive over 800 m of strike (open to the south), with the maximum values of 0.64 g/t Au, 1163 ppm Cu and 84 ppm Bi.

The Pinnacles North target is located 17 km west of Tennant Creek and represents a magnetic anomaly offset to the north of a strong gravity anomaly. Coarsely spaced, 12 m-deep, historical vertical RAB drilling yielded isolated anomalous Au and Cu values in 3 holes and it was decided to include the target within the ERM semi-detailed gravity survey. This survey revealed that the gravity anomaly is significant and may represent a haematite-hosted IOCG

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1 Principal Geologist, Emmerson Resources, 3 Kimberley Street, West Leederville, WA 6007, Australia. Email: gosborne@emmersonresources.com.au.
deposit. ERM covered this area with a RAB geochemical survey which located a blind haematite-magnetite oxide body under 5–10 m of cover, extending over 800 m of strike. RC drilling confirmed the body to have characteristics similar to mineralized “ironstones” elsewhere in the TCMF, yielding highly anomalous Au, Cu, Bi and Pb results. The best results from the initial 5 diamond drill holes is 2 m @ 50 g/t Au, 29 g/t Ag, 0.4% Bi and 0.23% Cu.

The Trinity target is located 18 km west of Tennant Creek, at the confluence of the Chariot-Peko; Mount Samuel-Knob and Southern Shear zones, and consists of a large gravity and coincident remanent magnetic anomaly. Drilling has revealed a large intermediate-mafic intrusive complex within red-rock-altered, brecciated and mylonitic Tennant Creek Supersuite granite. Haematite and chlorite alteration are locally developed and stockwork quartz-sericite-pyrite-galena mineralisation has been observed. This alteration and geology is characteristic of other IOCG deposits elsewhere. In 2010, ERM plan to spend $5M–$7M on a portfolio of undercover Tier-one projects including ca 360 000 m of drilling on new, early-stage targets, plus additional advanced projects. ERM are dedicated to Tennant Creek and to unlocking the next generation of IOCG deposits.

FINDING DEPTHS TO IRONSTONES USING FLIGHT LINE MAGNETIC DATA: AN EXAMPLE FROM THE TENNANT REGION

Roger Clifton¹

Ironstones in the Tennant Creek Goldfield host gold, copper and uranium. With varying degrees of magnetisation, the ironstones do not always respond to classical magnetic methods of detection.

Of particular interest to explorers is how to select ironstones that are at explorable depths from the 700-odd known occurrences. Accordingly, a method has been developed at NTGS which discriminates for dipoles and estimates the depth of a large proportion of the ironstones.

By passing the flight line data from the Tennant Creek airborne geophysics survey of 1998 through a new algorithm, depths to the equivalent dipoles of the ironstones can be estimated, but at the price of a loss of location information. Consequently, ironstones with a high signal-to-noise ratio report their depths from north and south of their location; this is seen as streaks in Figure 1.

Depth is calculated on the assumption that the dipole is immediately below the flight path, itself 60 m above the ground surface. The same values would also result from a shallower ironstone on either side of the flight path. The Little Ben mine ironstone would thus be shallower than 48 m, if it is the dipole being reported here in blue. Peter Pan mine is too far away from the nearest estimate, so its orebody is not presenting as a clear dipole.

Other old mines do not resemble a dipole sufficiently to trigger the algorithm’s estimation procedure and are therefore isolated on Figure 2. The figure corresponds to the Tennant Creek 1:250 000 mapsheet, the area of the magnetic survey used. To the north and south of the goldfield, dipole depth estimates appear without mines located nearby. These may indicate sharp magnetic features of, say, a mafic intrusion, or they may indicate ironstones that are known to be barren. However, they might also indicate unexplored targets that have previously escaped attention.

Results from the procedure are available as a database file, an extract from which is shown in Table 1. Although each analysis is performed on almost a kilometre of flight data, a repeated slight shift of the centre allows the location to be

Figure 1. Magnetic image of Tennant Creek townsite, overlain by abandoned mines in red. Blue positions show where the algorithm has detected a dipole, with median depth (m) estimates alongside. Green lines represent Tennant Creek street plan. Note that the method is finding a character in the flight line data, that is not coinciding with the strength of the magnetic field in the vicinity.

¹ Northern Territory Geological Survey, PO Box 3000, Darwin, NT 0801, Australia. Email: roger.clifton@nt.gov.au.
found despite noise effects. Often, such a table will show the extremes to the north and south as estimating deeper values, so the mode, rather than the mean value should be selected.

The narrow range of values on each target is due to the similarity of the data subsets, so does not cover the uncertainty range. Logically, the value amounts to an estimate of the maximum depth of the body’s sharper features. However, the absence of the highest frequencies acquired limits the shallowness that can be inferred. Figure 3, with colour coded depths, shows very few “surface” estimates, despite the area being known to have many surface ironstones.

This method has been applied to data from the NTGS’s 1988 Tennant Creek airborne geophysics survey. It illustrates the effectiveness of using currently available datasets as an early tool to determine the depth to ironstones of dipole signatures and depth to magnetic basement, before acquiring further detailed geophysical data.

Table 1. Results in the vicinity of the Fassifern Mine.

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Figure 2. Depth estimates for dipoles over the Tennant Creek 1:250 000 mapsheet. Abandoned mines are shown in red, dipole depths in blue. False hits occur along the roads, where the roadbase – probably taken from mine waste – is of a width that simulates a point source 10–20 m below the surface.

Figure 3. The same area as Figure 2, with the depth estimates coded by colour. From surface to 80 m deep, the colours run through red, orange, yellow, green, blue and purple.
In the 2008 NT Budget, the Government announced an additional $2.4 million for the final three years of Bringing Forward Discovery, for a new program of collaborative funding for greenfields exploration geophysics and drilling. The Geophysics and Drilling Collaborations program allocates three years of funding from 2008/09 to 2010/11 to provide 50% of costs (up to $100 000) to assist companies with the costs of selected exploration geophysics or drilling programs in remote areas. The aim of the program is to increase the intensity of exploration in under-explored greenfields regions, increase the knowledge base of the Territory’s geology and resources, and assist with future exploration. To this end, companies are required to submit a report, along with all drill core or geophysical data to the Northern Territory Geological Survey, within three months of the completion of co-funded programs, with all information to be made open file three months after the receipt of the report.

The first round of funding during 2008/09 attracted a total of 28 applications, of which seven received funding for drilling programs and four were awarded for geophysical surveys. Round 2 of the Collaborations attracted forty applications from 28 companies, representing a 42% increase from Round 1. As a result of the assessment of the Round 2 applications, 14 projects from 13 companies have been granted funding for the 2009/10 financial year. The distribution of the funded projects for both Round 1 and Round 2 collaborative funding is illustrated in Figure 1.

Currently, 80% of the programs undertaken under Round 1 and 20% of the programs funded under Round 2 are open file and available from the Minerals and Energy InfoCentre (geoscience.info@nt.gov.au), upon request. A full listing of the co-funded programs, the associated ELs and the Company Report number of the projects that have reached open file status can be accessed through the Geophysics and Drilling Collaborations website www.minerals.nt.gov.au/collaborations.

All of the information that has been obtained under the Bringing Forward Discovery Geophysics and Drilling Collaborations program has contributed to an increased knowledge of geological regions where there is a paucity of geoscientific data. In many cases, invaluable stratigraphic and structural insights, and new concepts of mineralising models have been derived, and results have stimulated continuing exploration in these greenfields areas.

Selected highlights from Round 1 and Round 2

Amadeus and Ngalia basins

Closely spaced ground gravity surveys in the Amadeus Basin by Quasar Resources (NTGS, Open File Company Report CR2009-0203, CR2009-0204, CR2009-0581) and Central Petroleum Ltd (NTGS, Open File Petroleum Report PR2009-0149) demonstrated the utility of this technique in delineating structures and potential diapirs in the basin. The high-resolution gravity datasets have

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1 Northern Territory Geological Survey, PO Box 3000, Darwin, NT 0801, Australia. Email: dorothy.close@nt.gov.au.
identified previously unrecognised structures that may involve the uplift of basement during the Carboniferous phase of the Alice Springs Orogeny.

A gravity survey at 1 km and 2 km spacing in the Ngalia Basin by Thundelarra Exploration (CR2009-0593) has identified a major structure in the central part of the basin. This will assist in determining the architecture and structural controls of the basin and will be a focus for future uranium exploration.

Tennant Region

Sipa Resources Ltd drilled four holes to test whether magnetic anomalies under cover to the west of the Warrego Granite represent Tennant Creek-style ironstones. Three of the drillholes intersected magnetite bodies with associated chlorite-haematite alteration, whereas the fourth drillhole intersected 73 m (from 126 to 199 m) of magnetite ironstone with strong chloritic alteration and anomalous gold-bismuth-molybdenum values (up to 87 ppb Au, up to 23 ppm Bi and up to 112 ppm Mo), considered a typical Tennant Creek-style magnetite ironstone. This drilling has successfully extended the known Tennant Creek mineral field under cover to the northwest, and Sipa Resources have announced that they will ‘aggressively pursue’ exploration in the area in 2010.

Arunta Region

Silex Exploration Australia undertook a 500 m diamond drillhole, targeting a dipole IP anomaly at the Oonagalabi Cu prospect, hosted in the Bungatina Metamorphics of the Aileron Province in the eastern Arunta Region (CR2009-0790). Results from the drilling identified anomalous base metals levels, associated with interpreted amygdallite alteration, with maximum intercepts of 2 m at 0.5% Cu, 1.4% Zn, 77 ppb Au. The association of amygdallite alteration with elevated base metals is typical of Cu-Zn-Pb mineralisation in this area of the Arunta Region (Hussey et al 2006). Although the drillhole did not intercept the targeted IP anomaly, the consistent presence of amygdallite alteration provides an encouraging vector potentially to a larger base metal system at depth.

Three diamond drillholes targeting coincident magnetic and gravity features below the Mesozoic Eromanga Basin were undertaken by AusQuest Ltd at the Caroline prospect, in the vast, underexplored Simpson Desert area of the southeastern Northern Territory. Assay results from the drilling confirmed the presence of a thick succession (>300 m) of sulfide-bearing sediments containing zones of elevated base and precious metals, suggesting that favourable host rocks for sediment-hosted base metals deposits may be present in the region (AusQuest Ltd, ASX announcement 16 Nov 2009).

Thick zones of elevated zinc (150–350 ppm Zn) and up to 1958 ppm Zn) and lead (40–ppm Pb), with occasional narrow zones of elevated copper (100–200 ppm Cu, up to 1800 ppm) and gold (10–45 ppb Au) are reported throughout the sulfidic sediments. (AusQuest Ltd, ASX announcement 16 Oct 2009). The highest metal values of 0.18% Cu, 423 ppm Pb, 0.12% Zn and 45 ppb Au were contained within sulfidic veins and breccias. On the basis of the current geochemical data, AusQuest Ltd has interpreted two metal associations within the Caroline prospect: a hydrothermal Cu, Au, Ag, Ni system and a sedimentary Pb, Zn, Cd system that potentially represent two mineralisation styles (AusQuest Ltd, Quarterly Report 28 Jan 2010).

The magnetic features targeted by AusQuest Ltd are in an area interpreted to lie within an undercover extension of the Iridinda Province of the Arunta Region. The Iridinda Province is a highly metamorphosed Neoproterozoic to Cambrian basin that includes correlatives of the Centralian Superbasin. The province includes a thick metasedimentary succession with subordinate igneous units, including metabasalt, mafic to ultramafic intrusions (Whelan et al 2010), granite and pegmatite. The dominant metamorphic event in the Iridinda Province is the pervasive upper amphibolite- to granulite-facies 480–460 Ma Larapinta Event, which is unique to the Iridinda Province and which has not been recorded elsewhere in the Arunta Region (Scrimgeour in press). The nearest exposed outcrop of the Iridinda Province lies 40 km to the west of the Caroline prospect and is composed of metasedimentary rocks and orthogneiss, metamorphosed to upper amphibolite facies. The nearest drillhole (BMR Hay River-4) is located 16 km southwest of the Caroline prospect, and intersected amphibolite-facies gneiss typical of the Iridinda Province, that was metamorphosed during the Larapinta Event at 469 ± 2 Ma (Carson et al 2009).

In contrast, the Collaborative drilling undertaken by AusQuest Ltd at the Caroline prospect identified a succession of sulfidic sediments with minor fine-grained felsic volcanic flows and thin carbonate units (AusQuest Ltd, ASX announcement 8 Oct 2009) at apparent lower greenschist to sub-greenschist facies. This indicates that the succession was not affected by high-grade metamorphism during the Larapinta Event that is pervasive elsewhere in the Iridinda Province. The identification of this relatively unmetamorphosed succession leads to two possible conclusions. One possibility is that the succession is a low-grade equivalent of the Iridinda Province, which would require the presence of a large structure lying to the southwest of the Caroline prospect with an offset of at least 20 km in order to explain the abrupt change in metamorphic character. The presence of such a crustal-scale structure does not appear to be supported by either the
regional-scale magnetic or gravity data. Alternatively, this succession represents a previously unrecognised basin at least half a kilometre thick that contains sulfidic sediments underlying the Mesozoic Eromanga Basin and overlying the Neoproterozoic to Cambrian Irindina Province. NTGS will undertake studies on the core to test these hypotheses, and whether or not a new, mineralised basin has been discovered.

