Northern Territory Geological Survey

AGES 2009

Annual Geoscience Exploration Seminar
23–25 March 2009, Alice Springs Convention Centre, Northern Territory

Record of abstracts

Organised by the Northern Territory Geological Survey, Department of Regional Development, Primary Industry, Fisheries and Resources
Supported by Industry Development, Department of Business and Employment

RECORD 2009-002
March 2009
Minister’s foreword

Welcome to the 10th Annual Geoscience Exploration Seminar (AGES), which once again showcases the rich mineral potential of the Northern Territory.

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.

AGES is used by the Northern Territory Geological Survey as a key platform to communicate the results and significance of its targeted geoscience programs, as well as collaborative geoscience undertaken by partner organisations.

It is also an opportunity to learn about some of the exciting new developments in exploration over the past year. For the third year, through co-operation with the Department of Business and Employment, a Mining Services Expo is being held concurrently with AGES.

This year’s AGES is being held at a difficult time for the global exploration industry, with the resources sector feeling the effects of the global economic crisis. Therefore, it is more important than ever to highlight the exciting exploration potential of the Territory, and for Government to assist explorers in maximising the effectiveness of their exploration investment in the Territory.

In 2008, the Northern Territory Government expanded the Bringing Forward Discovery initiative by an additional $2.4 million over three years, to undertake a program of Geophysics and Drilling Collaborations with industry. The collaborations are designed to increase the intensity of greenfields exploration in the Territory and provides valuable funds for explorers willing to test new exploration concepts. Bringing Forward Discovery also continues to focus on new generation pre-competitive geoscience designed to lower exploration risk.

The Territory Government also has dedicated strategies to assist explorers in attracting international investment into their exploration projects, particularly from China and Japan. I encourage all explorers seeking investment in their projects to talk to my Department about how we can assist in matching their projects with international investors.

Thank you for traveling 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
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<td>5:00–6:30</td>
<td>Registration and Ice Breaker</td>
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<th>DAY 2</th>
<th>Tuesday 24 March</th>
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<tr>
<td>8:00–8:30</td>
<td>Registration</td>
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<tr>
<td>8:30–8:40</td>
<td>Traditional Welcome to Country</td>
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<tr>
<td>8:40–8:50</td>
<td>Minister Vatskalis NT Government AGES opening address</td>
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**Session 1**

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<th>Time</th>
<th>Speaker</th>
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<th>Topic</th>
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<tbody>
<tr>
<td>8:50–9:20</td>
<td>Ian Scrimgeour</td>
<td>NTGS</td>
<td>Bringing Forward Discovery update</td>
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<tr>
<td>9:20–9:40</td>
<td>Timothy Hutchins</td>
<td>NTGS</td>
<td>NT Exploration Overview 2008</td>
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<tr>
<td>9:40–10:00</td>
<td>Mr Liu Yinan</td>
<td>CCCMC</td>
<td>Chinese-Australian co-operation for minerals development</td>
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<td>10:00–10:30</td>
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<td>Morning tea</td>
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**Session 2**

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<th>Institution</th>
<th>Topic</th>
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<tbody>
<tr>
<td>10:30–10:40</td>
<td>Mazhar Khan</td>
<td>NTGS</td>
<td>Metallogenic map of the NT</td>
</tr>
<tr>
<td>10:40–11:00</td>
<td>Russell Korsch</td>
<td>Geoscience Australia</td>
<td>Onshore Energy Security Program update</td>
</tr>
<tr>
<td>11:00–11:20</td>
<td>Rob Bills</td>
<td>Emmerson Resources</td>
<td>Reinvigorating the Tennant Creek mineral field</td>
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<tr>
<td>11:20–11:40</td>
<td>Jenny Saunders</td>
<td>NTGS</td>
<td>Accessing NTGS information</td>
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<tr>
<td>11:40–12:00</td>
<td>Andy Beckwith</td>
<td>Westgold Resources Ltd</td>
<td>The Rover Project - high grade gold and copper</td>
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<td>12:00–1:10</td>
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<td>Lunch</td>
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**Session 3**

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<th>Topic</th>
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<tbody>
<tr>
<td>1:30–1:50</td>
<td>Ian Scrimgeour</td>
<td>NTGS</td>
<td>Stratigraphic and tectonic evolution of the Alligator Rivers U field: a separate terrane to the rest of the Pine Creek Orogen? (Abstracts: Hollis et al b)</td>
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<tr>
<td>1:50–2:10</td>
<td>Greg Rogers</td>
<td>ERA Ltd</td>
<td>Overview of Ranger U exploration and expansion</td>
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<tr>
<td>2:10–2:30</td>
<td>Louise Fisher</td>
<td>CSIRO</td>
<td>An integrated 3D geochemical and mineralogical model of the Ranger 3 mine</td>
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<td>2:30–3:10</td>
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<td>Afternoon tea</td>
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<th>Organization/Company</th>
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<tr>
<td>3:10–3:30</td>
<td>Steve Tatzenko</td>
<td>NTGS</td>
<td>China and Japan investment strategies</td>
</tr>
<tr>
<td>3:30–3:50</td>
<td>John Fabray</td>
<td>Western Desert Resources</td>
<td>Overview of NT Exploration Projects</td>
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<tr>
<td>3:50–4:10</td>
<td>Chris Edgoose</td>
<td>NTGS</td>
<td>Phosphate prospectivity in the NT</td>
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<tr>
<td>4:10–4:40</td>
<td>Russell Fulton</td>
<td>Minemakers Ltd</td>
<td>Overview of the Wonaraha Rock Phosphate Project</td>
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<tr>
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<tr>
<td>7:00–late</td>
<td>Dennis Gee, Chairman, Torrens Energy</td>
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### DAY 3 Wednesday 25 March

#### Session 1

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<tbody>
<tr>
<td>8:50–9:10</td>
<td>Alan Holland</td>
<td>Titles Division, NT Government</td>
<td>Mining Act Review, Geothermal Legislation and Land Access</td>
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<tr>
<td>9:10–9:30</td>
<td>Andrew Wygralak</td>
<td>NTGS</td>
<td>Geology and mineral potential of Murphy Inlier region</td>
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<tr>
<td>9:30–9:50</td>
<td>Karin Orth</td>
<td>NTGS / CODES</td>
<td>Geochemistry and alteration of Palaeoproterozoic felsic and mafic volcanic successions at Calvert Hills</td>
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<tr>
<td>9:50–10:10</td>
<td>Ian Mulholland</td>
<td>Rox Resources</td>
<td>The Myrtle Zinc Deposit: An Exploration Case History</td>
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<td>Morning tea</td>
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#### Session 2

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<tr>
<td>10:40–11:00</td>
<td>Jo Whelan</td>
<td>NTGS</td>
<td>Magmatism in the eastern Arunta Region; implications for Ni, Cu and Au mineralisation</td>
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<tr>
<td>11:00–11:20</td>
<td>Jim McKinnon-Mathews</td>
<td>Mithril Resources</td>
<td>Blackadder goes forth: Nickel sulfides in the Irindina Province</td>
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<td>NTGS</td>
<td>Deep seated structures and mineralisation in the Arunta Region</td>
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<td>11:40–12:00</td>
<td>Jon Clauvé-Long</td>
<td>Geoscience Australia</td>
<td>Proterozoic Ni-PGE exploration: mafic-ultramafic magmatic events in the NT</td>
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<tr>
<td>12:00–12:50</td>
<td>Lunch</td>
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#### Session 3

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<tr>
<td>12:50–1:10</td>
<td>Roger Clifton</td>
<td>NTGS</td>
<td>Calibration and thresholding of NT radiometric data</td>
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<tr>
<td>1:10–1:30</td>
<td>Stephan Stander</td>
<td>Cameco</td>
<td>Presentation on the Angela Project</td>
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<tr>
<td>1:30–1:35</td>
<td>Ian Scrimgeour</td>
<td>NTGS</td>
<td>Closing remarks</td>
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- *Close of technical sessions*

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<thead>
<tr>
<th>Time</th>
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<tr>
<td>1:35–2:00</td>
<td>Afternoon tea</td>
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<tr>
<td>2:00–3:30</td>
<td>Workshop on Statutory Reporting and Titles Management</td>
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End AGES 2009
AGES 2009 sponsors

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emmerson resources
BRINGING FORWARD DISCOVERY

Ian Scrimgeour

During 2007/08, a record $132 million was spent on mineral exploration in the Northern Territory. However, as a result of the global economic crisis and resultant downturn in the resources industry, we now face a challenge to ensure that the Territory maintains or increases its share of Australian exploration expenditure during the current downturn, and that it is well placed to see numerous projects come into development as metal prices recover.

The Territory’s prospectivity for commodities such as phosphate, uranium, rare earths and gold, which are projected to maintain relatively strong prices in the short term, bodes well for the Territory’s ability to sustain a healthy exploration industry. Furthermore, the Territory Government, through the Northern Territory Geological Survey, is committed to programs designed to ensure that the Territory remains an attractive place to explore.

Significant potential exists for greenfields discoveries in the Northern Territory, 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. Recent undercover exploration successes, such as in the Rover field southwest of Tennant Creek, are testament to the prospectivity of this buried basement. Furthermore, recent new discoveries of outcropping copper and nickel-copper mineralisation southeast of the Harts Range indicates that discoveries can still be made in outcropping areas of the Territory.

The Northern Territory Geological Survey, through the NT Government’s four-year, $14.4 million Bringing Forward Discovery initiative, is committed to assisting explorers in unlocking the greenfields potential that exists over much of the Territory. We do this through a combination of the following:

• Providing high-quality new geoscience, including getting teams of geologists on the ground in under-explored areas.
• Acquisition of major new regional gravity datasets to assist in 3D interpretation of the Territory’s geology.
• A new program of collaborative funding of exploration geophysics and drilling in greenfields areas.
• Assisting companies in attracting international investment in their greenfields exploration projects.

In May 2008, the Northern Territory Government announced a major expansion to the Bringing Forward Discovery initiative, with the announcement of 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. The overriding selection criterion is that projects should have the potential to stimulate a new generation of mineral discoveries and further enhance the Northern Territory’s mineral prospectivity and exploration investment opportunities. Information gained from these collaborative drilling programs will be 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.

Exploration programs under Round 1 of the Geophysics and Drilling Collaborations, for the 2008/09 financial year, are now in progress. A total of 28 applications were received from 22 companies; these were assessed by a panel comprising senior representatives of the Northern Territory Geological Survey and independent representatives of industry and the Department of Chief Minister. Eleven projects were successful in receiving funding (Figure 1). Given the late start to the program and flooding across large areas of the Territory this wet season, most programs for 2008/09 are only just getting underway.