Murphy Inlier

Bondi Mining was awarded funding for their Murphy project under Round 1 and Round 2 of the Collaborations program, in order to target unconformity-style and Westmoreland-style uranium mineralisation under Cambrian and Cretaceous cover. The drilling targeted undercover extensions of the Westmoreland Conglomerate and mafic dykes intruding this succession, and aimed to identify reductant horizons in the underlying Murphy Metamorphics. Drilling under Round 1 of the Collaborations program at Bondi Mining’s U19 target successfully intersected anomalous uranium (107.4 ppm U₃O₈) and copper (1.04% Cu), associated with a greater than 100 m-wide zone of strong haematite-chlorite alteration in a mafic dyke intruding the Westmoreland Conglomerate. This provided a proof of concept for Westmoreland-style U mineralisation in this undercover area. Further drilling, approximately 28 km to the northeast at the U17 target, also intersected haematite-chlorite alteration with anomalous U levels (Bondi Mining, ASX announcement 2 Sept 2009).

Drilling by Bondi Mining under Round 2 of the Collaborations program successfully intersected the unconformity between the Westmoreland Conglomerate and Murphy Metamorphics, identifying a potential reductant interval in the basement metasediments and a zone of elevated U (44.3 ppm U₃O₈) within the Westmoreland Conglomerate within 1 m of the unconformity (Bondi Mining, ASX announcement 17 Nov 2009).

The Collaborations program drilling undertaken by Bondi Mining has provided valuable information on the undercover extensions of the Westmoreland Conglomerate and underlying Palaeoproterozoic Murphy Metamorphics along with depth to the unconformity. It has also highlighted the potential of these buried successions for U-Cu mineralisation.

Birrindudu Basin

Proto Resources and Investments Ltd drilled a deep hole (LBDI) at Lindemans Bore, targeting a geophysical anomaly that was interpreted to be a possible feeder for the Antrim Plateau Basalt with potential for Norilsk-style Ni-Cu-PGE mineralisation. Although the drilling did not intersect a mineralised feeder zone, this deep hole (CR2009-0607) provided a stratigraphic section through 322 m of the Limbunya Group of the Birrindudu Basin and 430 m of the unconformably underlying Palaeoproterozoic Inverway Metamorphics.

The 430 m of Inverway Metamorphics intersected by the Lindemans Bore drillhole provides valuable data into this poorly understood basement unit. The Inverway Metamorphics was previously only known from two small outcrops totalling approximately 2 km² in area in LIMBUNYA, the nearest located approximately 17 km from the Lindemans Bore drillhole site. This outcrop is composed of steeply dipping, brown muscovite quartz schist, which is overprinted by at least two cleavages, grey to red-grey acid volcanic rocks and minor siltstone, metamorphosed to greenschist facies (Cutovinos et al 2002).

Recent U-Pb SHRIMP dating of the outcropping Inverway Metamorphics by Geoscience Australia has provided an age constraint on this unit. Detrital zircons yielded a maximum deposition age of 1867 ± 5 Ma and the age spectrum is similar to that found in other Palaeoproterozoic metasedimentary successions elsewhere in the North Australian Craton, such as the Pine Creek Orogen and the Tanami Region (Carson 2010).

Approximately 50% of the cored interval of the Inverway Metamorphics in LBDI comprised fine-grained mafic sills that intrude a succession of dominantly stylolitic carbonate sedimentary rocks with lesser carbonate breccia, massive sandstone and laminated shale. The mafic sills are metamorphosed and do not intrude the unconformably overlying units of the Limbunya Group, thereby providing an upper age constraint for the magmatism of approximately 1640 Ma, which marks the onset of deposition of the Limbunya Group (Cutovinos et al 2002). This succession of carbonate-rich sediments pervasively intruded by mafic sills, as identified in the Lindemans Bore drillhole, is not currently recognised in similarly aged successions in the North Australia Craton. NTGS plans to undertake further investigations to determine the regional context and mineral prospectivity of this basement succession.

Round 3 Collaborations funding

Applications for funding under Round 3 of the Bringing Forward Discovery Geophysics and Drilling Collaborations program opened on 15 February 2010 with the closing date being COB on 16 April 2010. Funding will be available for projects that commence in the 2010/11 financial year. Guidelines for the applications and assessment criteria can be found at the Geophysics and Drilling Collaborations website (www.minerals.nt.gov.au/collaborations).
References


THE VICTORIA AND BIRRINDUDU BASINS: A U-Pb SHRIMP STUDY AND REVIEW OF RESOURCE POTENTIAL

Chris J Carson¹

The Victoria and Birrindudu basins (VBB) are exposed in the northwestern Northern Territory and cover an area of ca 120 000 km² (eg Cutovinos et al 2002). The VBB represent a stacked pair of Palaeo- to Neoproterozoic basins, dominated by mostly undeformed and un metamorphosed shallow-water siliciclastic and impure carbonate rocks (with rare interbedded volcanic rocks), unconformably overlying low-grade metamorphic basement. Although comprehensive studies by both BMR in the 1970s and NTGS in the 2000s presented a detailed lithological and stratigraphic assessment of the VBB (eg Sweet et al 1974a, b, Dunster et al 2000, Cutovinos et al 2002), there have been few isotopic investigations conducted. Such information may help strengthen lithostratigraphic correlations with other, more overtly mineralised Proterozoic Basins in the NT. As the VBB has received only sporadic attention from explorers over the last 30 years, improved lithostratigraphic interbasin correlations may provide welcome impetus for further resource exploration.

As the VBB and the underlying Inverway Metamorphics have few geochronological constraints, isotopic data can provide a robust framework for basin evolution, provenance and inter-basin correlations. The timing of siliciclastic deposition can be provided by dating intercalated tuffaceous layers; however, such volcanic rocks are rare within the VBB. Apart from the valuable constraints provided by four intercalated tuffs within dolostones of the upper Limbunya Group (ca 1635–1640 Ma; cited in Cutovinos et al 2002) and Rb-Sr mineral and whole rock isochron ages from the Tijunna and Auvergne groups (Webb and Page 1977), the chronological and isotopic evolution of the VBB remains poorly understood.

The VBB consists of seven groups, separated by inferred or recognised unconformities, from oldest to youngest, the Limbunya Group (historically the uppermost group in the Birrindudu Basin) and the Wattie, Bullita, Fitzmaurice, Tijunna, Auvergne and Duerdin groups, historically comprising the Victoria Basin. For a detailed assessment of the stratigraphy of the VBB, see Sweet et al (1974a, b), Dunster et al (2000) and Cutovinos et al (2002). Eight SHRIMP detrital U-Pb zircon samples were collected on selected units within these groups and the Inverway Metamorphics, and results are presented here.

Detrital zircon geochronology of the VBB

Basement to the VBB, the Inverway Metamorphics, is exposed as two small inliers (<3 km² in total) in the LIMBUNYA 1:250k mapsheet. It comprises alternating cross- and massively bedded, arkosic low-grade muscovite schist and minor siltstone. Detrital zircon ages show a dominant peak at ca 1870–1880 Ma and a broad subordinate peak at ca 2500 Ma. A conservative maximum deposition age (MDA) of 1867 ± 5 Ma (2σ) is calculated from the deconvolution function (UNMIX) within ISOPLOT v3.00 (Ludwig 2003). This zircon age distribution and MDA is reminiscent of many Palaeoproterozoic metasedimentary rocks exposed elsewhere in the North Australian Craton (NAC), particularly the Pine Creek Orogen, ca 400 km to the northeast (eg Burrell Creek Formation, Worden et al 2008, Hollis et al 2010) and the Tanami Region, ca 200 km to the south (eg Killi Killi Formation, Cross et al 2007).

¹ Geoscience Australia, GPO Box 378, Canberra, ACT 2601, Australia. Email: chris.carson@ga.gov.au.
The Stirling Sandstone (basal Limbunya Group) unconformably overlies the Inverway Metamorphics and is composed predominately of quartz sandstone. The detrital zircon spectrum is characterised by a broad asymmetric peak with a maxima at ca 1900 Ma and a subordinate peak at ca 2530 Ma. The asymmetric peak at ca 1900 Ma can be resolved into several subpopulations, including a young population at 1830 ± 13 Ma (the MDA for this unit), a population at ca 1865 Ma, which is a typical component in many NAC basin successions and underlying metasedimentary rocks, and an unusual population at ca 1900 Ma. Source rocks of ca 1900 Ma are rare in the NAC; one obvious source is the eastern zone of the Halls Creek Orogen, where magmatic rocks at ca 1900 Ma are known to outcrop.

The Wickham Formation (basal Wattie Group), is a haematitic quartz sandstone. The detrital zircon spectrum is dominated by a major asymmetric peak at ca 1770 Ma, with a shoulder at ca 1865 Ma, and scattered individual grains and small clusters to ca 2800 Ma. An isolated cluster of 4 zircons with a weighted mean age of 1639 ± 16 Ma (MSWD = 0.32) provides a good constraint on the MDA. The Neave Sandstone (also a unit within the Wattie Group) has a broadly similar detrital zircon spectrum as the Wickham Formation, with a young cluster defining the MDA at 1622 ± 32 Ma.

The Weaner Sandstone (Bullita Group) is a poorly sorted cross-bedded gritty sandstone, the detrital spectrum of which comprises a major complex irregular peak between ca 1770 Ma and ca 1860 Ma with a minor irregular cluster at ca 2500–2550 Ma. Two grains provide a tentative MDA of 1600 ± 24 Ma.

The Stubb Formation (Tijunna Group) comprises quartz sandstone interbedded with micaceous siltstone. The detrital spectrum is dominated by an irregular peak with a maxima at ca 1780 Ma and a broad shoulder at ca 1865 Ma. A young isolated cluster of 7 grains returns a weighted mean of 1621 ± 11 Ma, a conservative estimate on the MDA. However, an isolated young grain (1307 ± 104 Ma), not generally considered a reliable estimate of MDA, is consistent with the somewhat imprecise 5 point Rb-Sr whole rock isochron obtained by Webb and Page (1977) of 1347 ± 150 Ma. Although the usefulness of Rb-Sr whole rock dating on sediments is somewhat debatable, these data suggest that the depositional age may in fact be ca 1300–1400 Ma.

The Jasper Gorge Sandstone (basal Auvergne Group) comprises ripple-marked, texturally mature quartz sandstone. The detrital spectrum is dominated by a major peak at ca 1620 Ma, and a subordinate peak at ca 1770 Ma. A small cluster with a weighted mean of 1332 ± 22 Ma provides a conservative estimate on the maximum deposition age, although there are two isolated younger individual grains at ca 1171 Ma and ca 1243 Ma. One major feature of the detrital spectrum is that it contains almost no detritus older than ca 1800 Ma, a ubiquitous age population present in the underlying sedimentary rocks.

Finally, unconformably overlying the Auvergne Group is the basal unit of the Duerdin Group, the Black Point Sandstone Member, which comprises feldspathic sandstone and minor conglomerate. The zircon detrital spectrum for this unit is dominated by two major irregular peaks that have maxima at ca 1020 Ma and at ca 1600 Ma, a broad irregular peak between 1150–1250 Ma, and a minor peak at ca 1400 Ma. The MDA (determined via UNMIX) is 1018 ± 13 Ma. This unit also contains almost no detritus older than ca 1800 Ma and is notable in that it contains a significant influx of detritus of Musgrave Orogeny-aged zircons (1150–1250 Ma).

Discussion

Basin nomenclature revision

Figure 1 shows a compilation of the zircon detrital age spectra from this study. The VBB show a marked shift in zircon provenance during basin evolution, with perhaps the most significant change being the absence of detritus older than ca 1800 Ma in the younger units. The percentage of >1800 Ma material decreases from 47% in the Stubb Formation to 7% and 4% for the Jasper Gorge Sandstone and Black Point Sandstone Member respectively, reflecting a fundamental change in provenance and suggesting a major unconformity between the Tijunna Group and the overlying Auvergne and Duerdin groups. Recent proposals by NTGS to reassign the subdivision between the Birrindudu Basin and the Victoria Basin to the unconformity between the Tijunna Group and the Auvergne Group is strongly supported by these observations.

A brief review of possible lithostratigraphic correlations and resource potential

Walter et al (1995) proposed that the Auvergne Group correlates with Supersequence 1 of the Centralian Superbasin, a suggestion also supported by the Rb-Sr whole rock isochron age of 838 ± 80 Ma from the Angalarri Siltstone of the Auvergne Group (overlying the basal Jasper Gorge Sandstone). The Rb-Sr whole rock isochron age is consistent with inferred depositional ages for the Bitter Springs Formation in the Amadeus Basin in central Australia (Zhao et al 1994). Although these correlations are understandably tentative, they are nevertheless supported by the results of this study. Comparison of the detrital zircon spectra of the Jasper Gorge Sandstone with that available for the Heavitree Quartzite (Zhao et al 1992, Maidment 2005),
shows several remarkable similarities, notably peaks at ca 1620 Ma and 1770 Ma, together with a similarity in the scattered individuals and minor clusters. Although the use of detrital spectra as an interbasinal correlative tool over large distances is contentious, the similarity of the zircon detrital spectra of the Jasper Gorge Sandstone and Heavitree Quartzite strengthens previous correlations between the Auvergne Group and Supersequence 1 of the Centralian Superbasin.

The tuffaceous layers in the dolostones of the upper Limbunya Group (ca 1640 Ma) have provided robust chronological correlations (eg Dunster et al 2000, Cutovinos et al 2002) with similar dolostones and siltstones that host thin ca 1635–1640 Ma tuffaceous layers within the McArthur Basin (Teena Dolomite, Mount Les Siltstone and Barney Creek Formation) and which host the giant McArthur River lead-zinc deposit. Although Geopeko explored the dolomitic units of the Limbunya Group for base metal mineralisation with modest to encouraging base metal assays (Hurrell 1992), chronological and lithostratigraphic correlations with base-metal enriched units of the Lawn Hill Platform and McArthur Basin urges further exploration for similar syngenetic and epigenetic base metals mineralisation within the Limbunya Group in the VBB (eg Dunster et al 2000, Cutovinos et al 2002).