A call for applications has now been made for the second round of Geophysics and Drilling Collaborations, for projects to be undertaken in the 2009/10 financial year. The closing date for applications is April 17, and an announcement of successful applicants will be made by the end of May. Guidelines and further information on the program can be viewed at www.minerals.nt.gov.au/collaborations.

Drilling applications with a higher probability of success include those that target basement in areas of thick cover and where there is little or no known mineralisation. Applications targeting new mineralisation concepts in greenfields areas are also viewed favourably. Geophysical surveys will only receive funding if they are regional in extent and have the potential to assist in regional prospectivity assessments. Applications that are unlikely to receive funding include drilling programs targeting extensions or infills of previously drilled mineralisation, and prospect-scale geophysics aiming to define the extent of known mineralisation.

Under the Bringing Forward Discovery initiative, NTGS is also embarking on a major campaign of regional gravity acquisition, to complement the Territory’s near-complete magnetic and radiometric coverage. The 2008 Central Arunta gravity survey is complete, with all data now publicly available. This survey involved the acquisition of over 12 000 gravity stations over an area of 150 000 km² of central Australia, and has revealed important new information on major structures in the Arunta Region. A number of exploration companies

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1 Director, Northern Territory Geological Survey, GPO Box 3000, Darwin NT 0801. Email: ian.scrimgeour@nt.gov.au.
Figure 1. Map indicating the location of ELs for successful applications for Round 1 of the Geophysics and Drilling Collaborations under Bringing Forward Discovery.
Figure 2. Index of NTGS’s current and proposed gravity surveys.
contribute funds to infill parts of the survey, improving the resolution of the survey from 4 km-spaced grids down to 2 or 1 km-spacing. The next gravity survey, to be undertaken in 2009, will be the Barkly survey, which will cover a vast area of the central Georgina Basin, Murphy Inlier and southern McArthur Basin, largely on a 4 km-spaced grid (Figure 2). A 2 km-spaced survey over the poorly outcropping Litchfield Province (western Pine Creek Orogen) is also planned for 2009/10.

A major focus for NTGS continues to be the provision of high-quality new geoscience to provide new geological frameworks and baseline geochemistry over under-explored terranes. Since 2000, NTGS has been undertaking major programs in the Arunta Region, which have revealed the prospectivity of areas that were previously poorly understood and under-explored. This is also leading to a vastly improved geological framework for this complex region, which will allow explorers to be more predictive in their regional analysis and area selection. In areas such as the Warumpi Province, Casey Inlier and eastern Arunta Region, NTGS geoscience has led to the opening up of new areas for exploration, and the discovery of promising new prospects.

In the eastern Pine Creek Orogen, which is an area that has seen a higher intensity of past exploration, NTGS geoscience is still adding major value, with a fundamental revision of the regional geology (Hollis et al. 2009a, b, Glass et al. 2009), which has major implications for explorers. NTGS is also active in the Georgina Basin and Murphy Inlier area, and will be increasing its focus on understanding the underexplored geology beneath the shallow basins that cover much of the central parts of the Territory. NTGS has a policy of continuous disclosure of information during the course of projects, and the ongoing release of new geochemistry and site data can be a valuable resource to explorers in areas with a paucity of historical data.

NTGS has also committed under Bringing Forward Discovery to a continuous improvement in our delivery of geoscience data, particularly online. By the end of the initiative, we aim to have all NTGS text products, plus open file company reports available for immediate download over the web.

Finally, we are dedicated to assisting NT companies in attracting international investment for greenfields exploration programs. Through the China Investment Attraction Strategy, and a similar program targeting Japanese investment, the Department has facilitated contacts between Australian explorers and Chinese and Japanese companies that has already seen millions of dollars committed in expenditure for greenfields exploration in the Territory.

Given the relative difficulty that now exists for companies to raise funds for exploration, NTGS will be working with industry to lower exploration risk, fund innovative exploration and assist in investment attraction, to ensure that the Territory remains an attractive place to undertake greenfields exploration and discover new resources.

References


NT MINERAL EXPLORATION OVERVIEW 2008

Tim Hutchins1, 2 and John Dunster1

Exploration expenditure

Australian mineral exploration spending in 2007/08 rose by 41% to $2448 million. (an increase of almost $750 million on 2006/07, Figure 1). This increase can probably be attributed to China’s demand for Australian resources and increases in the cost of exploration. Only 40% of this total was spent on greenfields exploration. Western Australia and Queensland have traditionally attracted the largest proportion of the total exploration expenditure in Australia, by virtue of their size and their endowment in geologically prospective provinces, but South Australia has caught up significantly. In 2007/08, exploration expenditure in the Northern Territory moved slightly ahead of Victoria, but it remains behind New South Wales and South Australia, all of which were understandably ahead of Tasmania. The Northern Territory is working to redress this imbalance.

1 Northern Territory Geological Survey, GPO Box 3000, Darwin NT 0801.
2 Email: timothy.hutchins@nt.gov.au
and claw back to its previous best position of 10% of total exploration expenditure in 1990, from its present Australian market share of around 6% (Figure 2).

Tenement situation

At the end of 2008, 32% of the Northern Territory landmass was covered by 1152 granted exploration titles and 42% was under application. This is slightly less than last year, but is still five times the 2003 low. The number of grants per year is still at record levels, as is the total area under exploration titles. The Department is monitoring and encouraging the turnover of ground in all of the important geological provinces and that situation is also slowly improving (Figures 3, 4).

Exploration update

The exploration and mining highlights for calendar year 2008 are described below in terms of commodity.

Gold

GBS Gold International Inc filed an updated independent technical report on the mineral resource estimate for the Toms Gully gold project in the Pine Creek Orogen of the Northern Territory. This resource estimate comprises an indicated resource of 1 276 000 t at 8.4 g/t for 346 000 ounces of gold and an inferred resource of 592 000 t at 7.4 g/t for 140 000 oz of gold. At the Cosmo Deeps underground gold mining project, the company identified an initial probable reserve of 2.2 Mt at 5.0 g/t

Figure 1. Annual mineral exploration expenditure in the Northern Territory. At $132.7M, 2007/08 exceeded the previous 1995/96 record.

Figure 2. Mineral exploration expenditure by Australian jurisdiction, excluding western Australia.
for 350 000 oz of contained gold. The mineral reserve estimate was drawn from an indicated resource base of 4.2 Mt at 4.9 g/t Au (containing 670 000 oz), and an inferred resource of 4.5 Mt at 3.9 g/t Au (containing 570 000 oz). Drilling in the Fountain Head open pit concentrated on the deeper Tally Ho lodes. This drilling defined additional ore material with potential to extend the open pit mine life. The resource estimate for the Chinese "big pit" area now comprises an indicated resource of 7.2 Mt at an average grade of 1.7 g/t for 387 000 oz of contained gold, plus inferred resources of 2.9 Mt at 1.6 g/t for 151 000 oz of contained gold. The planned "big pit" area is approximately 3 km long and 450 m wide, encompassing the Chinese 1, 2 and 3, Chinese South and Big Howley historic open pits. The area also incorporates GBS Gold's previously reported Chinese South Extension and Mottrams deposits. A second ball mill in the Union Reefs plant was successfully commissioned in December 2007, providing further processing flexibility. In addition to the 25 590 oz Au produced, at the end of the December quarter, approximately 3700 oz of gold were contained in ore stockpiles at the Union Reefs plant ready for processing. Gold production increased by 34% to 3259 oz for the June 2008 quarter from the milling of 622 100 t of ore at an average head grade of 1.9 g/t and a processing recovery of 93.1%. Ore was sourced from the Brocks Creek underground mine, the Fountain Head and Chinese "big pit" area open pits and from historic low-grade stockpiles. GBS Gold reported a net loss of $A6.5 million in the last quarter of 2008, despite a 34% increase in gold production, and the company went into administration in October 2008.

At Tennant Creek, Emmerson Resources Ltd work continued at West Gibbet, Golden Forty and the Analytic prospect where a significant high-grade intercept was received including: 24 m @ 6.27 g/t Au and 3 m @ 48.3 g/t Au. Also in the Tenant Creek area, Excalibur Mining Corporation Ltd drilled at Nobles Nob and Rising Sun and Truscott Mining Corporation Ltd continued work at Westminster.

In the Rover Field, 100 km southwest of Tennant Creek, Westgold Resources Ltd commenced diamond drilling at the advanced Rover I (Au-Cu-Co) Prospect. The second drillhole returned bonanza gold and associated copper, cobalt, bismuth and silver mineralisation within well developed sub-vertical ironstone formations. Results included: 65.75 m @ 11.0 g/t Au, 0.75% Cu, 0.09% Co, 0.15% Bi and 2.5 g/t Ag from 492 m (65.75 m @ 17.7 g/t Au equivalent), including 11.0 m @ 18.3 g/t Au from 515 m and 15.75 m @ 29.4 g/t Au from 541 m. Also in the Rover Field, Adelaide Resources Ltd continued work at Rover 4.

**Copper-Lead-Zinc**

Copper production at Redbank Mine by Redbank Mines Ltd recommenced during May 2008 with the treatment of available high-grade stockpiles at a rate of 50 to 60 t of contained copper per month. The total inferred and indicated JORC-compliant resource is 5.2 Mt of oxide and sulfide at 1.4% copper for 75 000 t of contained metal. Exploration on the Copperado JV has identified a mineralised breccia pipe similar in scale to the larger pipes of the Redbank area. Field analyses with a Niton XRF analyser found that 0.3 to 0.8% copper was widespread in surface material in and around the pipe and identified a small high-grade vein of copper mineralisation with 18% copper.

Compass Resources Ltd commissioned the new Browns Project mill and copper electro-winning commenced at the oxide plant. Compass Resources shipped their first copper cathode from Browns during 2008, although production has currently halted and Compass Resources is now in receivership. The Area 55, Mount Finch and Browns East prospects were also drilled by Compass Resources during 2008.
Figure 4. Granted and relinquished exploration titles for the 2008 – 2009 fiscal year.
TNG Ltd announced a major increase in the total JORC mineral resource inventory for the Manbarrum Lead-Zinc-Silver Project to a combined polymetallic resource of 35.9 Mt of Pb, Zn and Ag. The upgraded resource inventory comprises a substantial increase in the mineral resource for the Sandy Creek deposit to 15.97 Mt grading 2.3% Zn+Pb and 5.4 g/t Ag and a maiden resource estimate of 19.9 Mt @ 16.4 g/t Ag for the Djibigtun Prospect.