Although using maximum deposition ages to facilitate lithostratigraphic correlations across large distances and between basins should be approached with caution, the MDA for the Stirling Sandstone (ca 1830 Ma) is, nevertheless, similar to several other platform sandstones immediately overlying metamorphic basement, such as the Depot Creek Sandstone (ca 1830 Ma, Tolmer Group; Carson et al in press) and the Westmoreland Conglomerate (ca 1830 Ma, McArthur Basin; Carson et al in press), and possibly other basal sandstones such as the Mamadawerre Sandstone (Kombolgie Subgroup). I propose that, given the lithostratigraphic and chronological similarity of these units, this observation may provide some measure of correlation between these, and other, basal sandstone units. If so, the Stirling Sandstone, which lies unconformably on metamorphic basement similar to that of the Pine Creek Orogen and the Tanami Region, may be prospective for unconformity-style U mineralisation. This suggestion is reinforced by the identification, in drillholes, of up to 55 m of unmetamorphosed black pyritic carbonaceous mudstone and shale (interpreted as undifferentiated Birrindudu Group by Cutovinos et al 2002), during base metals exploration by Geopeko (Hurrell 1992). This unmetamorphosed carbonaceous shale immediately underlies the Stirling Sandstone and overlies metamorphosed basement. Uranium was not assayed by Geopeko during this phase of base metals prospecting and this carbonaceous shale may thus represent suitable host lithologies for unconformity-style U mineralisation.

References


**BLACKADDER MEETS BASIL: MORE COPPER AND NICKEL SULFIDES IN THE IRINDINA**

Jim McKinnon-Matthews

In late 2009, Mithril announced the discovery of significant copper and cobalt mineralisation at the large Huckitta Project in the Northern Territory, located approximately 150 km northeast of Alice Springs (Figure 1). This new greenfields discovery, called Basil, is largely untested and the company believes it has the potential to deliver a large-tonnage, near-surface resource (Figure 2).

The Huckitta region is underexplored and, over the past 18 months, Mithril has identified six new nickel-copper sulfide prospects (Blackadder, Baldrick, Edmund, Kevin Darling, Miggins and Percy) and three new copper sulfide prospects (Basil, Poly and Manuel). All have been identified in outcrop through geological mapping and surface sampling (Figure 3).

The nickel-copper sulfide mineralisation occurs within weakly or unaltered olivine-bearing gabbroic intrusions within both the Cambrian Irindina Province and the Palaeoproterozoic Aileron Province, whereas the copper-cobalt mineralisation occurs as intervals within highly metamorphosed amphibolites of the Irindina Province.

The Basil mineralised trend was first identified in August 2009 and copper mineralisation has been mapped and rockchip sampled for a strike length of 10 km. The initial drilling program at Basil was completed in November 2009 and has only tested ca 900 m (centred on Rotten Hill) of the 10 km-long mineralised trend. Results include 41 m at 0.6% copper and 432 ppm cobalt from a depth of 74 m in drillhole LBRC12. Importantly, these results incorporate higher-grade intervals of 3 m at 1.4% copper and 284 ppm cobalt from 74 m, 9 m at 1.0% copper and 336 ppm cobalt from 87 m, and 5 m at 0.9% copper and 615 ppm cobalt from 109 m. These results indicate variability in the mineralised system and demonstrate potential to deliver higher grades. Wide intervals of mineralisation were also intersected, including 146.5 m of semi-massive and disseminated sulfides grading 0.24% copper and 328 ppm cobalt from a downhole depth of 117.5 m in drillhole LBDD3.

Initial drilling of two of the nickel-copper targets (Blackadder and Baldrick) returned anomalous nickel and copper values from intervals of mineralised gabbroic rocks. Results include a very encouraging intersection of 9 m averaging 0.48% nickel and 0.37% of copper (comprising both oxidised and sulfide mineralisation) from Baldrick and 3 m averaging 0.13% Ni from Blackadder.

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1 Mithril Resources Ltd, 60 King William Road, Goodwood SA 5034, Australia. Email: jimm@mirthlresources.com.au.
Manuel Cu-bearing gossans

Flashheart
3.9% Cu, 6.8 g/t Ag, 0.3 g/t Au

Basil/Polly copper trends
> 10 km long

Mithril 100% tenements (granted)
Mithril 100% tenements (ELAs)
Treasure JV (MTH earning 80%)
Hammer Hill JV (MTH earning 70% from ARA)
Harts Range JV (MTH earning 80% from Oklo)
Sammy JV (MTH earning 80% from Sammy)

Miggins
0.26% Ni, 0.5 g/t Pt + Pd

Percy Elevated Ni, Cu and PGE

Kevin Darling
0.14% Ni, 0.18% Cu

Elevated Ni & PGE

Baldrick
2.3% Ni, 2.4% Cu

Blackadder
3.8% Ni, 9.6% Cu

Edmund
2.6% Cu, 6.5 g/t Ag Elevated Ni & PGE

Figure 1. Huckitta Project location and prospects.

Figure 2. Basil copper prospect – Drillhole collars (yellow) on ALOS satellite image with VTEM anomaly (magenta area) and simplified geology. Triangles represent surface rockchip and lag samples, with green indicating >0.1% copper and red indicating >1.0% copper. Blue is <0.1% copper.

Figure 3. Prospects, copper anomalous rockchips, target areas (yellow polygons) and planned VTEM coverage on ALOS satellite image.
Exploration continues on the project with drilling focusing on the southern 2.5 km of the Basil mineralised trend. Geological mapping and sampling programs will focus on extending the Basil and Polly copper trends as well as assessing other regional targets on the project. These programs in conjunction with ground geophysical surveys will advance further nickel and copper targets to the drill stage. Airborne electromagnetic surveys covering the northern portion of Basil and the Polly trend will also be completed to ensure a full pipeline of regional targets going forward (Figure 3).

GEOCHEMICAL AND ISOTOPIC CONSTRAINTS ON MAFIC MAGMATISM IN THE IRINDINA PROVINCE, EASTERN ARUNTA REGION: IMPLICATIONS FOR MINERAL PROSPECTIVITY.

Jo A Whelan1, 2, Lachlan Hallett1, Dorothy F Close1 and Greg M Yaxley3

The Arunta Region covers approximately 200,000 km² and has undergone multiple tectonothermal events in a period spanning the Palaeoproterozoic to the Carboniferous. The Arunta Region is divided into the Palaeoproterozoic to Mesoproterozoic Warumpi and Aileron provinces and the Neoproterozoic to Cambrian Irindina Province, on the basis of differences in the sedimentary and igneous protolith ages (Scrimgeour 2004). The Arunta Region, as a whole, is characterised by a marked intensity and frequency of deformation, high-grade metamorphism and an abundance of granitoids that sets it apart from many of the other Proterozoic provinces in northern Australia (Shaw et al 1984, Hoatson et al 2005, Scrimgeour in press a, b).

In the eastern Arunta Region, the Irindina Province comprises a thick basin succession with stratigraphic affinities to the Neoproterozoic to Palaeozoic Amadeus and Georgina basins (Buick et al 2001, Maidment 2005). The province has undergone Palaeozoic granulite-facies metamorphism and mafic and ultramafic magmatism in an extensional setting that is currently not identified within the rest of the Arunta Region. The Irindina Province was structurally emplaced against the underlying Palaeoproterozoic Aileron Province, along a mylonitised sheet-like body of granite, the Bruna Granite Gneiss. A three-point Sm-Nd isochron age from a garnet-hornblende migmatite from the Bruna Granite Gneiss indicates that this movement occurred at 449 ± 10 Ma (Mawby et al 1999).

Recent targeted mapping, petrography, geochemical and isotopic studies, focusing on the diverse mafic and ultramafic intrusions in the Irindina Province (Figure 1), have identified a correlation between decreasing age and increasing isotopic evolution of these magmas. The following discussion explores the origin and tectonic setting of these mafic/ultramafic magmas.

Geological setting

The eastern Arunta Region has been affected by numerous tectonothermal events (Scrimgeour 2003, Hand and Maidment 2007), including: the 1780–1770 Ma Yambah Event, 1735–1690 Strangways Event, 480–460 Ma Larapinta Event and the 450–300 Ma Alice Springs Orogeny. This contribution will discuss the latter two.

The 480–460 Ma Larapinta Event has currently only been recognised in the Irindina Province and is characterised by upper-amphibolite- to granulite-facies metamorphism (Miller et al 1997, Mawby et al 1999, Buick et al 2005, Maidment 2005). It was accompanied by the intrusion of mafic to ultramafic dykes, plugs and sills, and the deposition of fine-grained sediments in an extensional setting (Mawby et al 1999, Hand and Maidment 2007).

Figure 1. Schematic regional geological map showing sample locations of different mafic suites in Irindina Province in ALICE SPRINGS and ILLOGWA CREEK. Rock type indicated by dot colour.

1 Northern Territory Geological Survey, PO Box 3000, Darwin, NT 0801, Australia.
2 Email: jo.whelan@nt.gov.au.
3 PRISE, Research School of Earth Sciences, The Australian National University, Building 61, Mills Road, Acton 0200, Australia.

190 Ma Alic Springs, 135 Ma Galah Creek, 105 Ma Lachlan Hallett, 103 Ma Warumpi, 100 Ma Aileron, 98 Ma Bruna, 97 Ma Mount Lloyd, 95 Ma A10-029.
The 450–300 Ma Alice Springs Orogeny has been divided into the Late Ordovician Rodingan Event, the Devonian Pertnjara–Brewer events and the Carboniferous Eclipse Event. This long-lived multiphase event began with basin inversion of the Irindina Province, followed by thick-skinned deformation and exhumation along major crustal-scale structures, amphibolite-facies metamorphism and felsic magmatism, including the intrusion of voluminous pegmatite. Large-scale fluid flow was responsible for widespread REE mineralisation (Hussey 2003).

Mafic magmatism in the Irindina Province

A component of recent field investigations in Quartz has focused on investigating the geochemical and isotopic character of the mafic magmatism, in order to understand the nature of the underlying crust and the source regions of these compositionally diverse mafic magmas. The nature and origin of three suites of mafic rocks that were emplaced in extensional settings, Riddoch Amphibolite Member (Irindina Gneiss), Stanovos Igneous Suite and Lloyd gabbro (informal name) are discussed below.

Riddoch Amphibolite Member

The Riddoch Amphibolite Member outcrops over large areas in ALICE SPRINGS and ILLOGWA CREEK (Figure 1), and hosts the Cu-Co-Ag prospects on the Basin and Poly trends (Mithril Resources, ASX announcement 28 Oct 2009). It consists of variably deformed metagabbro or metabasalite, interlayered with layered, quartz-rich amphibolite, metapsammopelite, metapelite, and minor marble and calc-silicatic rock, and quartzo-feldspathic gneiss. This has led some workers to interpret that the amphibolites were originally fine-grained lava flows (Sivell and Foden 1985, Hoatson and Stewart 2001). The rocks were metamorphosed to upper-grained lava flows (Sivell and Foden 1985, Hoatson and Stewart 2001). During the Larapinta Event, a strong layer-parallel fabric was developed, which obscured the relationship between the amphibolites and the Irindina Gneiss. Rare low-strain boudins of metagabbro and metapyroxenite are preserved.

The Riddoch Amphibolite Member consists of two geochemically distinct groups. The dominant metagabbroic compositions (plagioclase + clinopyroxene + amphibole + opaque oxides) are light rare-earth element (LREE) depleted and have REE patterns characteristic of normal mid-ocean ridge basalts (NMORB). In contrast, the layered quartz-rich amphibolites (quartz + amphibole + minor feldspar + opaque oxides) are LREE enriched, with pronounced negative Eu anomalies, and have REE patterns characteristic of Average North Australian Felsic Crust.

Stanovos Igneous Suite

In the vicinity of the Stanovos Valley, mafic rocks of the Stanovos Igneous Suite are gabbroic in composition and are variably intermingled with coarse-grained, porphyritic garnet-biotite granitoids and migmatite (Lawley 2005). The gabbros are locally plagioclase-phyric and, in places, preserve primary igneous textures. Coeval mafic/felsic magmatism in the area around Mount Karinga occurred at ca 520 Ma (Lawley 2005, Maidment 2005). The more mafic compositions share geochemical similarities with the ca 508 Ma Kalkarindji Suite of northern Australia (Glass 2002, Lawley 2005). This study has increased the extent of the Stanovos Igneous Suite further to the east and southeast of the Mount Karinga area.

The gabbroic rocks of the Stanovos Igneous Suite are tholeiitic with slightly LREE-enriched REE patterns. In contrast to the Riddoch Amphibolite Member, samples from the mafic units of the Stanovos Igneous Suite are elevated in LILE (Large Ion Lithophile Elements), such as Th and U. cNd (+0.7 to -0.7) values from this study indicate that the Stanovos Igneous Suite is more isotopically juvenile than the restricted range of the isotopic signature of the Kalkarindji Suite (cNd = -3.0 to -4.5; Glass and Phillips 2006).

Lloyd gabbro

The Lloyd gabbro hosts the Blackadder and Baldrick Ni-Cu prospects, and comprises olivine-bearing gabbro
and gabbronorite. These rocks preserve primary igneous textures and appear to be generally undeformed, with the exception of shearing at the contact with granulite-facies metasedimentary rocks of the Irindina Province. The Lloyd gabbro has a high MgO content (17 to 24 wt%), with elevated Ni, Cu, Cr and Co. La/Sm, ranges from 1.9 to 2.2, which may suggest a small amount of crustal contamination (Whelan 2009a).

U-Pb SHRIMP geochronology on magmatic zircons from the gabbronorite that hosts the Baldrick prospect yield a concordia age of 409 ± 9 Ma. Inherited grains with ages ranging 1701 to 1760 Ma and εNd = +0.7 suggest some crustal contamination.