Westgold Resources Ltd has announced a maiden JORC-compliant mineral resource estimate for the Explorer 108 (Zn-Pb-Ag) deposit in the Rover field. The total identified mineral resource estimate is 8.7 Mt @ 5.6% combined Pb and Zn, 20 g/t Ag, 0.3 g/t Au, using a lower cut-off grade of 2.5% combined Pb+Zn.

Rox Resources Ltd has announced significant zinc-lead mineralisation at the Myrtle prospect in the McArthur Basin. Following a drilling program in 2008, Rox Resources announced a maiden inferred mineral resource of 38 Mt @ 4.2% Zn and 1.0% Pb (5.2% combined Zn+Pb).

Drilling by Bulman Resources Pty Ltd on MLNs 726 and 727 (26 RC holes for a total of 255 metres) and EL 23814 (15 RC holes for a total of 415 metres) at Bulman in the McArthur Basin was completed during June-July 2008. The holes intersected zinc-lead mineralisation hosted by dolomitic and calcareous sediments above an intrusive dolerite contact. Drillhole BEL0001 intersected 3 m @ 11.63% Zn and 5.02% Pb from 15 m. Intersections of mineralisation within the historic MLNs are highly variable and range from 3 to 11 m @ 0.16% Zn to 8 m @ 2.20% Zn and 3 m @ 0.49% Zn.

Emmerson Resources Ltd intersected significant copper at Peko East, including: 3 m @ 4.01% Cu and 6 m @ 1.32% Cu.

Nickel

Further results from rock chip sampling of the Blackadder Prospect have returned high-grade nickel and copper values, along with anomalous values of cobalt, platinum and palladium. Mithril Resources Ltd has reported that two new nickel prospects have been identified on the company’s Huckitta project. The new prospects are Baldrick, located on the Treasure JV tenement and Edmund. At Baldrick, a rockchip sample returned assay values of 0.78% Ni, 23.2% Cu, 0.8 g/t Pt+Pd+Au and 25.5 g/t Ag. At the Edmund prospect, analytical results returned values up to 3.8% Cu, 488 ppm Ni, 0.16 g/t Pt+Pd+Au and 6.6 g/t Ag.

Tin-Tungsten

Segue Resources Ltd completed field work at the Coronet Hill tin and tungsten Project. Historical small-scale mining has identified massive sulfide mineralisation with significant silver and copper content. This ore also contains significant arsenic (20–30%).

Outback Metals Ltd A$2.6 million exploration program commenced on the 10th August 2008, with the mobilisation of an RC drilling rig to the Mount Wells tin and copper project, located approximately 200 km south of Darwin. The first 26 drillholes of the proposed 55 hole program (4000 m) have been completed. Highlights so far include: 3 m @ 7.13% Sn, 5 m @ 6.53% Cu and 2 m @ 1.47% W in separate holes.

Washington Resources Ltd announced that it had been conducting tungsten exploration at its Kurundi Project, 80 km south of Tennant Creek. Shallow drilling demonstrated widespread mineralisation, with the best intersection exceeding 0.5% tungsten oxide.

Thor Mining PLC announced results from its Hatches Creek Project, located around 160 km southeast of Tennant Creek. Results of up to 7.24 ppm Au and 13.3% W were recorded from rock chip and dump samples.

Manganese

OM Holdings Ltd updated the mineral resource and ore reserve estimates for its Bootu Creek Manganese Mine. Ore Reserves increased by 3.1 Mt or 43% to 10.3 Mt at 24.5% Mn with significant increases achieved at the Chugga South and Tourag deposits. Mineral resources (including ore reserves) increased by 1.85 Mt or 12% to 17.75 Mt at 25.7% Mn. Life-of-mine planning supports a mine life of 8.5 years at a production rate of 700 000 tpa.

Drilling at the Rosie Creek South Prospect in the McArthur Basin by Sandfire Resources NL has confirmed the widespread existence of manganese mineralisation.

Iron

In 2009, Territory Resources intends to upgrade its Frances Creek crushing and processing facility to boost capacity and throughput. The upgraded plant will assist the mine in achieving its production target of 3 Mtpa by June 2009.

Results from rock chip sampling by Western Desert Resources at the Roper Bar iron ore project varied from 33.2% to 56.6% Fe.

Reconnaissance rock chip sampling at the Manbarrum Project in the Bonaparte Basin by TNG Ltd resulted in the continuation of high-grade haematite iron mineralisation from the Legune Prospect with low levels of phosphorus and silica.

Uranium

Energy Resources of Australia Ltd (ERA) drilled the lower mine sequence at Ranger 3 deeps; this has extended the life of the Ranger Mine by six to seven years.

Energy Metals Ltd, as manager of the Biglryi JV, announced the results of an in-house updated scoping study at the Biglryi uranium and vanadium project. An initial
scoping study estimated an increased in the resource from 8.4M lb to 16.2M lb (up 93%). The vanadium content of the resource increased from 7.0M lb to 14.5M lb (up 107%), and the possible mine life increased from eight to twelve years, with improved plant utilisation. A new estimate, based on 2007 drilling and assay results, has doubled the JORC-inferred resource estimate for the Napperby uranium project from 1.47M lb to 3.13 M lb of uranium oxide.

Uranium Equities Ltd has been actively exploring the Twinbarleek and N147 prospect areas throughout 2008 in a 60/40 JV agreement with Cameco Australia Pty Ltd. Significant drill intersections from N147 included 36 m @ 0.17% U₃O₈ and 15 m @ 0.22% U₃O₈. Atom Energy Ltd has announced a resource estimation on the Twin and Dam deposits within the Cleos uranium project in the Pine Creek Orogen. The inferred resource at a 100 ppm U₃O₈ cut off is summarised as: Twin – 824 000 tonnes grading 316 ppm U₃O₈; Dam – 585 000 tonnes grading 286 ppm U₃O₈; total 1 409 000 t grading 304 ppm U₃O₈.

A Paladin Energy Minerals NL and Cameco Australia Pty Ltd JV was selected to develop the Angela and Pamela uranium deposits near Alice Springs.

Diamonds
North Australian Diamonds Ltd increased its JORC resource for the Merlin diamond mine at various stages throughout 2008 after numerous drilling programs. They are now targeting a 400 000 ctpa operation.

Rare Earths
Arafura reported a major new discovery of strong phosphate-rare earths mineralisation at their Nolans prospect located between the current north and south resource zones. Assays, confirming substantial intervals of rare earths-phosphate-uranium mineralisation, have now been received. Best results include: 20 m at 6.3% REO 28.5% P₂O₅ 1.1 lb/t U₂O₆ from 26 m in drillhole NBRC172, 54 m at 5.0% REO 25.4% P₂O₅ 0.7 lb/t U₂O₆ from 55 m in drillhole NBRC363, 72 m at 4.0% REO 20.8% P₂O₅ 0.6 lb/t U₂O₆ from 61 m in drillhole NBRC365. This discovery is likely to significantly increase the current resource base. A shortfall in supply for higher-value rare earths in the medium to long term (Nd, Pr, Dy, Eu, Tb) means that Nolans is well placed relative to other REE deposits worldwide.

Phosphate
Minemakers Ltd have defined new resource estimates for their Wonarah and Arruwarra prospects in the northern Georgina Basin, which together are the largest undeveloped phosphate deposits in Australia.

Uramet hold prospective phosphate ground in the Georgina Basin at Marquya near the Queensland border. Phosphate Australia Ltd has received a second batch of drilling results from its Highland Plains phosphate project in the Georgina Basin. The best intersection was from aircore hole HAC020 – 11 m @ 27.2% P₂O₅ from 4 m, including 6 m @ 30.2% P₂O₅ from 5 m.

The Board of Directors of Korab Resources Ltd has received several expressions of interest in respect of Korab’s 100% owned GeoSec rock phosphate deposit, located 65 km south of Darwin in the Pine Creek Orogen. Recent diamond drilling assay results include: DDH6–37.2% P₂O₅ over 6.9 m from 7.1 m to 14 m, DDH1–20.36% P₂O₅ over 7.6 m to 21 m.

Nolans, operated by Arafura Resources, has phosphate derivatives from its resource measured at 13.5% P₂O₅.

Coal
Central Petroleum Ltd intersected coal in EP 93 in the Pedirka Basin. Coal intersections occurred over an interval exceeding 100 m in thickness and at varying depths below 600 m and were found in each of the petroleum/coal bed methane wells, Blamore-1 and CBM 93-01. Central Petroleum describes the coal intersections in these two wells as significant, and has stated that “…diagnostic seismic signatures in the general area are representative of a widespread coal resource at various depths covering approximately 9000 km² of EP 93.”

Reference
Some material here was sourced from Australian Stock Exchange announcements. The Department of Regional Development, Primary Industry, Fisheries and Resources maintains a database of Exploration News for the Northern Territory. This can be accessed from [http://apps.minerals.nt.gov.au/explornews/](http://apps.minerals.nt.gov.au/explornews/)

THE 1:2.5M METALLOGENIC MAP OF THE NORTHERN TERRITORY

Mazhar Khan1, 2, Masood Ahmad3 and Andrew Wygralak1

A Metallogenic Map is “A map, usually on a regional scale, on which is shown the distribution of particular assemblages or provinces of mineral deposits and their relation to such geological features as tectonic trends and petrographic types.” Bates and Jackson (1987)

The recently released Metallogenic Map of the NT is an extension of the Mineral Occurrence Database (MODAT) for the Northern Territory. This database currently has 3000 records and each record contains linked tables that collectively provide information on all the mineral deposits and occurrences of the NT including location, status, shape, ore deposit model, etc.

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origin, exploration methods, structure, ore and gangue minerals, alteration, stratigraphy, production, reserves, size and important references.

The Metallogenic Map of the NT shows the spatial distribution of various types of mineral deposits, as well as their shape, size, orientation, deposit type, origin and their relation to broad stratigraphic subdivisions, lithology and structure.

The first step in the preparation of the metallogenic map was to establish a 1:2.5M generalised lithostratigraphic base map. This map was compiled mainly using the 1:2.5M geological map of the Northern Territory (Ahmad and Scrimgeour 2006). The base map was generalised to show eight major lithological types: arenite/quartzite, argillite, carbonate, gneiss/schist, felsic volcanic rocks, granite/gneiss, mafic volcanic rocks and mafic intrusive rocks. Different colours were assigned to each lithological type (eg blue for carbonate rocks, green for mafic volcanic rocks etc) and colours were shaded to show the age of the lithology (ie, the darker the colour the older the strata).

The size of the mineral deposits was based on the amount (production plus reserves/resources) of a particular mineral commodity. This classification was determined in 1987 for the 1:250 000 metallogenic map of Calvert Hills and it was also used for the 1:250 000 metallogenic map of Pine Creek in 1993. The size classification is loosely based on equivalent commodity price. Although size classification for most of the commodities is still the same, class values for some of the commodities have been changed according to the 1:1M Metallogenic Map of the Republic of South Africa (Martini et al 2000).

All the MODAT records have been plotted on the base map, but only small, medium and large mineral deposits show information regarding orebody shape, origin, orientation and status (Figure 1). The size of the enclosing circle reflects the size of a particular deposit. Although small mineral occurrences are plotted on the map as small circles they only show information about their location and commodity. Various colours are assigned to the major commodity types present in the NT; white is universally assigned to less common commodities. The orebody shape and origin are shown by nine different symbols (Figure 2). The direction of the ore body shape symbol shows the orientation of the deposit.

Some details on small, medium and large deposits are given on the left side of the map. In some cases, several adjacent deposits which could not be plotted separately are shown by one symbol. For example, this is generally the case with Sn-Ta-bearing pegmatites in the Bynoe region, where over two hundred occurrences are currently known.

Due to the close proximity of mineral deposits in the Pine Creek, Tennant Creek and Rum Jungle regions insets for these areas have been incorporated into the mapface for greater clarity.Insets for the Pine Creek and Tennant Creek areas are 1:1 000 000 scale, whereas the inset for the Rum Jungle area is 1:500 000 scale.

References


EXPLANATION OF DEPOSIT SYMBOL

- Circle diameter indicates size of deposit
- Colour indicates principal commodity
- Shape, morphology and orientation of deposit
- Colour indicates principal commodity
- Map reference number

The above example represents a NE-striking stratiform zinc deposit, classified as a Large deposit. The map reference number 119 identifies this deposit in the List of Significant Mineral Deposit as McArthur River.

**Figure 1.** Explanation of mineral deposit symbols from 1:2 500 000 Metallogenic Map of the Northern Territory.

DEPOSIT SHAPE AND ORIGIN

- Irregular / Metasomatic
- Pegmatite
- Pipe / Hydrothermal / Magmatic
- Placer
- Stratiform / Sedimentary / MVT
- Stratiform / SEDEX
- Surficial / Residual / Pedogenic
- Vein / Hydrothermal
- Unconformity U

*Note there is no orientation for irregular, pipe, placer and surficial groups of deposits.

**Figure 2.** Symbols for ore body shape and origin from 1:2 500 000 Metallogenic Map of the Northern Territory.
GEOSCIENCE AUSTRALIA’S ONSHORE ENERGY SECURITY PROGRAM IN THE NORTHERN TERRITORY: CURRENT RESULTS AND FUTURE DIRECTIONS

Russell Korsch1,2, Paul Henson1, David Huston1, Alan Whitaker2, Chris J Carson3, Roland Maas3 and Kelvin Hussey4

As part of its Energy Security Initiative, the Australian Government allocated Geoscience Australia $59 million in August 2006, to undertake a five-year Onshore Energy Security Program. This is designed to deliver precompetitive geoscience data and scientifically based assessments to reduce the risk in exploration for onshore energy resources, including petroleum, uranium, thorium and geothermal energy. The program, some of which is outlined below, is being conducted in collaboration with the State and Territory geological surveys and is scheduled for completion in June 2011. A range of new data are being acquired to better define the geology in energy-prospective areas.

Acquisition of seismic and magnetotelluric data in the NT

A deep seismic reflection line, oriented approximately north–south for 635 km next to the Adelaide–Darwin railway line, was designed to image the whole of the crust and was acquired in late 2008. Approximately 85 km of this line was acquired across the southernmost Amadeus Basin and Musgrave Province in the Northern Territory, and the line continued into South Australia to also image the eastern Officer Basin and northern Gawler Province. A new deep reflection seismic line, also oriented north–south, is currently being planned to image the eastern Arunta Region and Georgina Basin.

An east–west seismic line across the western Pine Creek Orogen is also in the planning stage. Where possible, magnetotelluric data to image the whole of the crust will be collected in conjunction with the seismic data acquisition.

AEM (Airborne Electromagnetic) survey in the NT

The Pine Creek AEM survey area is directed at providing a new geophysical and geological context in areas prospective for unconformity-style uranium deposits. The survey area includes Archaean to Palaeoproterozoic basement and cover rocks east (VTEM survey) and west (TEMPEST survey) of Kakadu National Park, and from just west of Darwin, south to Katherine (Figure 1). The prime objectives of the survey include mapping the subsurface unconformities between metamorphic rocks of the Pine Creek Orogen and overlying Kombolgie Subgroup, and between the Finniss River Group and overlying Tolmer Group. Additional objectives include the mapping of the distribution of basement-hosted graphitic schist, the location of palaeochannel sediments and the thickness of regolith cover.

Eleven companies/organisations, including the National Water Commission, are paying for infill of the regional lines acquired by Geoscience Australia (regional line spacing of 5 km and 1.66 km). The infill data will remain confidential for twelve months, whereas the regional data will be released as soon as they have undergone appropriate quality checks. At this point in time, about 75% of the approximate 30 000 line km of surveying have been acquired. The remaining acquisition will be undertaken between March and June this year. The project has acquired data on nearly 2500 drillholes, and carried out conductivity logging of 25 exploration holes or water bores. These data will be used to review the inversion of the acquired airborne data to conductivity with depth, and will be incorporated in the interpretation of results, scheduled for the second half of 2009.

3D geological map of the onshore Carpentaria Basin

The onshore Carpentaria Basin (formerly Dunmarra Basin), in the northern part of the Northern Territory (Figure 2), consists of a relatively thin, undeformed succession of poorly exposed Jurassic to Cretaceous sandstone and shale, deposited in a marine to fluvial environment. The stratigraphy and basin architecture are poorly known. The onshore Carpentaria Basin overlies Cambrian shallow-marine carbonate and siliciclastic sedimentary rocks of the Daly Basin, and basalt intersected in drill core at the base of the Cambrian succession is correlated with the Antrim Plateau Volcanics. The basement to the Cambrian succession is not well understood, but could include Palaeoproterozoic to Mesoproterozoic sedimentary and metasedimentary rocks equivalent to the Victoria, Birrindudu and McArthur basins, and Tennant Region.

The onshore Carpentaria Basin currently is the focus of uranium exploration, both for unconformity-style mineralisation and for sandstone-hosted uranium, with the Pine Creek Orogen representing a potential uranium source. However, this exploration is hampered by a poor understanding of the geometry of the regional unconformities and stratigraphy, which would have played an important role in guiding fluid flow and creating redox boundaries. The northeastern part of the basin is coincident with a positive thermal anomaly, evident in an estimated crustal temperature image of Australia. In this

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area, the thickness and composition of the sedimentary succession and the depth of the heat producing rocks are important aspects of the geology that remain largely unknown.

A three dimensional (3D) digital data project was set up to collate and visualise digital data collected from the onshore Carpentaria Basin area, in order to further understand the geology and structures, including its potential mineral and geothermal prospects. A 3D geological map of the base of the basin and major surfaces within it would allow models for fluid flow to be better evaluated. Data were sourced from the Northern Territory Geological Survey and Geoscience Australia, in various digital formats. These data included six seismic lines, drillhole, water bore and petroleum well information, magnetic and gravity images, and geology maps. From these raw data, numerous GoCAD point sets, grids, surfaces, curves, wells and voxets were created to best represent these data in 3D space. The main objects created were: a digital terrain model (DEM) surface, and surfaces to represent the tops of the Cretaceous, Upper Cambrian, Middle Cambrian, Lower Cambrian, and Proterozoic layers, as picked in the drillholes and wells. The GoCAD project has been left in a state where more digital data can be added to it, or the GoCAD objects can be saved in other

Figure 1. Map showing areas in Pine Creek Province to be covered by AEM data acquisition.
AGES 2009

Digital formats to allow them to be displayed in other 3D software if required.

**Geochronology in Birrindudu and Victoria basins**

The stacked Birrindudu and Victoria basins cover a wide area of the western Northern Territory, and have a combined original thickness of up to 8 km, deposited between the Palaeoproterozoic and Neoproterozoic. Diagenetic xenotime from the base of the Birrindudu Basin has an age of 1632 ± 3 Ma (Vallini et al. 2007), whereas volcanic rocks higher in the succession (Limbunya Group) have yielded ages of ca 1640 Ma (Cutovinos et al. 2002), indicating that sedimentation in the Birrindudu Basin took place at a similar time to uranium mineralisation in the Pine Creek Orogen. There are few timing constraints for the Victoria Basin, the bulk of which was previously considered to have been deposited between 1610 Ma and 1570 Ma. The Auvergne Group near the top of the succession was considered to have been deposited between ca 850 Ma and ca 730 Ma. SHRIMP U-Pb zircon geochronology has been carried out to better constrain the timing of sedimentation. There are few potential chemically reducing units in the Birrindudu Basin, but the Victoria Basin does contain thin black carbonaceous shale units and hydrocarbons in places. Identification of coincident reductants and basement-tapping faults could identify areas that may be prospective for a variant of the Westmoreland-style of uranium mineralisation.

Preliminary U-Pb SHRIMP zircon geochronology, undertaken by Geoscience Australia as part of its Onshore Energy Geodynamic Framework project, is starting to provide time constraints for the ages of the stratigraphic successions. An initial result from the basal Stirling Sandstone (Limbunya Group – Birrindudu Basin), which unconformably overlies metamorphic basement, provides a maximum depositional age of ca 1830 Ma, and suggests a possible correlation to other sandstones that form part of the North Australian platform successions (e.g. Depot Creek Sandstone, Tolmer Group and Kombolgie Sandstone – McArthur Basin), and hence is relevant for uranium exploration. Many units in the Limbunya and Wattie groups (ca 1640–1610 Ma) appear to represent time equivalents of units in the southern McArthur Basin and Lawn Hill Platform in the Mount Isa region, although further work is needed to fully assess potential correlations. Near the top of the Victoria Basin, new geochronology from the basal part of the Jasper Gorge Sandstone (Auvergne Group) suggests a possible correlation with sandstones from the base of the Centralian Superbasin (Heavitree, Vaughan Springs and Dean quartzites).