Discussion and mineral prospectivity

The eastern Arunta is a highly prospective under-explored region despite its recognised potential for mafic-hosted mineralisation (Hoatson et al 2005). It has undergone multiple phases of deformation and long-lived fluid flow during the Palaeozoic Alice Springs Orogeny and multiple mineralising events associated with magmatic activity. Recent work in the Arunta Region has identified a plethora of commodity types associated with mafic magmatism. In the Aileron Province, vanadium-titanium-iron mineralisation associated with Palaeoproterozoic mafic magmatism is present at Mount Peake (TNG Ltd) and within the Attutra Metagabbro (Arafura Resources Ltd). In the Irindina Province, Ni, Cu and PGE are associated with the Lloyd gabbro (Mithril Resources Ltd). Historically, the Riddoch Amphibolite Member has been explored for carbonate vein-hosted PGE-Au-Cu mineralisation southeast of Mount Riddoch (Tanami Gold NL), and Cu-Zn and vein-hosted Cu occurrences have also been noted (Hoatson and Stewart 2001). More recently, Mithril Resources Ltd have discovered significant Cu, Co and Ag mineralisation associated with isotopically juvenile magmas of the Riddoch Amphibolite Member (Basil prospect; Mithril Resources, ASX announcement 28 Oct 2009)

The mafic magmatic units of the Riddoch Amphibolite Member, Stanovos Igneous Suite and Lloyd gabbro all have geochemical signatures indicative of magmatism in an extensional environment. Nd isotopic data show a broad isotopic progression from juvenile to increasingly evolved mafic magmatism with decreasing age of emplacement in the Irindina Province. The Riddoch Amphibolite Member was emplaced early in the history of the Irindina Sub-basin at least 600 million years ago. Its N-MORB-like geochemistry and isotopically primitive signature are consistent with large degrees of partial melting during extensive rifting. Almost 100 million years later, mafic rocks of the Stanovos Igneous Suite intruded the lower levels of the Irindina Sub-basin; slight LREE enrichment and more isotopically evolved compositions suggest some crustal contamination during emplacement. The Lloyd gabbro was emplaced after the juxtaposition of the Aileron and Irindina provinces. The relatively isotopically evolved nature of this unit and the presence of inherited zircons of Yambah and Strangways age suggest that the contaminant may be underlying Palaeoproterozoic crust.

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REGIONAL GEOLOGY AND PROSPECTIVITY OF THE AILERON PROVINCE IN THE ALCOOTA 1:250 000 MAPSHEET AREA

Eloise E Beyer1,2, Chris J Edgoose3, Leon C Vandenberg4, Gordon Webb5, Simon Bodorkos6

The Arunta Region extends over an area of approximately 200 000 km² and has undergone a series of tectonothermal events spanning from the late Palaeoproterozoic through to the Palaeozoic. The region is subdivided into three provinces with distinct protolith ages and histories: the 1860–1700 Ma Aileron Province, the 1690–1600 Ma Warumpi Province and the Neoproterozoic to Cambrian Irindina Province. In 2007, NTGS commenced work on a 3-year project in the central Arunta Region, focused in ALCOOTA (Figure 1), which is dominated by rocks of the Aileron Province. The central Arunta is critical to furthering the development of an integrated framework of the Arunta Region, and builds on NTGS work since 2000 in the southwestern, northern and eastern Arunta. The project is now nearing completion and this document outlines the contribution this study has made to further understanding the evolution of this multi-component terrane. The complexity of the stacked basins affected by multiple tectonothermal events, combined with large areas of poor outcrop, presents explorers with both a challenge in assessing the prospectivity of the complex geology and an opportunity, given the potential for a wide range of mineralisation styles and settings.

1860–1830 Ma metasedimentary units

The oldest known exposed rocks in the Aileron Province are widespread clastic sediments, now at various metamorphic grades, collectively known as the Lander Rock Formation (LRF). This package of rocks is characterised by interbedded pelitic and psammitic metasedimentary rocks that are interpreted to have a predominantly turbiditic origin and maximum deposition ages ranging from 1860–1830 Ma (Scrimgeour in press). New zircon U-Pb geochronology of the granulite-facies metasedimentary rock units in ALCOOTA has shown that many of them were deposited before 1830 Ma and are either direct correlatives of the LRF, or were deposited at about the same time. The Aileron Metamorphics, which is part of the eastern extension of the Reynolds Range

1 Northern Territory Geological Survey, Arid Zone Research Institute, GPO Box 8760, Alice Springs NT 0871, Australia.
2 Email: eloise.beyer@nt.gov.au.
3 Geoscience Australia, GPO Box 378, Canberra ACT 2601, Australia.
4 Names of 1:250 000 mapsheets are in large capital letters, eg ALCOOTA.
in the southwest of ALCOOTA, is confirmed as a LRF equivalent with a maximum deposition age of 1864 Ma. The Woolla Gneiss in the far northwest part of ALCOOTA has a slightly younger maximum deposition age of around 1836 Ma. The Mount Bleechmod Granulite, once thought to have been part of the 1810–1800 Ma lower Strangways Metamorphic Complex (SMC), has a maximum deposition age of 1830 Ma and is now considered a correlative of the LRF. The age of the Kanandra Granulite, which outcrops in the far eastern part of ALCOOTA and in parts of adjacent HUCKITTA, is less well defined, with maximum deposition ages ranging from 1844 Ma to 1798 Ma.

**Strangways Metamorphic Complex**

The Delmore Metamorphics and Delny Gneiss are a package of dominantly siliciclastic metasedimentary rocks that outcrop extensively in the central and western parts of ALCOOTA. The Delmore Metamorphics comprise metapelitic, metapsammitic and possible meta-volcaniclastic rocks, minor amphibolite and scattered lenses of cordierite-anthophyllite rock. The Delny Gneiss is a lithologically complex unit, comprising quartzfeldspathic metasediment, mica schist with muscovite clots possibly after andalusite, amphibolite, minor quartzite and rare calc-silicate rock. These two units, informally referred to here as the Delny package, belong to the Jinka domain, a belt of high-T, low-P metamorphic rocks that lies to the north of the Delny-Mount Sainthill Fault Zone. The Jinka domain comprises rocks that are stratigraphically equivalent to the lower Strangways Metamorphic Complex, based on volcaniclastic protolith ages of around 1805 Ma, and includes such units as the Bonya Schist and the Deep Bore Metamorphics and Cackleberry Metamorphics (Scrimgeour and Raith 2001). Dating of rocks from the Delny package gives a range in maximum deposition ages from 1806 ± 21 Ma in a metavolcaniclastic rock from the Delmore Metamorphics to 1825 ± 11 Ma in a metapsammitic from the Delny Gneiss. Unlike units of the Strangways Metamorphic Complex, which are characterised by no to very little inheritance of older zircons (Hussey et al 2005, Claué-Long et al 2008), the detrital spectra for the Delny package rocks indicate a provenance from the North Australian Craton (NAC), not unlike that of the Lander Rock Formation.

**Stafford Event (1810–1790 Ma)**

The Stafford Event is a tectonothermal and magmatic event that affected extensive areas of the Aileron Province. In the eastern Aileron Province, no metamorphism is recognised associated with this event, although there is extensive volcanism and volcaniclastic sedimentation in the Strangways Range to the south, along with felsic and mafic magmatism (Scrimgeour in press). The only metamorphic Stafford age identified in ALCOOTA is a single zircon rim (1797 ± 8 Ma) in the Aileron Metamorphics. However, 1805–1795 Ma magmatism has been found to be significantly more widespread across the central Arunta Region than previously thought. Two main intrusive episodes have been identified in ALCOOTA during this event, occurring at 1805 Ma and 1795 Ma. The older intrusives include a tonalite from the Woolla Gneiss region and an unnamed hornblende-orthopyroxene-bearing orthogneiss, outcropping north of the Ledan Schist. The younger intrusives comprise a tonalite from the Woolla Gneiss region and an unnamed felsic gneiss, both of which outcrop in the southeast of the mapsheet, and an unnamed intermediate granite on Bushy Park Station. A metagabbro in the Mount Lucy area, north of the Aileron Metamorphics, may be of a similar age, although geochronology on this unit is inconclusive.
Yambah Event (1780–1770 Ma)

This event is characterized by felsic and less-abundant mafic magmatism, and variable metamorphism and deformation across much of the Aileron Province (Scrimgeour in press). Although the Yambah Event is the dominant magmatic event across the southern half of the Aileron Province, no magmatism of this age has been identified through geochronology in ALCOOTA. However, it is postulated, based on field relationships, that both the Copia and Crooked Hole granites may have intruded during this event. Despite the relative lack of 1780–1770 Ma magmatism, there is good evidence for metamorphism of this age, with the four LRF-equivalent metasedimentary rock units having zircon rim populations in the range 1773–1758 Ma. The Queenie Flat Granite also has zircon rims with a metamorphic age of 1775 ± 5 Ma.

1780–1750 Ma metasedimentary units

A quartz-rich metasedimentary succession unconformably overlies rocks of the LRF and SMC in the central Arunta Region. Collectively known as the Ledan package, it comprises the upper greenschist–lower amphibolite-facies Ledan Schist (with overlying Utopia Quartzite) and Mendip Metamorphics, plus the granulite-facies metasedimentary rocks of the Chiripee Gneiss and Anira Metamorphics. The Ledan package may be a correlative of the unmetamorphosed upper Hatches Creek Group of the Davenport Province to the north. Together, these packages may constitute part of an intracratonic basin that formed to the north of a plate margin during rollback of an interpreted north-dipping subduction system to the south and southeast (Scrimgeour 2006). The Ledan Schist comprises a succession of quartz-muscovite ± biotite ± andalusite schist, and metapsammite with minor amphibolite, which is unconformable on the Delmore Metamorphics, and which has a maximum deposition age of 1775 Ma (Maidment et al. 2005). The Mendip Metamorphics are predominantly quartz-rich metasedimentary rocks with minor gneiss and amphibolite; this unit is interpreted to be unconformable on the Mount Bleechmore Granulite and has a maximum deposition age of 1770 Ma (Maidment et al. 2005). Metapelitite and metapsammite of the Chiripee Gneiss and Anira Metamorphics have maximum deposition ages of 1770 ± 11 and 1785 ± 19 Ma (Carson et al. 2009), respectively.

Strangways Event (1735–1690 Ma)

The 1735–1690 Ma Strangways Event was the major tectonic event in the eastern Arunta Region. In central and eastern ALCOOTA, metamorphic grade is predominantly granulite to upper amphibolite facies south of the Delny-Mount Sainthill Fault Zone, and upper greenschist (Ledan Schist) to granulite facies (Anira Metamorphics) to the north. In contrast, outcrops towards the western edge of ALCOOTA (eg Woolla Gneiss and Aileron Metamorphics) show no evidence of the Strangways Event. Preliminary P-T estimates for the Mount Bleechmore granulite indicate peak metamorphic conditions (attributed to the Strangways Event) of 600–800°C and 6–8 kbar. P-T conditions in the Kanandra Granulite to the east in HUCKITTA were calculated to be 770–850°C and 5–7 kbar (Scrimgeour and Raith 2001). Zircon rims in the Mount Bleechmore Granulite also record two distinct Strangways-aged metamorphic episodes, one at 1733 ± 16 Ma and another much younger event at 1655 ± 9 Ma. A metapelite from the Kanandra Granulite has zircon rims at 1729 ± 4 Ma, whereas a mafic granite from the same unit shows resetting of its zircon U-Pb systematics at 1726 ± 5 Ma. A metabasite in the Mount Bleechmore Granulite also shows evidence of metamorphic resetting at 1713 ± 7 Ma. Most of the Delny package metasediments are too low grade to have associated zircon growth, with only a single rim age of 1676 Ma recorded in the Delmore Metamorphics. However, the Delmore Metamorphics do contain a mafic intrusive dated at 1710 ± 2 Ma. Both the Anira Metamorphics and Mendip Metamorphics record zircon rims at about 1724 Ma (Carson et al. 2009, Maidment et al. 2005), whereas the Chiripee Gneiss shows no geochronological evidence for Strangways metamorphism.

Chewings Orogeny (1590–1560 Ma)

The 1590–1560 Ma Chewings Orogeny is an event of fundamental importance throughout large regions of the central and southern Aileron Province. The Lander Rock Formation in the Reynolds Range is overprinted by high-T low-P granulite-facies metamorphism belonging to the Chewings Orogeny (Hand and Buick 2001). This event has now been shown to extend to the eastern margin of ALCOOTA, with Chewings-aged metamorphism now recognized in all three of the Palaeoproterozoic metasedimentary packages above as well as in many of the intrusive rocks. A metapelitite from the Mount Bleechmore Granulite has zircon rim ages of 1554 ± 18 Ma and two mafic intrusives from the same unit show complete resetting of their zircon U-Pb isotopes at about 1570 Ma. These ages are all within error of the 1572 Ma overgrowths determined for zircons from the underlying Mendip Metamorphics (Maidment et al. 2005). The Chiripee Gneiss to the north of the Mount Bleechmore Granulite has also recorded Chewings metamorphism with zircon rim ages of 1558 ± 9 Ma. Mafic intrusive rocks of the
Delmore Metamorphics and the Delny Gneiss also show evidence for Chewings metamorphism.

**Mineral potential and exploration activity**

In general, the integrated geochronological and geochemical data, mapping and geophysical interpretation suggests a series of stacked and/or tectonically juxtaposed metasedimentary basins in ALCOOTA. This improved understanding of the distribution of the sedimentary packages and their tectonothermal development allows new insights into potential mineral systems and prospectivity.

**Lander Rock Formation – lode Au**

The extent of the Lander Rock Formation, equivalent sedimentary successions and 1820–1790 Ma magmatism is now understood to extend further east than previously identified. Interpretation of regional magnetic and gravity data, together with mapping of the limited exposures indicates that the region is cut by numerous major fault and shear zone systems. Many of these structures are likely to have been initiated during the Proterozoic, although all are likely to have been active during the 450–300 Ma Alice Springs Orogeny. In particular, regional gravity data indicates that several crustal-scale structures dissect the region and, by inference, these structures may have had long protracted histories of movement (eg Woolanga Lineament).