**Geochronology of the Nolans deposit**

A number of intrusive-related and/or metasomatic deposits in the eastern Arunta contain significant quantities of U and Th as potential by-products (Hussey 2003). The primary example is the world-class Nolans REE-P-U deposit (30.3 Mt @ 2.8% REO, 12.9% P2O5 and 200 ppm U3O8) in the southeastern Reynolds Range. The deposit consists of east-northeast-trending, steeply dipping veins of fluorapatite cross-cutting Palaeoproterozoic basement gneiss (ca 1805 Ma Boothby Orthogneiss). The veins contain accessory allanite, monazite and thorite. Preliminary U-Pb dating of the apatite indicates an age of 1244 ± 10 Ma, and juvenile initial 87Sr/86Sr (0.705–0.707) and evolved Nd isotopes (εNd,1250 = -12 to -4), suggest enriched mantle source(s).

Although not recognised elsewhere in the Aileron Province, this ca 1240 Ma age broadly coincides with the age of the Mudginberri phonolite dykes in the Pine Creek Orogen, which have K-Ar and Rb-Sr mineral ages of 1300–1200 Ma and a Rb-Sr isochron age of 1316 ± 40 Ma (initial 87Sr/86Sr ca 0.7063; Page et al. 1980), and a global carbonatitic and alkalic magmatic event between 1300 and 1130 Ma (Pidgeon et al. 1989).

![Figure 2. Province map of Northern Territory showing location of onshore Carpentaria Basin (courtesy of NTGS).](image)
The Nolans age also broadly overlaps with the early part of the Musgrave Orogeny in the Musgrave Province to the southwest. There, moderate-pressure metamorphism up to granulite grade was followed by voluminous syn- to post-tectonic felsic magmatism, spanning an age range of ca 1235–1195 Ma (White et al 1999; Edgoose et al 2004). These data suggest that the Nolans Bore deposit was emplaced during a more widespread Mesoproterozoic thermal event.

Acknowledgements

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References


ACCESSING INFORMATION FROM THE NORTHERN TERRITORY GEOLOGICAL SURVEY

Jenny Saunders and Tracey Rogers

The Northern Territory Geological Survey (NTGS) has continued with digital data capture and scanning projects throughout the past 12 months and data delivery to clients has been enhanced. Significant achievements include the completion of scanning of all open file mineral exploration reports, a substantial increase in the upload of geochemical data into Explorer 3, and a further 10 new GIS mapsheets released. Two new layers (seismic, and whole rock) were added to STRIKE. A third layer (historical petroleum tenure) is underway.

Exploration reports and data management

Open file mineral and petroleum reports and data are searchable via databases available on the website. All open file mineral reports have now been scanned, and the scanning of petroleum reports and data has commenced. Additional resources have been dedicated to in-house scanning to accelerate progress.

NTGS is not yet web-serving exploration reports and data, but work has commenced on the specifications for a web-delivery system. NTGS is aiming to commence web delivery of company exploration data in about 18 months time.

The physical relocation of hard-copy onshore petroleum exploration data from an off-site storage area to our Darwin head office last year has significantly enhanced the ability of staff to respond quickly to client requests, and has assisted in the commencement of the scanning project. The onshore petroleum reports have been reorganised to ensure more efficient retrieval and reflect industry needs.

Drill core and cuttings stored in the NTGS core facilities in Darwin and Alice Springs are another source of data. The NT Geological Survey is participating in a collaborative Federal and State government program to develop a National Virtual Core Library (NVCL). Core will be scanned using CSIRO-developed Hylogger spectroscopic technology. Explorers will be able to access a virtual view of the core and its related spectral data via the internet before visiting the core facilities. The Hylogger instrument is due to arrive at the Darwin facility in July 2009 and an initial requirement of NTGS’s participation in the program is to achieve representative Northern Territory coverage from all terranes.

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Web delivery, web development and NTGS products

The release of the 'Metallogenic map of the Northern Territory' this year at AGES 2009 has followed a major upgrade of the Mineral Occurrence Database (MODAT) that commenced in June 2006. A further 42 mineral occurrences were added to MODAT, and the updated version has been released for AGES.

Throughout the year, NTGS announced 10 new GIS dataset releases and published LANDER RIVER and LAKE MACKAY, and several reports. NTGS has also just completed a revamp of its website, focusing on simplifying the structure and improving navigation.

NTGS has also progressed a major new publication, 'Geology and resources of the Northern Territory', which is scheduled for release later in 2009. This will be the first time that a single-volume compilation of the geology, geophysics, and mineral and petroleum resources of the Territory has been produced. It will contain over 40 chapters, with descriptions and discussions of all the Territory's major onshore regions and provinces, and will be available in digital and hard-copy formats.

A set of 28 x 1:250K explanatory notes, originally released in hard copy, were scanned and are now available in PDF format on CD. NTGS 1:100k explanatory notes are currently being scanned and will be made available later this year as digital products.

Substantial effort was put into uploading geochemical data into Explorer 3 throughout 2008. More than 35 000 records were added to the Northern Territory geochemical database. An updated version of this dataset has been released for AGES, and is available on STRIKE.

The Central Arunta Gravity Survey was added to the Geophysical Image Web Server (GIWS) during the year. The number of visits to GIWS increased by 26%, from 2967 in 2007 to 3993 in 2008.

NTGS Corporate Database Project

During the past 12 months, user testing of the NTGS corporate database identified a number of shortfalls that were subsequently addressed, although the spatial interface has proved difficult.

The final production installation is expected in 2009. It is anticipated that this will entail a fully functional geochemistry module, replacing our current MS Access geochemistry database. The geological unit and structural component of the system will still require further work to be considered a full production version. The system forms the foundation for improving data delivery in the future.

Geoscientific literature

In addition to digital data, maps and reports, clients are able to access geoscientific literature from the NTGS Information Centre, which is staffed by information professionals. Resources and services that are available to both staff and external clients include literature searching, interlibrary loans and electronic document delivery, and access to a range of academic and industry literature.

Please contact NTGS at geoscience.info@nt.gov.au for further information

EXTENSIVE EXPOSED NEOARCHAEAN CRUST IN ARNHEM LAND, PINE CREEK OROGEN: U-PB ZIRCON SHRIMP GEOCHRONOLOGY

Julie A Hollis1, 2,3, Chris J Carson2 and Linda M Glass1

Archaean basement rocks in the North Australian Craton are uncommon. In the Pine Creek Orogen, Archaean basement includes the Rum Jungle (2534–2520 Ma) and Waterhouse (2545–2535 Ma) domes, the Nanambu Complex (2470 Ma), the subcropping Woolner Granite (2675 Ma), and the recently identified Kukulak gneiss (informal name) in the Caramal Inlier, west Arnhem Land (2510 ± 4 Ma). The recognition of Archaean basement has important implications both for understanding large-scale crustal structure and tectonic evolution, and for mineral prospectivity. In particular, there are strong spatial associations of uranium and base metal occurrences in the oldest Palaeoproterozoic strata (P1 and P2 subdivisions of Ahmad 2001), which immediately overlie Archaean basement in the Pine Creek Orogen. For example, in the East Alligator Rivers region, the Cahill Formation, which overlies the Archaean Nanambu Complex, is host to world-class uranium deposits at Ranger, Jabiluka, Koongarra and Nabarlek. Recent NTGS mapping and Geoscience Australia-NTGS SHRIMP U-Pb zircon age data have confirmed that a significantly greater extent of Neoarchaean basement rocks are exposed in Arnhem Land than was previously thought.

The Pine Creek Orogen (PCO) comprises a thick (>4 km) succession of Palaeoproterozoic clastic, carbonate, and carbonaceous sedimentary and volcanic rocks unconformably overlying Neoarchaean (ca 2670–2500 Ma) granitic and gneissic basement. It has been broadly subdivided into three regions (eg Worden et al. 2008b; Carson et al. 2008; Hollis et al. 2008). These are the amphibolite- to granulite-facies Litchfield Province in the west, the greenstist-facies Central Domain, and the amphibolite-facies Nimbuwah Domain in the east (Figure 1). Recent NTGS mapping in the PCO has focused on the relatively little-studied Nimbuwah Domain.

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Neoarchaean basement in the Nimbuwah Domain comprises ductily deformed granitic gneiss (Dunn 1962, Needham and Stuart-Smith 1980, Needham 1988, Hollis et al 2008). This is structurally overlain by Palaeoproterozoic strata comprising the Kakadu Group, Cahill Formation, and Nourlangie Schist. Both the Palaeoproterozoic strata and the underlying Neoarchaean basement are regionally metamorphosed typically to middle amphibolite facies. The heat source of metamorphism is attributed to the emplacement of late deformational granitic, granodioritic, and subordinate tonalitic gneisses of the ca 1867–1862 Ma Nimbuwah Complex (Page et al 1980, Worden et al 2008a, Hollis et al 2009). The dome and basin structure controlling the outcrop pattern of Neoarchaean basement is attributed to post-Nimbuwah Complex fold interference patterns (Johnston 1984, Needham 1988, Hollis et al 2009).

A ca 470 km² extent of exposed Neoarchaean crust in Arnhem Land is inferred from field-mapped structural and tectonostratigraphic relationships. This was tested by U-Pb zircon SHRIMP dating of magmatic crystallisation of four granitic gneiss

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**Figure 1.** Geological domains of Pine Creek Orogen (indicated by red lines) showing extent of now-recognised Neoarchaean crust. Boundary between Central and Nimbuwah domains is characterised by change in metamorphic grade. Inset shows location of the Pine Creek Orogen within Northern Territory. Dashed box shows location of study area (Figure 2). Sample locations for SHRIMP analysis are indicated.
samples (Figure 2). A sample from the eastern Myra Falls Inlier yielded 2527 ± 3 Ma, similar to the age of the Kukulak gneiss in the Caramal Inlier (Hollis et al. 2008). Likewise, a drill core sample from Wellington Range, beneath 250 m of Cretaceous cover, yielded 2513 ± 13 Ma. These are consistent with the age of the Rum Jungle and Waterhouse domes in the Central Domain. In contrast, a sample from the northeastern Myra Falls Inlier yielded 2671 ± 3 Ma, making this the oldest exposed Archaean basement yet recognised in the Northern Territory. This age is consistent with that of the subcropping Woolner Granite in the Central Domain, some 200 km to the west. A further sample from the Arrarra area yielded an age of 2640 ± 4 Ma. These older two samples (ca 2640–2670 Ma) have metamorphic zircon rims at ca 2500 Ma.

The new SHRIMP data indicate that Neoarchaean crust in the PCO comprises several distinct age components at ca 2670 Ma, ca 2640 Ma and ca 2530–2510 Ma. The oldest and youngest of these are recognised in basement in both the Central and Nimbuwah domains. The youngest magmatic phase appears to be volumetrically dominant and its emplacement is probably responsible for metamorphism of the older crust into which it was emplaced at ca 2500 Ma. All three age components are recognised in detrital zircon signatures of the overlying Palaeoproterozoic strata, particularly in the basal units, which is indicative of local derivation of these

Figure 2. Interpretive geological map of study area in Nimbuwah Domain. Major Archaean and Palaeoproterozoic metasedimentary and igneous units are shown. Sample locations and results of SHRIMP analyses are indicated.
sediments from the underlying basement. These findings are consistent with a common Neoarchaean basement beneath a large part of the Pine Creek Orogen.

References


GEOCHEMICAL AND ISOTOPIC DISCRIMINATION METHODS FOR NEOARCHEAN AND PALAEOPROTEROZOIC ROCKS IN WESTERN ARNHEM LAND, PINE CREEK OROGEN: APPLICATIONS FOR URANIUM EXPLORATION

Linda M Glass1,2, Julie A Hollis3 and Chris J Carson4

The Nimbuwah Domain in western Arnhem Land represents the easternmost region of the Pine Creek Orogen (PCO; Figure 1). It includes the Neoarchaean Nanambu Complex felsic gneiss, which is overlain by Palaeoproterozoic metasedimentary rocks, and intruded by the Palaeoproterozoic Nimbuwah Complex, a suite of porphyritic granitoids and migmatites. The recent identification of previously unrecognised Neoarchaean felsic suites (ca 2.53–2.50 Ga Kukulak gneiss and ca 2.67–2.64 Ga gneiss) in the Nimbuwah Domain (Hollis et al 2009, Figures 1 and 2) is important, because within the PCO, there is a strong spatial association of known uranium mineralisation close to existing Neoarchaean felsic inliers. However, in these mineralised areas, the nature of this relationship is somewhat unclear, given the contrasting models that exist for the primary source of uranium. Despite the new age determinations reported in this volume, only a small number of rocks in this region have radiogenic age constraints, and a significant proportion of Precambrian felsic igneous rocks remain undated.

Examination of trace element and Nd isotopic data indicates that the Neoarchaean (ca 2.5 Ga Kukulak gneiss; older ca 2.67–2.64 Ga gneiss suite) and Palaeoproterozoic (ca 1.86 Ga Nimbuwah Complex) rocks can be chemically separated on the basis of distinctive trace element geochemical (a feature noted previously by Wyborn et al 1992) and isotopic characteristics. These geochemical and isotopic parameters can be further applied to granitoids of unknown age and affinity. This means that undated felsic igneous rocks can be classified

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as being Neoarchaean or Palaeoproterozoic, based on chemical constraints. The chemical classification is further supported by statistical discriminant analysis and by the spatial distribution of these new Neoarchaean or Palaeoproterozoic groups, which conform to known field stratigraphic relationships.

The most distinctive geochemical discrimination parameter relates to the slope of the Light Rare Earth Elements (LREE) compared to the Heavy Rare Earth Elements (HREE) on a Chondrite-normalised REE diagram, and on this basis, known dated Neoarchaean and Palaeoproterozoic granitoids can be chemically separated by their distinctive REE signatures (Figure 3). Neoarchaean felsic rocks in the Nimbuwah Domain are strongly fractionated, i.e., they have steep REE patterns with pronounced HREE depletion, ([La/Yb] = 30 to 135), indicating the presence of garnet in the source. In contrast, Palaeoproterozoic rocks (Nimbuwah Complex)
Figure 2. Recently identified Neoarchaean gneiss in the Nimbuwah Domain, Pine Creek Orogen.

Figure 3. Graph of Chondrite-normalised REE abundances, showing distinctive REE signatures of Neoarchean and Palaeoproterozoic granitoids. Neoarchean is shown in blue and Palaeoproterozoic is shown in green. Normalising values from McDonough and Sun (1995).
are weakly to moderately fractionated ([La/Yb] = 4 to 50). This observation is supported by additional data from other Neoarchaean suites in the PCO, e.g., the Nanambu Complex in the western Nimbuwah Domain and the Rum Jungle and Waterhouse complexes in the westernmost region of the Central Domain. Both suites have similar steep, sloping REE patterns to the newly identified Kukuluk gneiss and older ca 2.67–2.64 Ga gneisses.

The second chemical discrimination parameter involves silica content. Silica values for Neoarchaean rocks range from ca 65 to 78 wt% SiO₂, which is consistently higher than the Palaeoproterozoic suites, which range from ca 56 to ca 70 wt% SiO₂ (Figure 4). Neoarchaean suites are dominantly monzogranite to granodiorite, and although Palaeoproterozoic Nimbuwah rocks overlap in composition, they include a substantial quartz monzodiorite component. All suites are I-types; however, all Neoarchaean rocks are weakly peraluminous, the excess Al being accommodated by biotite. Palaeoproterozoic rocks also include weakly peraluminous compositions, although most samples are metaluminous. Both rock types are hornblende bearing. Based on the alkali-lime index of Peacock (1931) both suites are calc-alkaline to alkali-calcic; however Neoarchaean suites have a greater alkalic-calcic component.

New Nd isotope data show that the Neoarchaean suites are consistently close to Bulk Earth, with εNd ranging from -0.1 to -0.7. In contrast, the Palaeoproterozoic Nimbuwah Complex sample has a εNd of -3.9.

In summary, the marked geochemical and isotopic differences between Neoarchaean and Palaeoproterozoic suites in the PCO, enable new samples of unknown affinity to be classified by chemical means. Given the spatial association of uranium mineralisation proximal to Neoarchaean terranes, this represents a potentially cost effective tool for evaluating uranium prospectivity.

References


STRATIGRAPHIC AND TECTONIC EVOLUTION OF THE NIMBUWAH DOMAIN: A SEPARATE TERRANE TO THE REST OF THE PINE CREEK OROGEN?

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Regional metamorphism of the Pine Creek Orogen (PCO), and of the Northern Australian Craton in general, in the period ca 1880–1850 Ma, has historically been referred to as the ‘Barramundi Orogeny’. This was generally envisaged as a broad period of tectonic activity involving intra-plate continental rifting, basin formation, and subsequent compression (Etheridge et al 1987, Needham et al 1988, Page and Williams 1988).

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Included in the foundations of this intra-plate model was the similarity in metamorphic and deformational styles across the Northern Australian Craton, a lack of evidence for significant crustal thickening, the absence of paired metamorphic belts, and the absence of magmatic rocks with geochemical characteristics indicative of subduction-related processes (Etheridge et al. 1987). However, geochemical, petrographic, and geochronological studies in the PCO have now isolated distinct thermal events in different regions, with different styles of metamorphism, and indications of crustal thickening and of subduction-related tectonism (Glass 2007, Worden et al. 2008a, b, Carson et al. 2008, Glass et al. 2009, Hollis et al. 2009, this study). Here we present new mapping, laser and SHRIMP U-Pb zircon geochronology, petrographic and metamorphic data for the Nimbuwah Domain of the PCO, demonstrating that its Palaeoproterozoic depositional and metamorphic history is distinct from other parts of the orogen. Along with the identification of extensive exposed Neoarchaean crust in the Nimbuwah Domain (Hollis et al. 2009), and geochemical and isotope studies of important mafic and felsic magmatic rocks (Glass et al. 2009), these findings have implications for understanding the geological evolution of the PCO as a whole.

**Background**

The Pine Creek Orogen is exposed over 47 500 km² and forms the northern margin of the North Australian Craton. It comprises a >4 km-thick succession of Palaeoproterozoic clastic, carbonate, and carbonaceous sedimentary rocks and volcanic rocks, unconformably overlying ca 2670–2500 Ma, Neoarchaean granitic and gneissic basement. The Palaeoproterozoic stratigraphy of the PCO hosts over 1000 known mineral occurrences, including Au, Pb-Zn-Ag, PGEs, Cu-Co-Ni, Fe, Sn-Ta-W, phosphate, and world-class U deposits (eg Ahmad 1998, 2007).

The PCO has been broadly subdivided into three regions (eg Worden et al. 2008b, Carson et al. 2008, Hollis et al. 2008). These 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 relatively well defined stratigraphy of the Central Domain has been subdivided into the ca 2020 Ma Woodcutters Supergroup (P1–P2 subdivision of Ahmad and McCready 2001) and the unconformably overlying ca 1862 Ma Cosmo Supergroup (P3–P4 subdivision of Ahmad and McCready 2001, Worden et al. 2008b). Correlation of these with strata in the Litchfield Province and the Nimbuwah Domain is complicated by poor exposure and differences in structural style and metamorphic grade.

Recent NTGS mapping in the PCO has focused on the relatively little-studied Nimbuwah Domain. Neoarchaean basement in the Nimbuwah Domain comprises ductily deformed granitic gneiss (Dunn 1962, Needham and Stuart-Smith 1980, Needham 1988, Hollis et al. 2008), structurally overlain by Palaeoproterozoic strata comprising the Kakadu Group, Cahill Formation, and Nourlangie Schist. The term Myra Falls Metamorphics (Dunn 1962) is here abandoned as this is now known to comprise components of the Cahill Formation and Neoarchaean basement. Both the Palaeoproterozoic strata and the underlying Neoarchaean basement are regionally metamorphosed to middle amphibolite facies. The heat source of metamorphism has been attributed to emplacement of late deformational granitic, granodioritic, and subordinate tonalitic gneiss of the ca 1867–1862 Ma Nimbuwah Complex (Page et al. 1980, Worden et al. 2008a). The dome and basin structure controlling the outcrop pattern of the Neoarchaean basement has been attributed to post-Nimbuwah Complex fold interference patterns (Johnston 1984, Needham 1988).

**Detrital zircon geochronology**

Laser Ablation Inductively Coupled Plasma Mass Spectrometry was used to collect U-Pb data for detrital zircon from eight sedimentary samples from the Central Domain and six metasedimentary samples from the Nimbuwah Domain. The new geochronology data add to the detrital zircon data available for the PCO as a whole and contribute to the understanding of possible relationships between the stratigraphy in these domains. P1–P2 strata is represented by the Kakadu Group in the Nimbuwah Domain. Detrital zircon spectra for the Kakadu Group are indicative of a dominantly 2520–2500 Ma erosive source, consistent with spectra for the P1–P2 Manton, Mount Partridge, and Namoona groups in the Central Domain (Cross et al. 2005, Worden et al. 2008a), which supports this correlation. The spectra suggest derivation of these (meta)sedimentary rocks from underlying Neoarchaean basement granite and gneiss in the Central and Nimbuwah domains (Cross et al. 2005, Hollis et al. 2009). In contrast two samples of the Crater Formation, a basal unit of the Woodcutters Supergroup in the Central Domain, have dominant ca 3125 and ca 3670 Ma sources. Basement rocks of this age are currently unknown in the PCO and in the Northern Territory in general, and significant proportions of detritus of this age have not been identified at higher levels in the Palaeoproterozoic PCO stratigraphy.

Five samples were collected from various stratigraphic levels in the Burrell Creek Formation of the Finniss River Group (P4, Cosmo Supergroup). Four produced detrital spectra with a dominant 1865–1860 Ma source with smaller contributions from older material, particularly a ca 2500 Ma source. Similarities in the detrital spectra support previous correlations with the Hermit Creek and the Welltree metamorphics of the Litchfield Province (Worden et al. 2008b). The fifth
sample, collected from immediately beneath the Tolmer Group, at the stratigraphic top of the Burrell Creek Formation, has a slightly younger maximum depositional age of 1851 ± 9 Ma. This constrains deformation and greenschist-facies metamorphism in the Central Domain to this time or later.

The Cahill Formation and Nourlangie Schist in the Nimbuwah Domain have been proposed as possible P2 and P3 equivalents, respectively (Needham et al 1980, Stuart-Smith et al 1980). This correlation is not supported by the new U-Pb detrital zircon data. Five samples of the Cahill Formation show mutually consistent detrital zircon age spectra with a significant ca 2500 Ma source and a spread in younger Palaeoproterozoic sources in the range ca 2500–1900 Ma. Notably, they contain no ca 1865–1860 Ma component, which dominates detrital spectra from the Central Domain. A sample of the Nourlangie Schist has a similar detrital spectrum to a previously analysed sample (Worden et al 2006b) and also to the Cahill Formation samples, and is also devoid of ca 1865–1860 Ma detritus. The Cahill Formation and Nourlangie Schist samples are distinct from both the Woodcutters Supergroup and Cosmo Supergroup of the Central Domain, as the Woodcutters Supergroup was deposited earlier, at ca 2020 Ma (Worden et al 2004, 2008a, b), while the Cosmo Supergroup was primarily derived from distinct, younger source rocks. These differences suggest that Palaeoproterozoic metasedimentary rocks overlying

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**Figure 1.** Geological domains of the Palaeoproterozoic Pine Creek Orogen; boundaries indicated by red lines. The boundary between the Central and Nimbuwah Domains is characterised by a change in metamorphic grade. Palaeoproterozoic PCO shown in brown, Neoarchaean basement in dark pink, Litchfield granites in lighter pink, Cullen and Jim Jim suite granites in orange. Major faults are shown in black. Detrital zircon sample locations (including existing data) indicated by filled red circles.
the Kakadu Group in the Nimbuwah Domain comprise a distinct stratigraphy from the Central Domain.

**Structural evolution**

In the Nimbuwah Domain, Neoarchaean granitic gneiss preserves evidence for multiple phases of ductile deformation, in the form of isoclinal refolded folds and variably transposed gneissic fabrics, and heterogeneous development of high-strain fabrics. These are assigned to a composite $D_3$ event, although they probably reflect several phases of deformation. $D_2$ foliations affecting both basement and overlying Palaeoproterozoic strata are at a low angle to bedding and are associated with northwest-verging, low-angle high-strain thrusts. $D_2$ is also expressed as recumbent $F_2$ folds, a $S_2$ schistosity and high-strain zones with associated east-trending stretching lineations consistent with a top-to-the-west sense of movement (see also Johnston 1984, Hollis et al 2008). This is succeeded by $D_4$ in the Myra Falls Inlier, possibly a later stage of $D_3$, which produced shallow, east-northeast-to west-southwest-plunging, tight, upright to overturned northwest-vergent folds, thrusts, and high-strain zones, and folding of $L_3$ lineations. $F_4$ upright horizontal to reoriented to open to isoclinal north–south folds are refolded by east–west open to tight $F_2$ folds, resulting in the dome and basin structure of exposed Neoarchaean basement (see also Johnston 1984, Needham 1988, Hollis et al 2008).

**Metamorphsm**

Quantitative PT calculations using thermocalc software were made using mineral chemical data for garnet hornblende-plagioclase-quartz amphibolites and for garnet-staurolite-biotite-hematite-muscovite-plagioclase-quartz ± kyanite assemblages in the Nurlangie Schist and Cahill Formation. The samples were collected from drill core from Wellington Range, Jim Jim, Howship, and Oenpelli, spanning a wide area of west Arnhem Land. Results indicate peak PT conditions in the range ca 450–600°C at 8–10 kbar.

These PT calculations assume that chemical equilibrium has been maintained between all mineral phases; however, some mineral chemical zonation and growth of retrograde mineral phases (eg sericite, chlorite, and prehnite) has occurred. Thus, in order to test the veracity of the PT estimates obtained, calculations were also made on the basis of bulk rock, rather than preserved mineral chemical compositions. Bulk rock compositional analyses for several similar samples of garnet-staurolite-hematite-mica schists from Wellington Range and Jim Jim indicate that these are extremely oxidised rocks, with in excess of 80 mol% Fe$^{3+}$ component of total Fe. This is in contrast to the common generalisation that Palaeoproterozoic metamorphic basement rocks in the Alligator Rivers region are relatively reduced. High oxygen fugacity at an early stage in the metamorphic history is indicated by the formation of hematite at the expense of garnet in metamorphic reaction textures that also include staurolite-kyanite-mica-bearing assemblages as replacement products of garnet. However, the possibility that the oxidation state of these rocks was enhanced by late oxidised fluids cannot be ruled out. Therefore, calculations were made on the basis of the measured whole rock composition of a garnet-staurolite-hematite-mica schist from Wellington Range with adjustment (reduction) of oxidation fugacity to a level at which the predicted garnet compositions at the minimum PT stability of garnet matched the analysed garnet compositions (which show little chemical zonation). Results indicate a minimum P stability of the observed garnet-bearing assemblages of ca 9 kbar, consistent with PT results based directly on mineral chemical data. The reaction textures, which are indicative of the breakdown of garnet to staurolite-hematite-kyanite-mica and later sillimanite-bearing assemblages are consistent with significant decompression of ca 4 kbar. These results indicate amphibolite-facies metamorphism at relatively high-P conditions in the Nimbuwah Domain, in contrast to greenschist-facies, low-P (locally andalusite-bearing) metasedimentary rocks in the Central Domain and low-P, high-T metamorphism (ca 600–730°C at 4–5 kbar) in the Litchfield Province (Carson et al 2008).

The heat source of amphibolite-facies metamorphism in the Nimbuwah Domain is commonly attributed to the emplacement of granodioritic plutons of the Palaeoproterozoic Nimbuwah Complex, which has induced local migmatisation of the adjacent metasedimentary rocks. The age of emplacement has been previously constrained to 1866–1860 Ma (Page et al 1980, Worden et al 2008a), which is consistent with new U-Pb zircon results from a sample from Wellington Range that yielded a magmatic crystallisation age of 1868 ± 5 Ma. Metamorphic zircon rims on detrital cores from a leucosome in a migmatitic metasedimentary gneiss, immediately adjacent to the Nimbuwah Complex in the Caramal Inlier, yielded a consistent metamorphic age of 1867 ± 4 Ma. However, the timing of regional amphibolite-facies $D_2$–$D_3$ fabric development remains to be tested.

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

The new detrital zircon data indicate distinct differences in the depositional history of the Nimbuwah Domain from other parts of the PCO. The basal unit of the Palaeoproterozoic stratigraphy, the P1 Kakadu Group, appears to correlate well with P1 stratigraphy in the Central Domain. However the overlying Palaeoproterozoic stratigraphy of the Nimbuwah Domain shows marked differences. These are younger than the ca 2020 Ma P1–P2

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1. Names of 1:100k mapsheets are in small caps.
Woodcutters Supergroup, but have no ca 1865–1860 Ma detrital component, indicating a different provenance from P3–P4 Cosmo Supergroup of the Central Domain and correlatives in the Litchfield Province. This is consistent with depth-to-basement modelling of regional magnetic and gravity data (Lewis et al. 1995), which shows a distinct eastern trough, separated from strata of the Central Domain by an Archaean basement high.

This distinct Palaeoproterozoic sub-basin may have developed during, or after separation from the Central Domain during ca 2020 Ma rifting of Neoarchaean basement (Needham et al. 1988, Worden et al. 2008a). It was subjected to moderate-T, high-P metamorphism at ca 1865 Ma (Nimbuwah Event), coincident with the emplacement of granodioritic Nimbuwah plutons in the Nimbuwah Domain and with felsic volcanism in the Central Domain (Gerowie Tuff, Lally and Worden 2004, Worden et al. 2004, Worden et al. 2008b). This high-P ca 1865 Ma thermal event in the Nimbuwah Domain was associated with the development of amphibolite-facies ductile fabrics dominated by W-vergent folds and low-angle thrusts, consistent with deformation at a continental margin. It contrasts with metamorphism in the Litchfield Province, which occurred about 10 My later at ca 1855 Ma and involved development of low-P, amphibolite-facies northeast-trending fabrics or granulite-facies assemblages with no associated fabric development (Johnston 1984, Pietsch and Edgoose 1988, Lally 2002, Carson et al. 2008). This was synchronous with the emplacement of 1862–1850 Ma S-type granites (Walpole et al. 1968, Page et al. 1980, Wyborn et al. 1997, Worden et al. 2008a) and ca 1860 Ma arc-related (?) mafic rocks (Glass 2007, Carson et al. 2009). Furthermore, the Nimbuwah Event is postdated by continued deposition of P4 stratigraphy in the Nimbuwah Domain, associated with the development of amphibolite-facies ductile fabrics dominated by W-vergent folds and low-angle thrusts, consistent with deformation at a continental margin. This contrasts with metamorphism in the Litchfield Province, which occurred about 10 My later at ca 1855 Ma and involved development of low-P, amphibolite-facies northeast-trending fabrics or granulite-facies assemblages with no associated fabric development (Johnston 1984, Pietsch and Edgoose 1988, Lally 2002, Carson et al. 2008). This was synchronous with the emplacement of 1862–1850 Ma S-type granites (Walpole et al. 1968, Page et al. 1980, Wyborn et al. 1997, Worden et al. 2008a) and ca 1860 Ma arc-related (?) mafic rocks (Glass 2007, Carson et al. 2009). Furthermore, the Nimbuwah Event is postdated by continued deposition of P4 stratigraphy in the Central Domain through ca 1855 Ma or later, derived primarily from ca 1865–1860 Ma rocks, possibly represented by the upthrust Nimbuwah plutons or their volcanic equivalents, or by ca 1865–1860 Ma volcanic rocks of the Litchfield Province. Thus, greenschist-facies metamorphism and tight upright folding in this domain occurred after ca 1855 Ma, but prior to the 1829 Ma deposition of the El Sherana Group (Jagodzinski 1998) and emplacement of I-type granites of the ca 1835–1820 Ma Cullen and Jim Jim granitic suites (Walpole et al. 1968, Stuart-Smith et al. 1993, Bajwah 1994, Jagodzinski and Wyborn 1997, Wyborn et al. 1997, Wyborn et al. 2001).