In this general setting, there is potential for lode-style Au deposits such as those found in the adjacent western Aileron Province or the Tanami Region further to the northwest, particularly in areas of greenschist- to amphibolite-facies metamorphism. In these adjacent regions, ‘Tanami-style’ lode-gold mineralisation is generally associated with the Lander Rock Formation or with sedimentary packages of equivalent age and provenance, along with 1815–1790 Ma magmatism and tectonism.

However, there are some important differences in ALCOOTA to these known settings for ‘Tanami-style’ lode-gold deposits. Stafford-aged granite bodies in ALCOOTA are moderately to strongly metaluminous and these ‘atypical’ geochemical signatures and mineralogy have strong affinities with potential back-arc volcanism in the Strangways Metamorphic Complex further to the south. The geochemical signatures possibly indicate sourcing from deeper crustal levels, and this is also implied by the generally higher metamorphic grade of these Lander Rock Formation (equivalent) packages.

**Mafic-hosted mineralisation**

There is also potential for mafic intrusive-related Ni-Cu, and V-Ti-Fe mineralisation systems, which are associated with mafic units that locally outcrop (eg Mount Lucy area) and may be more widespread under cover. In particular, the northern part of ALCOOTA is geologically continuous with areas in MOUNT PEAKE and BARROW CREEK that contain the Prospect D amphibolite-hosted Ni-Cu prospect and the Mount Peake V-Ti-Fe deposit. The economic potential of mafic rocks in ALCOOTA remains untested.

**Iron-oxide copper-gold**

Within the Aileron Province, there appears to be a general spatial association between Cu-Au mineralisation (potential IOCG systems) and the presence of 1780–1770 Ma felsic magmatism (Whelan et al 2009). Geochronological data from the numerous granitic bodies that can be identified or inferred in ALCOOTA remains quite limited, and the possible extent of felsic magmatism of 1780–1770 Ma age and associated potential mineralisation remains uncertain. However, at the Perenti copper prospect, immediately to the east in HUCKITTA, copper mineralization is associated with haematite alteration in the 1770 Ma Dnieper Granite. Limited drilling at the prospect intersected haematite- and chloride-altered granite, with chalcopyrite- and haematite-bearing quartz veins, and haematite-quartz-chlorite-fluorite breccia (Ivanac 1970). The mineralisation is spatially associated with splay off the Delny-Mount Sainthill Fault Zone and appears to be fault controlled, with strong affinities to IOCG systems. This fault system extends into ALCOOTA, and splay off this fault system extend north into BARROW CREEK, where they are spatially associated with the Wapiti Au prospect and Home of Bullion Cu–Pb-Zn prospect. This prospective corridor remains fundamentally underexplored.

**Tantalum and tungsten**

There is a strong association between felsic intrusives of 1730–1710 Ma age and tantalum and tungsten mineralisation. Small sub-economic Ta and W mineralisation is associated with 1730 Ma-aged pegmatite intrusives (eg “Utopia” pegmatites, Bundey River/Spotted Wonder prospects). Calc-silicates of the Delmore Metamorphics also locally host W mineralisation. Further east in HUCKITTA, the Molyhil W-Mo skarn deposit is also associated with 1730–1710 Ma magmatism. However, the potential for this style of mineralisation is not necessarily restricted to intrusives of this age. For example Sn-, Ta- and W-bearing pegmatites that have been mined historically in adjacent MOUNT PEAKE (ca 1770 Ma) and BARROW CREEK (ca 1805 Ma) are associated with Stafford and Yambah-aged magmatism.

**VHMS and Carbonate Replacement Cu-Pb-Zn**

The recognition of ca 1805 Ma volcaniclastic and quartz-cordierite, cordierite-anthophyllite rocks in the Delmore
Metamorphics (Delny package) suggests that this package may be prospective for VHMS and epigenetic base metal mineralisation. The quartz-cordierite and cordierite-anthophyllite rocks show mineral assemblages characteristic of the lower Strangways Metamorphic Complex. Warren and Shaw (1985) and Hussey et al (2005) suggested that this alteration took place prior to metamorphism and, in the Strangways Range, they host VHMS and epigenetic base metal occurrences. Although the rocks in the central Arunta are of lower metamorphic grade than those in the Strangways Range, they appear to share a similar tectono-metamorphic and thermal (intrusive) history.

In the Harts Range area to the south, carbonate-replacement base metal deposits occur at the Oonagalabi prospect within the Bungatina Metamorphics, which may be a stratigraphic equivalent of rock units in the Ledan package (Hussey et al 2005). However, volcanic and carbonate components characteristic of the Bungatina Metamorphics have not been identified in the Ledan Schist or Mendip Metamorphics. Similar-aged sedimentary basins in the eastern Arunta (eg Albertia Metamorphics) are associated with felsic units with a geochemistry that is indicative of a back-arc setting related to subduction further to the south. The siliciclastic Ledan package is interpreted to represent a near-margin contemporaneous intracratonic setting, and consequently, would not be considered a target for similar mineral systems.

Uranium and REE
The Woolanga Lineament is a major, deep-seated crustal structure that passes undercover through southwestern ALCOOTA and it has a strong spatial association with alkaline magmatism and REE mineralization (Close et al 2009). In particular, this structural zone has potential for Nolans Bore-style fluorapatite vein-hosted REE, U, P mineralisation. Minor REE and vermiculite mineralisation is also associated with possible carbonate in the Mount Bleechmore Granulite domain, north of the Mud Tank zircon and vermiculite field.

Recent exploration activity in ALCOOTA has largely focused on palaeochannel or calcite-hosted uranium, associated with the Cenozoic Ti Tree/Aileron Basin. Further potential uranium mineralisation may also lie in the Georgina Basin, given that potential sources for uranium mineralisation include high U- and Th-bearing felsic intrusives such as the Copia Granite in the northeast of ALCOOTA. Furthermore, the recent identification of U-rich alaskite by Uramet Minerals at their Adnera uranium project immediately north of ALCOOTA, with rockchip samples of up to 540 ppm U from preliminary sampling (Uramet Minerals, ASX Release, 28 Oct 2009), highlights the potential of the area for Rossing-style granite-hosted uranium mineralisation.

References

TNG LTD: OUTLOOK FOR 2010

Paul Burton

TNG Ltd is an Australian mining and exploration company with a portfolio of quality exploration projects in western and northern Australia. The company’s core focus is exploration at its 100%-owned Manbarrum zinc-lead-silver project and its Mount Peake vanadium–titanium–iron project. Both projects are advanced with JORC resource estimates and high potential to increase the current resources.

TNG’s board of directors and management team have extensive experience in the mining and exploration industries – in Australia and internationally. They are committed to increasing shareholder value by carrying out exploration and maximising the company’s leverage to discoveries.

This presentation will outline the company’s current activities in the Northern Territory and outlook for 2010.

Northern Territory exploration

TNG’s Northern Territory portfolio includes a broad range of exploration projects, ranging from advanced projects with existing resources, to greenfields exploration. Its tenements include exposure to a wide range of commodities, including gold, lead, zinc, nickel and copper. The Company’s two advanced projects are reviewed in this presentation.

Manbarrum project overview:

The Manbarrum zinc-lead-silver project is located in the prospective Bonaparte Basin, 70 km northeast of Kununurra, in the Northern Territory. The tenements cover a 52 km strike length of identified zinc-lead-silver mineralisation of the Mississippi Valley Type (MVT). This project currently hosts a combined resource inventory of >35 Mt of open pittable lead-zinc-silver deposits, of which the Sandy Creek deposit is most advanced. A new resource estimate is underway for the Sandy Creek deposit.

The 2010 exploration program aims to build on the increased resource inventory.

Mount Peake overview

TNG’s 100% owned Mount Peake project is located in the highly prospective Arunta Region, 80 km northeast of Alice Springs in the Northern Territory. The Arunta Region has long been considered prospective for nickel–copper and platinum group minerals. TNG is actively exploring for these commodities, while continuing to evaluate the recently discovered vanadium–titanium–iron resource.

The project is strategically located close to existing infrastructure, including the Alice Springs–Darwin Railway, Stuart Highway and the new LPG pipeline, 20 km to its east.

In early 2008, TNG announced a significant magnetite-titanium-vanadium discovery, following preliminary test work from diamond drillhole ARD02. In 2009, TNG announced a maiden JORC Inferred Resource estimate of 107 Mt @ 0.4% V2O5, 9% TiO2 and 28% Fe. This resource estimate was carried out by Snowden Mining Industry consultants.

TNG announced preliminary scoping study results also carried out by Snowden. These showed positive economics, based on the inferred resource.

In late 2009, TNG completed further drill testing of extensions to the mineralisation. Results are currently being compiled into an updated Resource Estimate.

In addition, a number of priority EM targets have been defined, with drill testing scheduled for 2010.

NTGS DATA AND SERVICES: WHAT’S NEW AND WHAT WE ARE DOING FOR YOU

Tracey C Rogers

Over the last 12 months, there have been two important highlights in terms of information delivery by the Northern Territory Geological Survey (NTGS). On 1 August 2009, the Minerals and Energy InfoCentre introduced a new client request and enquiry system that enables improved monitoring and tracking of requests for both the InfoCentre and clients, while at the same time, building a knowledge base to assist with similar future enquiries. More recently, the Geophysical Image Web Server (GIWS) web interface has been redeveloped to enable individual survey images to be accessed directly from the main interface and overlain or be overlain by the NT-wide imagery. The redeveloped system is currently scheduled to be available via the NTGS website by the end of March 2010.

Other significant achievements include the completion and delivery of images and data for the Barkly gravity survey, the availability of Geoscience Australia’s Pine Creek

1 TNG Ltd, Level 1, 282 Rokeby Road, Subiaco WA 6008, Australia. Email: paul.burton@tngltd.com.au.
airborne electromagnetic (AEM) survey sections via GIWS, and the release of 21 new and updated GIS datasets, an updated gold deposits report, and four 250k geological maps and corresponding combined explanatory notes covering a major portion of the Georgina Basin.

Web delivery systems

Major changes to the Geophysical Image Web Server (GIWS) are in the process of being completed. Whereas for the last few years, the individual survey images have only been accessible in a separate window with reduced functionality, the redeveloped system enables individual survey images to be directly accessible in the main interface and these can overlie or be overlain by the NT wide imagery. To achieve this, all imagery has been converted to GDA94 geodetic coordinates and as a result transparency, geolinking and overview functions will be applicable to all imagery. The new system should be available by the end of March 2010.

Preliminary images of the 2009 Barkly gravity survey were available on GIWS from July 2009 and the final images were published in October 2009. A new NT-wide gravity stitch incorporating the Barkly data was released in December 2009 and a further update is scheduled for the end of March 2010. Images representing conductivity sections at various depths from the Pine Creek airborne electromagnetic survey, flown by Geoscience Australia (GA) in three separate areas between July and December 2009, are now available on GIWS. The point-located and grid data is available for download from the GA website.

With the advent of geothermal legislation, two new layers showing title applications and reserves are now available via STRIKE and an historical petroleum titles layer was also added in June 2009. Other layers continue to be updated and recently significant additions have been made to the company airborne geophysical survey index and geochemistry layers.

NTGS products, spatial data and client services

Twelve older maps have been converted to GIS since March 2009: five 100k outcrop geology, two 250k outcrop geology, three 250k interpreted geology, one 500k outcrop geology and one 500k interpreted geology. Another four new 250k outcrop geology maps, covering part of the Georgina Basin, and their corresponding GIS datasets were also released. The project to convert older GIS datasets into the current NTGS data dictionary has continued, with one 500k interpreted geology and four 250k outcrop geology datasets re-released since March 2009.

Due to the development of the new geochemistry database, very little new data was added to the system in 2009, but in the last two months, outstanding NTGS whole-rock geochemistry has been added and entry of company data from the large backlog has commenced. A total of 794 new NTGS samples has been added, and a further 773 have had trace element data added. Over 1000 samples from company reports were added to the database up to the end of February 2010. At this stage, the data is available via STRIKE only, as work continues on the database.

NTGS publications released in the last 12 months include a 2nd edition of the 1999 Gold deposits of the Northern Territory (Report 11), Alroy, Brunette Downs, Walhallow, Frew River 1:250 000 geological maps and combined explanatory notes, and five Records including a report on the first two years of the Bringing Forward Discovery initiative.

Over the last few years, the number of client requests and enquiries to the InfoCentre reached a peak of just over 6000 in 2006–07 and was still around 4500 in 2008–09. At the same time, the number of exploration reports and data being distributed continues to rise steadily as clients request more data in each request. In 2008–09, over 18 000 exploration reports and data were distributed. To assist in maintaining a professional information service, we have introduced RefTracker, a web-based enquiry management system that is linked to the InfoCentre email and accessed through the NTGS website. All InfoCentre staff (regardless of location) are able to see the incoming requests. Each new request is assigned to a staff member, but everyone can view who is responsible for each enquiry and all request details, including responses. The system assigns a number to each request and clients use this reference number when making responses and for tracking purposes.

RefTracker has led to consistency and a general increased speed of response, as we can easily ensure that each client is receiving the same responses and same level of service as those clients who have already posed the same question. In the longer term, it is also facilitating an improvement in the quality of responses. As the complete request histories are stored in the system to form a searchable knowledge base, staff members have increased opportunities to learn from previous requests and from each other, ultimately leading to improved client service. Finally, the system provides for the easy gathering of statistics, enabling us to see how many requests, numbers of users and what types of enquiries are being made. Within broad categories, we also capture numbers of products distributed.

Reports and data management

Scanning of petroleum reports has continued slowly, as resources permit, and in response to specific client requests.

The Geothermal Energy Act came into force on 1 December 2009, but it is not expected that reports will be generated by these titles until at least the second half of 2011. In the meantime, a new database has been created for
internal use, and reporting guidelines for content, format and media will be developed.

The bill for the new Mineral Titles Act is being introduced into Parliament at the time of writing and it is expected that the new Act will come into force later in 2010. There are some changes to reporting requirements under the new Act and much of the detail will be incorporated in the Regulations and reporting guidelines, which are still being drafted. The major changes that relate to reporting will be the introduction of a sunset clause, resulting in the open filing of most reports within five years of the due date of submission and penalties for the late submission of reports. As a consequence, for an initial period there will be larger numbers of reports becoming open file than usual, and new procedures and alerting mechanisms will be put in place.

**NTGS corporate database system**

During the last 12 months, progress on the geochemistry module of the corporate database has been very slow. Bulk data loading and further testing during 2009 highlighted several major issues. Work to fix the problems is now well underway. Bulk loading of surface sample data is now fully operational and the focus has moved to bulk loading of drill sample data and data export.

**ARCHAEOAN AND PALAEOPROTEROZOIC CRUSTAL EVOLUTION PROCESSES IN THE PINE CREEK OROGEN: U-Pb, Hf, O, Nd ISOTOPIC DATA AND GEOCHEMISTRY**

Linda M Glass1, 2, Julie A Hollis1, Chris J Carson3, Greg M Yaxley4 and Richard Armstrong5

Crustal differentiation over geological time is largely represented by repeated episodes of magmatism. Understanding the timing and processes of magmatic differentiation is important to constructing realistic tectonothermal models and can be crucial in understanding mineralising systems.

Previous work has demonstrated that Archaean and Palaeoproterozoic magmatic rocks of the Pine Creek Orogen (PCO) can be distinguished on the basis of distinct trace element and some major element geochemical patterns (Glass et al 2009), which make useful discriminators in rocks with largely similar bulk-rock geochemistry. However, determining whether the processes from magma genesis to crust formation were constrained by melt segregation from a mantle source or by a component of crustal recycling is difficult to resolve by geochemical means alone. Isotopic studies, combined with geochronological data, offer further powerful insights.

Whole-rock Nd data yield valuable information on the nature and timing of crust formation and Sm-Nd model ages reflect either the timing of melt extraction from the mantle or, in most cases, an average crustal resident age of mixed mantle and/or reworked crustal sources. Additional information can be extracted from the Hf and O isotopic compositions of individual zircon grains from magmatic rocks. The Hf isotopic system behaves similarly to Nd, while the O isotopic composition is sensitive to low-temperature processes and can reveal whether the zircons grew from a mantle-derived melt ($\delta^{18}$O <6.5‰), or from a melt derived from rocks that have experienced a weathering cycle, i.e. crustal rocks ($\delta^{18}$O >6.5‰). In short, Hf-O combined with U-Pb zircon data and Nd whole-rock data allow the processes and timing of crust formation to be unravelled.

We present newly acquired Nd data, SHRIMP U-Pb zircon geochronological data, and zircon O and Hf data for selected magmatic samples from igneous suites largely within the Nimbuwah Domain of the PCO. These complement recent NTGS findings from regional mapping, provenance and metamorphic studies, which give new insights into the Neoarchaean to Palaeoproterozoic tectonothermal history of the PCO and reveal important distinctions in the timing and nature of magmatism, sedimentation, and metamorphism across the PCO.

**Regional geology**

The PCO, on the northern margin of the North Australian Craton (NAC), is exposed over 47 500 km² and comprises a >4 km-thick succession of Palaeoproterozoic clastic, carbonate, and carbonaceous sedimentary and volcanic rocks, unconformably overlying Neoarchaean (ca 2670–2500 Ma) granitic and gneissic basement. The PCO is broadly subdivided into three regions, each distinguished by its Palaeoproterozoic stratigraphy, structural style, and timing and nature of magmatism and metamorphism. The three regions are the amphibolite- to granulite-facies Litchfield Province in the west; the greenschist-facies Central Domain, and the amphibolite-facies Nimbuwah Domain in the east (Figure 1). The latter is the main focus of this study.

Neoarchaean granitic magmatism in the PCO is largely constrained to three temporal episodes: ca 2670 Ma, ca 2640 Ma and ca 2530–2500 Ma. In the Central Domain, these include the Woolner Granite (2674 Ma; this study)

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1 Northern Territory Geological Survey, PO Box 3000, Darwin, NT 0801, Australia.
2 Email: linda.glass@nt.gov.au.
3 Geoscience Australia, PO Box 378, Canberra, ACT 2601, Australia.
4 PRISE, Research School of Earth Sciences, The Australian National University, Building 61, Mills Road, Acton ACT 0200, Australia.
and Rum Jungle Complex (2545–2520 Ma; Cross et al. 2005). In the Nimbuwah Domain, they include the Arrarra Gneiss (2671 and 2640 Ma; Hollis et al. 2009a, c), Nanambu Complex (2520 Ma; Hollis et al. 2009a, c) and Kukalak Gneiss (2527–2510 Ma; Hollis et al. 2009a, c, Figure 1). Archaean basement has not been identified in the Litchfield Province.

The overlying Palaeoproterozoic strata have been subdivided into the Woodcutters Supergroup, probably deposited ca 2020 Ma, and the unconformably overlying Cosmo Supergroup, deposited at ca 1862 Ma (Ahmad and McCready 2001). The Nimbuwah Domain experienced moderate- to high-P amphibolite-facies metamorphism, probably associated with the emplacement of voluminous, granodioritic, 1867–1860 Ma Nimbuwah Complex plutons. This is in contrast to the Litchfield Province, which experienced low-P, high-T metamorphism at ca 1855 Ma (Carson et al. 2008) with associated mafic magmatism and the intrusion of S-type granites of the Allia Creek Suite. The Central Domain experienced greenschist-facies metamorphism at, or after ca 1852 Ma (Hollis et al. 2009b). These events were succeeded by post-tectonic emplacement of the 1835–1820 Ma, I-type Cullen Granite Complex in the Central Domain.

The PCO is a multi-commodity province with major commodities including Au, U, Pb-Zn-Ag, PGE, Cu-Co-Ni, Fe, Sn-Ta-W and phosphate (Ahmad 2007). There are strong spatial associations of U and of base metal occurrences within the oldest Palaeoproterozoic strata, proximal to, and unconformably overlying and onlapping Neoarchaean basement.

**U-Pb SHRIMP geochronology**

New SHRIMP U-Pb zircon magmatic ages have been obtained for the Woolner Granite from the Central Domain and for the Nimbuwah Complex from the Beatrice Inlier in the Nimbuwah Domain. SHRIMP U-Pb zircon detrital zircon spectra have also been obtained for a metasedimentary rock from the Beatrice Inlier.

The Woolner Granite has only been identified in drill core, ca 60 km east of Darwin, and is concealed under 40–120 m of Cretaceous cover, where its presence is evident by pronounced negative gravity anomalies. Williams and Compston (1983) documented a U-Pb SHRIMP zircon age for the Woolner Granite of 2675 ± 14 Ma; however, this was produced prior to cathodoluminescence imaging capabilities. A new, more precise, SHRIMP U-Pb zircon age of 2674 ± 3 Ma validates the older data. This is within error of the age of the Arrarra Gneiss (ca 200 km to the east) in the Nimbuwah Domain, which has yielded an emplacement age of 2671 ± 3 Ma (Hollis et al. 2009a, c).

Samples of metadiorite and granodiorite from the Beatrice Inlier have yielded magmatic crystallisation ages of 1862 ± 3 Ma and 1861 ± 4 Ma, respectively. These ages confirm that they are part of the Palaeoproterozoic.

**Figure 1.** Pine Creek Orogen showing surrounding basins and Neoarchaean and Palaeoproterozoic stratigraphy. Red dashed lines show approximate boundaries between the three PCO domains.
Nimbuwah Complex. Unlike the Myra Falls and Caramal inliers, located some 10–15 km to the north and northeast respectively, no Archaean magmatic rocks have yet been identified in the Beatrice Inlier.

An amphibolite-facies metasedimentary schist from the northeastern Beatrice Inlier has a detrital age spectra with a dominant peak at ca 1900 Ma and a small ca 2500 Ma component, consistent with previously determined detrital spectra for the Cahill Formation and Nourlangie Schist (Hollis et al 2009b), also in the Nimbuwah Domain.

Neodymium isotopes

New Nd isotope data have been obtained for 24 magmatic rocks from the Central and Nimbuwah domains to assess possible genetic relationships between suites with similar emplacement ages. The results are shown in Figure 2.

The oldest rocks, the 2674 Ma Woolner Granite in the Central Domain and the 2671 Ma Arrarra Gneiss in the Nimbuwah Domain, although coeval, are isotopically distinct (Figure 2). The Woolner Granite has a more juvenile εNd composition (1.7), relative to the Arrarra Gneiss (-1.7), which appears more isotopically evolved. It is difficult to reconcile differences in isotopic signature, given there are only two samples. It may be argued that they represent end-member compositions over a spread of data. However, as they are separated by 3.4 εNd units, we suggest that these two coeval (but spatially separate and isotopically different) suites may not be genetically related and are perhaps derived from different sources. In contrast, the younger 2640 Ma Arrarra Gneiss has a marked juvenile composition (εNd = 2.9), similar to depleted mantle at this time (Figure 2) and this is consistent with direct derivation from this source.

The ca 2500 Ma Kukalak Gneiss and Nanambu Complex combined (Nimbuwah Domain) have a restricted spread of isotopic composition (εNd = -1.0 to -0.1), forming a cluster within 1 εNd unit (Figure 2) and reflecting evolved compositions. The data indicate they are most likely derived from the same source. Isotopically, they are further distinct from the Palaeoproterozoic 1867–1860 Ma Nimbuwah Complex, which also has a restricted range at far more evolved compositions (εNd = -4.4 to -3.2, Figure 2). A similar-aged metadiorite of the Nimbuwah Complex from the Beatrice Inlier is marginally less isotopically evolved (εNd = -2.3).

For the majority of the igneous suites in the PCO, calculated Sm-Nd model ages confirm an element of recycling of older crust. The exception is the 2640 Ma Arrarra Gneiss, which, when combined with a positive εNd value (εNd = 2.9), has a model age of 2740 Ma. This is close to the emplacement age and is consistent with derivation directly from a depleted mantle source with little crustal influence. In contrast, a component of crustal recycling is evident in the other suites; for example, the older 2671 Ma Arrarra Gneiss in the Nimbuwah Domain (εNd = -1.7) has a model age of 3110 Ma. The coeval 2674 Ma Woolner Granite in the Central Domain, in contrast, has a model age which is considerably younger, at 2860 Ma. The ca 2530–2500 Ma Kukalak and Nanambu gneisses have model ages close to 2900 Ma and the ca 1867–1860 Ma Nimbuwah Complex has model ages at about 2600 Ma.

In summary, with the exception of the 2640 Ma Arrarra Gneiss, which has a dominant mantle source component, the other suites have Nd isotope compositions and model ages that indicate a component of recycling of crustal material. These model ages therefore are only an estimate of the average time that these samples have been resident in the crust.

Figure 2 shows comparative Nd isotopic data for the ca 2535–2521 Ma Rum Jungle Complex in the Central Domain (recalculated from McCulloch 1987) and the ca 1860 Ma Kalkadoon Granodiorite from Mount Isa (McDonald et al 1997), plotted for comparison with the Nanambu and Kukalak gneisses and the Nimbuwah Domain. The data are presented in order to determine whether similar-aged suites share a common Nd isotopic signature. In contrast to the Nanambu and Kukalak Gneisses, and with the exception of one sample which is isotopically similar, the Rum Jungle Complex generally

![Figure 2](image-url)
appears to be more evolved than the same-age Nanambu Complex and Kukalak Gneiss; however, this interpretation would benefit from additional data for the Rum Jungle Complex. In contrast, the Kalkadoon Granodiorite in northwestern Queensland is isotopically indistinguishable from the coeval Nimbuwah Complex.

**Oxygen and Hafnium isotopes**

Oxygen isotopic data have been collected for three Neoarchaean magmatic rocks and one sample of the Palaeoproterozoic Nimbuwah Complex. The 2671 Ma Arrarra Gneiss has a relatively unradiogenic and dispersed Hf signature ($\epsilon_{Hf} = -2.5$ to -8.9, Figure 3) with dominantly mantle-like $\delta^{18}O$ (5.5–6.7‰ with only 2 grains >6.5‰). This is consistent with melting of a mix of mantle-derived 3650–3200 Ma sources, with relatively limited reworking of supracrustal material with elevated $\delta^{18}O$. The younger 2640 Ma component of the Arrarra Gneiss has a tightly clustered, more radiogenic $\epsilon_{Hf}$ (dominantly 3.4 to 1.9), consistent with mantle-like $\delta^{18}O$ data (typically 5.2–5.8‰) and with a juvenile $\epsilon_{Nd}$ signature (2.9). This indicates a dominant ca 3000 Ma mantle source. Hf data for the 2527 Ma Kulakal Gneiss clusters below CHUR (0.2 to -4.6). Oxygen data indicate a significant reworked supracrustal component ($\delta^{18}O = 6.7–8.9‰$). Combined with the relatively clustered $\epsilon_{Hf}$ data, this is consistent with reworked supracrustal sources that have an average crustal residence age of ca 3100–3000 Ma. A sample of 1867 Ma Nimbuwah Complex has clustered $\epsilon_{Hf}$ of -2.5 to -5.5 with elevated $\delta^{18}O$ (6.2–8.9‰). This is consistent with reworked sources of a similar origin, with an average crustal residence age of ca 2800–2700 Ma.

These U-Pb-Hf-O data indicate that Neoarchaean felsic magmas were derived from sources extracted from the mantle at ca 3650–3200 Ma and ca 3000 Ma. The more evolved and dispersed nature of the Hf and O isotopes of the 2527 Ma Kulakal Gneiss and the 1867 Ma Nimbuwah Complex is consistent with increased assimilation and crustal reworking in the late Neoarchaean and Palaeoproterozoic.