The combined findings of detrital zircon studies of Palaeoproterozoic (meta)sedimentary rocks of the Central and Nimbuwah domains, and constraints on the timing and nature of deformation and metamorphism across the PCO illustrate that the Nimbuwah Domain experienced a distinct depositional and tectonometamorphic history from other parts of the PCO in the period ca 2020–1860 Ma. Notably, the world-class Koongarra, Ranger, Jabiluka, and Nabarlek uranium deposits all fall within the Nimbuwah Domain, hosted by Palaeoproterozoic strata now known to have distinct provenance and different tectonometamorphic histories from strata of the Central Domain and the Litchfield Province. This has potentially important implications for mineral prospectivity in the PCO.

References


STRUCTURAL SETTING OF THE RANGER 3 URANIUM OREBODY: IMPLICATIONS FOR RESOURCE MODELLING

Greg Rogers1, 2, Angus McCoy3, Aaron Bertram4 and Arnold Van der Heyden3

Recent interpretations of geological data from the Ranger 3 ore body and a separate down-dip mineral resource known as Ranger 3 Deeps have provided new insights to the structural architecture and ore-forming processes.

A project with CSIRO Exploration and Mining to incorporate this knowledge into a mineral systems analysis of the lease area has the potential to highlight additional blind deposits and guide future exploration activities.

The initial development of a deposit-scale 3D model forms the nucleus for a tenement-scale structural model constrained by numerous geophysical datasets. Ultimately, the model will become the framework for the interpretation of alteration and geochemical footprints, as well as providing a framework geometry for advanced numerical modelling studies.

More locally, in order to test the down-dip extension, ERA has increased the drill spacing to approximate a 50 m x 50 m pattern. A significant effect on the resource modelling has been the need to increase both the block spacing (from 12 m x 12 m x 3 m to 25 m x 25 m x 10 m) and a composite length (from 1 m to 2 m). The follow-on effect of this has been the overall smoothing of the grade distribution, effectively increasing the amount of medium grade apparently available to the operation.

In order to evaluate opportunities for ERA, a more accurate estimate of the grade distribution needs to be determined. To achieve this, ERA has developed a non-linear recoverable resource model using Multiple Indicator Kriging modelling methods. This presentation outlines the transition from Ranger Ordinary Krigged models to the currently utilised MIK model, and discusses the processes, advantages and disadvantages of these techniques.

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PHOSPHATE PROSPECTIVITY IN THE NORTHERN TERRITORY

Christine Edgoose5

Phosphate mineralisation occurs in a variety of styles and settings within the Northern Territory, with approximately 30 known occurrences. The majority of these occur as sedimentary deposits within the Cambrian successions of the Georgina, Wiso and Amadeus basins, and represent a Neoproterozoic–Cambrian phosphogenic episode that is recognised on a global scale. Many phosphate deposits were identified during the 1960s as part of a national search for prospective phosphate regions.

The most significant occurrences in the Northern Territory are concentrated in Middle Cambrian sedimentary rocks of the Georgina Basin, including the world-class deposit at Wonarah. This basin is the major source of phosphate within Australia and large deposits occur to the east in Queensland, where mining has historically taken place. The next most significant province for phosphate mineralisation in the Northern Territory is in the Rum Jungle area of the Pine Creek Orogen, where about 15 separate sedimentary occurrences are recorded, also mostly identified during the 1960s.

A significant, recent basement-hosted discovery is at Nolans, which is a REE-phosphate-calcium carbonate hydrothermal vein system, located in the Arunta Region near Aileron, north of Alice Springs.

A long period of relatively low phosphate prices made the NT deposits unattractive economically, but significant price increases in recent years and a shift to short-term supply contracts have reignited interest in the exploration and development of phosphate resources. This has included a resurgence in greenfields exploration, with major grassroots exploration campaigns underway across the Georgina Basin, and growing interest in exploring the Amadeus and Wiso basins.

Recent testing of waterbores in the Georgina, Wiso and Daly basins, conducted by NTGS, highlighted several anomalous areas in both the Wiso and Georgina basins (Figure 1), marginal to the Palaeoproterozoic Tennant Region and these warrant further investigation (Khan et al 2007). NTGS has recently completed new generation 1:250 000 geological mapping of the Georgina Basin, with a revised stratigraphy that provides an improved framework for phosphate explorers (Kruse et al in press). In the next few months, a helicopter-borne regional gravity survey of the central Georgina Basin will be conducted by NTGS, and this has the potential to identify further sites suitable for phosphate deposition.

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Sedimentary deposits

Georgina Basin

Australia’s inferred phosphate resources are dominantly within phosphorite occurring in the Georgina Basin (Geoscience Australia 2008). All of the defined phosphate resources in the NT section of the Georgina Basin are located in the central part of the basin, associated with middle Cambrian sedimentary rocks that flank the Alexandria-Wonarah Basement High. The Lower Cambrian Helen Springs Volcanics (Kalkarindji Volcanic Group) were extruded along the Alexandria-Wonarah Basement High, which divides the platformal central portion of the Georgina Basin into an eastern Undilla Sub-basin and a western Barkly Sub-basin. The Middle Cambrian represented a period of widespread sedimentation in the basin, with deposition in the central and northern parts of the basin largely terminated by its end. In the southern Georgina Basin, sedimentation continued into the Devonian. Cook (1986) provided a summary of the geology and phosphate deposits of the Georgina Basin and divided the Cambrian into six informal time slices. Most phosphate deposits are found in his ‘Time Slice 3’. Southgate and Shergold (1991) divided the Middle Cambrian succession into two depositional sequences and recognised three discrete phosphogenic episodes. Sequence 1 (early Middle Cambrian) comprises terrestrial siliciclastic rocks, peritidal and marine shelf carbonate rocks, carbonaceous shale and phosphatic carbonate rocks; sequence 2 (remainder of Middle Cambrian) comprises siliciclastic and carbonate rocks, phosphorite and phosphatic limestone, and carbonaceous shale. Major phosphate deposits are apparently in sequence 2, including the Wonarah, Alexandria and Alroy deposits in the Northern Territory. Most of the Georgina Basin phosphorites are grainstones, with lesser mudstone-hosted mineralisation (Cook 1986).

More recent NTGS work in the central Georgina Basin has refined the distribution of middle Cambrian units (Kruse et al in press). A widespread early Middle Cambrian marine transgression deposited subtidal marine carbonate rocks throughout the Barkly Sub-basin, although not on the Alexandria-Wonarah Basement High. These units represent Middle Cambrian stratigraphic sequence 1. A second marine transgression (sequence 2)

Figure 1. Distribution of phosphorite facies in Georgina, Wiso and Daly basins and boundaries of depocentres in Georgina Basin (after Khan et al 2007).
generated subtidal dolostone and siliciclastic mudstone of the Wonarah Formation on and adjacent to the Alexandria-Wonarah Basement High, but these pass westward into peritidal, mixed carbonate-siliciclastic deposits of the Anthony Lagoon Formation. All of these post-volcanic Middle Cambrian formations are constituents of the Barkly Group.

The largest identified resources in the NT are the Wonarah and newly defined, nearby Aruwarra deposits, which have recently announced JORC-compliant resources of 330 Mt @ 18.9% $P_2O_5$ and 131 Mt @ 18.6% $P_2O_5$, respectively. These are currently being investigated by Minemakers Ltd, in the central Georgina Basin and are the largest-known rock phosphate resources in Australia. The deposits were first discovered by IMC Development Corporation in 1967, and were more recently investigated by Rio Tinto Ltd in the early 2000s. Howard (1989) characterised the deposit as two successive phosphorite beds, comprising phosphatic mudstone, silty mudstone and grainstone (of reworked mudstone clasts).

Alexandria lies approximately 100 m north-northeast of Wonarah, on the east side of the basement high. It is not exposed, and occurs between 10 and 55 m below the surface. The phosphatic horizon varies from 1.5–6 m in thickness, and is described as a shoestring deposit, with a width of about 300 m and a possible length of 24 km. The grade and lithologies are variable, with marked facies changes away from the high. It is mainly a relatively low-grade mudstone phosphorite, averaging 10–16% $P_2O_5$. Earlier estimates were that the resource could be up to several hundred million tonnes, but recent investigations by Phosphate Australia Ltd estimate a resource of 6.1 Mt @ 15.6% $P_2O_5$, from 48.8 m.

Alroy is 90 km due north of Wonarah, and is both on the flanks and draped over the Palaeoproterozoic basement high. The phosphorite is associated with limestone and chert, with drill intercepts at depths of 10–15 m. Phosphate Australia has current estimates of 4.6 Mt @ 15.5% $P_2O_5$ from 17.4 m for this resource. The Buchanan Dam deposit has an estimate of 6.1 Mt @ 25% $P_2O_5$ from 12.2 m (Phosphate Australia). The Highland Plains occurrence (Figure 2) sits on the NT–Qld border, northeast of the other deposits, and recent investigations give a best drill intercept of 11 m @ 27.2% $P_2O_5$ from 4 m, including 6 m @ 30.2% $P_2O_5$ from 5 m. The phosphorite has an average thickness of 4 m and a maximum of 7.6 m.

In addition to these known prospects, a number of greenfields occurrences have been identified throughout the basin, particularly in the southern part. Uramet Minerals Ltd have recorded up to 39.4% $P_2O_5$ from surface rock and soil sampling at their Marqua phosphate project and have delineated high-grade phosphate across an extensive area of the tenement (Uramet Minerals Ltd, ASX release 21/8/08). Nupower’s Lucy Creek prospect has been estimated from historic drilling to have potential for up to 43 Mt at up to 21% $P_2O_5$, and 104 Mt at up to 16% $P_2O_5$ (Nupower