**Implications for the tectonic evolution of the Pine Creek Orogen**

U-Pb, Nd, Hf, and O data show that the (ca 2670–2640 Ma) granitic magmas of the Woolner Granite (Central Domain) and the Arrarra Gneiss (Nimbuwah Domain) were dominated by direct melting of a depleted mantle source, with limited crustal recycling. However, they have distinct Nd isotopic systematics, with Sm-Nd model ages of ca 2860 Ma and ca 3100 Ma, respectively. The latter Sm-Nd model age for the Arrarra Gneiss is younger than the Hf model age of 3650–3200 Ma. The existence of Eo-to Palaeoarchaean juvenile magmatism is also indicated by Hf data for 3125 Ma detrital zircons from the Crater Formation, a basal unit of the Woodcutters Supergroup in the Central Domain (also with ca 3550 Ma and ca 3670 Ma peaks; Hollis et al. 2009b), which have average crustal residence ages in the range 3700–3500 Ma. Rocks of this antiquity have not been identified in the PCO or the NAC. The slightly younger 2640 Ma Arrarra Gneiss has a juvenile Nd isotopic signature and a Sm-Nd model age of 2740 Ma, again younger than the ca 3000 Ma Hf model age.

The late Neoarchaean and Palaeoproterozoic heralded a significant change in the nature of magma genesis in the PCO. Oxygen and Hf isotope data indicate that there was significant crustal reworking at this time, as is shown by more evolved and dispersed Hf signatures and elevated $\delta^{18}O$ for the ca 2530–2520 Ma basement rocks (Kukalak Gneiss and Nanambu Complex) and 1867 Ma Nimbuwah Complex. Average Hf and Sm-Nd crustal residence ages are ca 3100–3000 Ma and ca 2900 Ma for the Kulakal Gneiss and Nanambu Complex, and ca 2800–2700 Ma and ca 2600 Ma for the Nimbuwah Complex.

Nd isotope data indicate that although felsic magmatism occurred at ca 2670 Ma and ca 2530–2500 Ma in both the Central and Nimbuwah domains, there are differences in isotopic character. It may mean that these rocks do not form contiguous basement under cover across the PCO and perhaps instead indicate spatially discrete, but temporally similar episodes of Neoarchaean magmatism. However, this hypothesis would benefit from additional datasets.

Recent studies indicate significant differences in the Palaeoproterozoic tectonothermal evolution of different domains of the PCO until cessation of significant tectonism at ca 1830–1800 Ma (Carson et al. 2008, Hollis et al. 2009b).
Palaeoproterozoic strata in the Nimbuwah Domain (Cahill Formation and Nourlangie Schist) have a distinct provenance to strata of the Central Domain and the Litchfield Province. They have a significant ca 2500 Ma detrital age peak with a spread in younger ages in the range ca 2500–1900 Ma (Hollis et al 2009b). They also lack the distinctive ca 1865–1860 Ma age peak that dominates strata of the Central Domain and Litchfield Province (Worden et al 2008a, b). This indicates separate Palaeoproterozoic depocentres for the Nimbuwah Domain compared with the Central Domain and Litchfield Province (Hollis et al 2009b), which is also suggested by depth-to-basement modelling of regional magnetic and gravity data (Lewis et al 1995). Furthermore, the timing and nature of deformation and metamorphism within the PCO is different for each of the three domains. Amphibolite-facies moderate to high-P metamorphism occurred synchronously with emplacement of the Nimbuwah Complex in the Nimbuwah Domain at ca 1865 Ma. This contrasts with low-P, high-T metamorphism in the Litchfield Province at ca 1855 Ma (Carson et al 2008) and greenschist-facies metamorphism in the Central Domain at, or after ca 1852 Ma (Hollis et al 2009b).

Several authors (Needham et al 1988, Worden et al 2008a) have suggested that a previously proposed ca 2020 Ma episode of rifting of Neoarchaean basement might be responsible for the generation of the distinct Palaeoproterozoic depocentres of the Central and Nimbuwah domains (Stuart-Smith et al 1980, Needham et al 1988, Worden et al 2008b), accounting for their distinct stratigraphy (Hollis et al 2009b). The distinct isotopic signatures of Neoarchaean basement rocks in the Central and Nimbuwah Domains presented here suggest that they may not have shared a common Neoarchaean history and may represent discrete geological terranes. Alternatively, they may reflect significant chemical variation of contiguous source material that formed the Neoarchaean crust in the PCO. We stress that further data are required to assess this hypothesis.

References


REDDUCING EXPLORATION RISK AND PROMOTING EXPLORATION WITH RESULTS FROM THE PINE CREEK AIRBORNE ELECTROMAGNETIC SURVEY, NORTHERN TERRITORY.

Marina T Costelloe1,2, Mike A Craig1, Song Fa Liu1, Alan J Whitaker1, DK Hutchinson1 and Ian C Roach1

The Pine Creek airborne electromagnetic (AEM) survey (Figure 1) is the largest undertaken in the Northern Territory to date, covering an area of 74,000 km² (roughly the size of Tasmania). Funded by the Australian Government’s Onshore Energy Security Program at Geoscience Australia (GA), the survey was flown over the Pine Creek Orogen and parts of the McArthur, Victoria and Daly basins in the Northern Territory during 2008 and 2009, to enhance exploration for uranium and other mineral systems. Flight lines, spaced at 1666 m and 5000 m, were flown over the Whites, Dyson, Ranger and Nabarlek uranium deposits, and other uranium occurrences, including the recently discovered Thunderball prospect.

The Pine Creek survey comprises three survey areas: Kombolgie, east of Kakadu National Park; Woolner Granite, near Darwin; and Rum Jungle, west of Kakadu National Park. The TEMPEST fixed wing AEM system was used to acquire survey data in the Woolner Granite and Rum Jungle survey areas and these data were publicly released by GA in July and September 2009, respectively. The VTEM helicopter AEM system was used in the Kombolgie survey area and these data were publicly released by GA in December 2009.

Nine companies contributed financially to fly detailed areas at closer line spacings within the GA-funded lines. Many more industry partners provided important drillhole information, historical EM datasets and access to cased holes for essential conductivity logging. All company-infill AEM data will be released to the public domain in December 2010.

Preliminary interpretation of the data has provided subsurface information for assessing the potential of uranium mineral systems, such as sandstone-hosted, unconformity-related and vein-type deposits. Positive results include: mapping the conductive groundwater in coastal and estuarine areas; imaging through Mesozoic cover into the

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**Figure 1.** Pine Creek airborne electromagnetic (AEM) survey areas. Depths slice conductivity image (at 40 m) over 1:1 000 000 surface geology map by Geoscience Australia.
Cambrian Daly Basin; detecting mafic sills and dykes within the Kombolgie Subgroup; and mapping the unconformity at the base of the Kombolgie Subgroup and discrete conductors in the basement of the Pine Creek Orogen.

GA’s integrated approach to the interpretation of the AEM data using surface geology, solid geology, drillhole logs, gravity and magnetic observations, radiometric data and SRTM topography data has lead to an improved understanding of uranium mineral systems in this area. When utilised as a regional mapping tool, AEM data and its derivative products also have potential to reduce exploration risks for other commodities, including copper, lead, zinc, gold, tin and nickel, in both brownfields and greenfields areas.

CORONATION HILL: A COMPLEX LONG-LIVED U+Au+Pt+Pd SYSTEM

Karin Orth1,2, Garry Davidson1 and Sebastien Meffre1

Coronation Hill is a major U+Au+PGE deposit in the South Alligator Mineral Field in the Northern Territory. The deposit lies to the south of the large unconformity-style deposits of the Alligator Rivers Uranium Field, which includes Ranger, Jabiluka, Koongarra and Nabarlek (Figure 1). A total of 13 mines in the South Alligator Mineral Field produced 146,500 t of ore averaging 0.12–2.5% U3O8, including 28,850 t ore averaging 0.26% U3O8 mined from Coronation Hill between 1955 and 1964. Some gold was also produced.

Exploration in the late 1970s and 1980s by the Coronation Hill Joint Venture recognised the abundance of gold and the presence of Pt and Pd. A deposit located to the east of the old Coronation Hill uranium mine was then outlined and named as the Coronation Hill PGE deposit. In 1988, the joint venture partners estimated the reserves at 3.49 Mt @ 5.12 g/t Au, 0.21 g/t Pt and 0.56 g/t Pd, with an inferred resource of 2.85 Mt @ 7.25 g/t Au, 0.35 g/t Pt and 1.31 g/t Pd. As part of the mineral assessments for Kakadu National Park, the Resource Assessment Commission undertook a regional geological and resource appraisal for the area between 1989 and 1994 (Wyborn et al. 1990, Wyborn 1992, Mernagh et al. 1994). Despite the richness of the metal concentrations and the value of the deposit, it was not mined because the area was included in Stage 3 of Kakadu National Park in 1991.

During this study, new techniques were applied to selected drill core samples, including PIMA (Portable Infrared Mineral Analyser), HyLogger (CSIRO), Scanning Electron Microscope, Microprobe and LA-ICPMS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry) for dating, low-detection limit analysis and elemental scale mapping.

The results of the study indicate that complex, long-lived, low-temperature hydrothermal systems were involved in the formation of the Coronation Hill ore bodies.

1 Centre for Ore Deposit Research, University of Tasmania, GPO Box 252–79, Hobart TAS 7001, Australia.
2 Email: karin.orth@utas.edu.au.

Figure 1. Map of Pine Creek Orogen, showing location of Coronation Hill deposit in South Alligator Mineral Field, Alligator Rivers Uranium Field, Rum Jungle Mineral Field and other selected uranium deposits.
Kinematic and lithological controls are evident from the location of the orebodies, commonly within faults, on the brecciated margins of quartz-feldspar porphyry units and in carbonate- or graphite-rich hosts. Intense localised alteration overprints regional alteration that involved sericitisation of feldspars. The obvious alteration assemblages include orange potassium+hematite, yellow to light green illite and vein-controlled dark green chlorite, commonly spatially associated with Au. Late brick-red hematite and specular hematite developed along faults and fractures. Carbonate phases are evident and include calcite, dolomite and some siderite. Dissolution of quartz is also evident, but deep in the deposit, the Koolpin Formation carbonate is partially silicified. It is possible that the silicification is earlier and not related to mineralisation.

Interpretation of the HyLogger data by Jon Huntington (CSIRO) indicates an association between the intensity of illite alteration and the Au+PGE orebody in drillhole CHDDH049. Furthermore, a halo of possible tourmaline appears at the ore body fringes. Tourmaline was not detected during core logging and is not evident in the PIMA data from the relevant intervals, and samples from this zone are being re-assessed to determine the exact nature of the mineral assemblage.

The high-grade Au+PGE zones in CHDDH049 are co-incident with a high-grade uranium zone. The host is a breccia with abundant rhyolite and black shale clasts. Uraninite fringes breccia fragments and is scattered through the black shale clasts. It is associated with an illite matrix and late quartz overgrowths. Spaces and veins were later filled by pyrite, intergrown with Co-Ni-rich pyrite, late galena and dolomite. The late Co-Ni pyrite also hosts Ag, As, Au, Bi, Cu, Hg, Sb and Se. Variable radiometric isotope data from one sample indicate the growth of galena from radiometric Pb released from the uraninite. Younger uraninite is also present elsewhere in this sample. Another mineral associated with uraninite is abundant florencite. Despite the large size of one florencite (ca 2 cm across), it has a uniform chemical composition. Apatite is also present.

Pre-uranium pyrite is present in drillhole CHDDH100, where large early pyrite grains postdate the host diorite. Remnants of the early pyrite form islands surrounded by veins of pyrite containing Au, As, Bi, Hg, Sb and radiogenic Pb. U is also present in significant amounts in the chlorite that has altered most of the surrounding groundmass of the diorite.

Gilbert (1987) reported an association of Au, Pd and Sb minerals from samples high in the system, below the old pit. Similar minerals and mineral relationships are evident in dolomite breccia about 400 m below the surface. Nuggety Au is rimmed with Pb-selenide, identified as clausthalite, and a Pd-Sb-As mineral, probably isomertieite. LA-ICPMS analysis indicates that Pd is found throughout the Au grains and also in the surrounding minerals. The presence of the same minerals exhibiting the same relationships at the top and at depth in the deposit suggests that the same mineralising process was widespread.

Eleven breccia facies were recognised in the drillholes. The breccias range from polymeric sedimentary breccia near the base of the succession, some of which may have formed contemporaneously with basalt, to monomictic breccia on the margins of rhyolite and quartz-feldspar porphyry. The latter commonly hosts the mineralisation.

Although galena from prospects within the South Alligator Valley have been dated (El Sherana and Palette 600–900 Ma, Greenshalgh and Jeffrey 1959) and recently uraninite was dated (1573 ± 160 Ma at El Sherana, 841 ± 94 Ma at Palette; Chipley et al 2007), no dating of minerals from samples at Coronation Hill has previously been undertaken. Attempts to date zircon, uraninite, galena, pyrite, clausthalite and apatite were carried out using LA-ICPMS. The results are complex, attesting to the low-temperature character and longevity of the system. The oldest dates suggest that the pre-uranium pyrite, which appears to postdate the intrusion of the host diorite may be as old as 1800 Ma and that all the U, Au, Pt and Pd entered the system subsequently and probably synchronous with uraninite, prior to 1270 Ma. Remobilisation and growth of later pyrite, galena and uraninite seems to have occurred episodically through the Neoproterozoic.

Coronation Hill was a complex long-lived mineral system. Early pyrite, as old as 1800 Ma, postdates its diorite host and is overprinted by pyrite rich in Au, As, Bi, Hg, Sb and radiogenic Pb. Uraninite in the ore zones has a similar age, possibly as old as 1575 ± 71 Ma to uraninite from El Sherana (1573 ± 160 Ma; Chipley et al 2007). These ages overlap with the Sm-Nd age for Nabarlek and Jabiluka of 1615 ± 132 Ma (Maas 1989). Disturbances in the Pb isotope systematics are evident at 1300 Ma and 900 Ma. High-grade Au-PGE and co-incident U are hosted in black shale, black shale clasts in polymeric breccia and in fractures in monomictic quartz-feldspar-porphyry clast breccia. Late Co-Ni pyrite is associated with elevated Ag, As, Au, Bi, Cu, Hg, Sb and Se and galena, with Pb derived from the decay of the uraninite. Desilicification is associated with mineralisation, and phosphate is elevated with apatite throughout the deposit and with florencite in the high-grade zones. Au-PGE zones, which are 400 m deep and hosted in stromatolitic carbonate and carbonate breccia, have the same ore mineralogy as near-surface samples, indicating that some processes were occurring in the open systems of some fault zones. The similarity of mineralogy and the overlap in ages support the generally held view that Coronation Hill is related to the unconformity-type deposits in the Alligator Rivers Uranium Field.

Coronation Hill-style Au-PGE-U deposits could also occur where long-lived faults intersect the unconformity at the base of the McArthur Basin, or favourable felsic
volcanics within the McArthur Group. One area where this unconformity is exposed or near-surface is around the Murphy Inlier near the Queensland border, where known uranium prospects of similar age occur in the basal Westmoreland Conglomerate (Polito et al. 2005). Similarly, basement fault zones in regions once covered by McArthur Basin sandstones, such as the Pine Creek Orogen, are prospective for this style of mineralisation. One emerging means of identifying such zones during regional exploration in the NT is to study stream sediment samples for the distinctive chemistry and age of phosphate minerals. Our project is evaluating this possibility, as well as combining it with geochemical bedrock indicators that are evident in our geochemistry. This approach is particularly intended to target deposits that contain no obvious U (i.e. no radiometric response), but do have distinctive geochemical and mineralogical haloes that are being unroofed.

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HOW GEOCHEMISTRY MAPS UPFLOW IN THE RANGER U MINERAL SYSTEM: USING THIS DATA FOR EXPLORATION

James S Cleverley1,2, Louise A Fisher1, Mark Pownceby1 and Colin Macray1

The Ranger 1 No 3 deposit is an unconformity-related uranium mineral system, one of the largest in the Alligator Rivers Uranium Field. The deposit currently contains the open pit and newly discovered Ranger Deeps ore bodies, with a current reported reserve of 145 kt U3O8 at Ranger 3 pit. The deposit is hosted by the Proterozoic Cahill Schist, which is divided into several units within the mine: Lower Mine Sequence (LMS) – dolomitic carbonate rocks; Upper Mine Sequence (UMS) – chloride-rich schist; Hanging Wall Sequence (HWS) – muscovite- and biotite-bearing schist. Granitoid-gneiss of the Archaean Nanambu Complex forms the footwall to this succession. The bulk of the uranium is located along the lithological boundary between the LMS dolostone and UMS schist. The upper unconformity, between the Cahill Schist and overlying Kombolgie Sandstone, crosscuts the entire mine succession.

One of the key controversies in unconformity-related U systems is whether the fluid migrated upwards as a deep-sourced fluid, or downward as a basin-related fluid. This has big implications for the exploration model, in knowing whether one is exploring for the signals of outflow or inflow when above U mineral systems (such as exploration in the Kombolgie Sandstone). In order to assess the Ranger U mineral system, CSIRO MDU (Minerals Down Under Research Flagship) partnered with ERA in an R&D program that integrated structural analysis, 3D model building, hyperspectral logging and geochemistry. This was part of the Joint Surveys Uranium Mineral Systems Project, which is a collaboration between CSIRO, industry, NTGS and PIRSA. This talk discusses the results from the geochemical work and the implications for exploration in Ranger-style U mineral systems.

ERA have collected an extensive whole-rock geochemical dataset across the Ranger 1 No 3 system,

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1 CSIRO Minerals Down Under Research Flagship, Australian Resources Research Centre, PO Box 1130, Bentley WA 6102, Australia.

2 Email: james.cleverley@csiro.au.
which includes ca 22 000 9-element analyses and 7000 29-element analyses. This data was clustered and classified relative to the key discriminator, Mg, in the schists and carbonate rocks. Spatial plots of these classifications show a broad halo of Mg metasomatism related to chlorite alteration. The Leapfrog™ software allows us to integrate multiple datasets collected down hole, enabling us to explore 3D relationships between lithology, architecture and geochemistry. 3D models of Mg show evidence for Mg pipes extending into the schists above the main mineralised contact with the dolostones (Figure 1). These pipes are coincident with steep zones of K-depletion, and anomalous U (especially when the zones cross-cut amphibolites within the schists). S and Cu also provide evidence for steeper zones of enrichment oriented steeply from the dolostone contact.

Complete REE element analyses (from ICP-OES digest) were also completed on ca 100 samples from the Ranger Deeps system (Figure 2). The REE also show a broad zonation associated with the Mg metasomatism described previously. There, the most distal rocks (Ba-K, K) show a close-typical REE pattern relative to Proterozoic sediments, with some possible slight LREE enrichment. The dolostones are similar, although with bulk depletion in REE as expected for carbonate rocks. The ore transitional and ore rocks (Trans, Chl) show depletion in LREE and enrichment in HREE, especially dysprosium. Mass balance modelling of these data show that LREE were likely to have been stripped from the succession during the Mg-metasomatism event and these may have become concentrated in phases within the overlying Kombolgie Sandstone, especially with upflow dominating the flow regime.

In situ real-time geochemical investigation of the Ranger core was completed using an InnovX portable XRF instrument (handheld Omega). The advantage with this technique is the ability to take spot analyses of key intervals at the cm-scale, as well as representative analyses of visually logged alteration. This technique was used to investigate the chemistry of dark stylolites that are often observed in the dolostone units beneath the ore body. It showed that there were key trace element signals with minor U in these structures.

A MULTIDISCIPLINARY INVESTIGATION INTO THE MURPHY INLIER REGION

Andrew S Wygralak

The Murphy Inlier, which straddles the Northern Territory–Queensland border (Figure 1), is arguably the least studied portion of the Palaeoproterozoic North Australian Craton (NAC). Within CALVERT HILLS, this basement terrane, together with the southernmost edge of the McArthur Basin to the north and the South Nicholson Basin/Lawn Hill Platform to the south, hosts over 100 mineral occurrences, including four types of uranium deposits, copper, gold, tin, tungsten, lead, manganese and vanadium. In addition, the Westmoreland deposits, which occur in adjacent regions of Queensland, have a significant undeveloped uranium resource of nearly 22 000 t of U3O8.

The first ‘wave’ of modern exploration in the 1950s resulted in the discovery of several uranium deposits (El Hussen, Cobar II, Old Par), uranium-gold (Eva), copper (Norris) and tin (Crystal Hill), which were the subject of small-scale mining operations.

Renewed exploration interest in late 1970s/early 1980s led to discovery of numerous new uranium and uranium/gold prospects, as well as several manganese occurrences. Also during this period, microdiamonds were detected in the Coanjula area, highlighting the prospectivity of the area for diamonds.

1 Northern Territory Geological Survey, PO Box 3000, Darwin, NT 0801, Australia. Email: andrew.wygralak@nt.gov.au.
2 Names of 1:250 000 and 1:100 000 mapsheets are in large and small capital letters respectively, eg CALVERT HILLS, NICHOLSON RIVER SPECIAL.
Current exploration largely concentrates on uranium in the eastern part of the region, which is characterised by poor or non-existent outcrop. Other projects involve uranium/gold exploration at Eva Mine and advanced copper exploration at Redbank. The latest exploration indicates that previously unrecognised styles of mineralisation may exist in the Murphy Inlier region, including uranium-copper and vanadium mineralisation.

The highlights of 2009 exploration include:

**Redbank Copper Ltd**
Exploration at Redbank in 2009 confirmed the presence of four new breccia pipes, and an increase in the total resource to 6.24 Mt @ 1.5% Cu. This represents a 28% increase in total copper metal to 95 900 t. Mining is scheduled to recommence in 2010 (ASX Announcement 02/02/10).

**Bondi Mining Ltd**
Drilling at the UC19 prospect intersected anomalous uranium and copper in hole MURD002, associated with over a 100 metre-wide zone of strong hematite-chlorite alteration in a mafic intrusive within the Westmoreland Conglomerate with Cu up to 1.04% and U$_3$O$_8$ up to 107.4 ppm (ASX Announcement 02/09/09).

**NuPower Resources Ltd**
The first drilling program by NuPower at the historic Eva mine has led to significant uranium-gold intersections (ASX Announcement 15/12/09), including:

- Drillhole EV002: 7 m @ 0.79% U$_3$O$_8$, 5.69 g/t Au from 3 m and 7.5 m @ 0.59% U$_3$O$_8$, 6.18 g/t Au from 11.5 m
- Drillhole EV023: 20 m @ 0.416% U$_3$O$_8$, 5.07 g/t Au from 9 m including 4 m@ 1.26% U$_3$O$_8$, 18.32 g/t Au from 27 m
- Drillhole EV024: 27 m @ 0.77% U$_3$O$_8$, 5.10 g/t Au from 4 m including 4 m @ 1.18% U$_3$O$_8$, 4.26 g/t Au from 8 m and 4 m @ 2.24% U$_3$O$_8$, 17.72 g/t Au from 20 m.

**Southern Uranium Ltd**
A new vanadium prospect, named Vanadis, has been discovered. Sixteen samples of hematitic hydrothermal breccia from the prospect averaged 0.74% V$_2$O$_5$ and 27.7% Fe over an area of 250 m by 250 m (ASX Announcement 19/12/09).

**Current NTGS program**

Acknowledging insufficient understanding of the geology and mineral potential of the Murphy Inlier region, NTGS has embarked on a project addressing the key knowledge gaps. The project will involve 1:100k mapping of Nicholson River Special (incorporating Nicholson River and part of Benmara), structural work on relationships between the Murphy Inlier basement and surrounding younger geological units, and a reassessment of the mineral potential of the region.

Mapping of Nicholson River Special is expected to provide new geochronological and stratigraphic data, allowing better correlations with other parts of the NAC. It will also include a structural study, which will concentrate on:

- detailed mapping of faults along the basement/Westmoreland Conglomerate contact and their relationships to uranium mineralisation (initial work completed in 2009 indicates that structurally controlled uranium mineralisation may depend on the direction of faulting/jointing)
- structural mapping of the thrust contact between the basement and Westmoreland Conglomerate to establish the relative age of thrusting (there is an ‘outlier’ of horizontally bedded Westmoreland Conglomerate and Seigal Volcanics overlying the Murphy Inlier. This

**Figure 1.** Simplified geological map of the Murphy Inlier and surrounding regions derived from 1:2 500 000-scale map of the Northern Territory (Ahmad and Scrimgeour 2006) and Westmoreland (Grimes and Sweet 1979).
indicates that there was a previously unrecognised uplifting event after deposition of the Seigal Volcanics)
• studying the deformatonal history of the Murphy Metamorphics (initial observations suggest the presence of at least three cleavages)
• studying the stratigraphy of the Murphy Metamorphics, including possible correlations with the Tennant Region.

The study of the mineral potential will include the following:

• **Proving the presence or absence of a uranium-copper mineral system.** Data supporting the existence of such a system and remaining uncertainties were discussed by Wygralak et al (2009). New data shows elevated uranium (44 ppb) in a waterbore drilled in the Gold Creek Volcanics and co-existing uranium-copper mineralisation in altered basic dykes intersecting the Westmoreland Conglomerate (Bondi Mining, ASX Announcement, 02/09/2009).

• **Investigating the provenance of uranium mineralisation.** Recent discovery of aluminium phosphate-sulfate minerals, such as crandallite CaAl$_3$[(PO$_4$)$_2$(OH)$_{2n}$]$_2$(OH)$_n$, at the East Alligator River Uranium Field in the Pine Creek Orogen, indicates that the source of uranium was Archaean basement (Gaboreau et al 2005, 2007). Another mineral of the same group, Swanbergite (SrAl$_3$[PO$_4$][SO$_4$][OH]$_n$), has been discovered in the lowest part of the Westmoreland Conglomerate, just above the unconformity with the Palaeoproterozoic Clifftdale Volcanics. At this stage, it remains unanswered how this relates to the source of uranium in the Murphy Inlier region, or whether it can indicate presence of Archaean basement there.

• **Investigating the provenance of copper mineralisation in Redbank.** The provenance of copper in the Redbank breccia pipes remains unclear (Wygralak et al 2009). Copper could be either remobilised from the underlying Wollogorang Formation, or from the deeper source raising a possibility that the breccia pipes are only a near-surface expression of deeper copper mineralisation. Comparing biomarkers of the pyrobitumen matrix from mineralised breccia pipes with organic matter of the Wollogorang Formation may contribute to solving this problem.

• **Investigating potential similarities in mineralisation at the Eva and Coronation Hill deposits.** Both of these deposits contain uranium-gold (+PGE in Coronation Hill) mineralisation hosted by felsic volcanic rocks, with similar alteration styles and in proximity to high-level felsic intrusions (Crystal Hill greisen and Jim Jim Granite respectively). Do they represent a similar style of mineralisation?

• **Assessment of depth to the basement unconformity north of the Murphy Inlier.** Along its lower contact, the nearly vertical Westmoreland Conglomerate is thrust against the Palaeoproterozoic basement. Further from the contact, its dip rapidly changes to horizontal and the unconformity gradually submerges into the subsurface. Establishing the depth to the unconformity and detecting reduced rock packages in the basement may result in new plays for uranium exploration.

References


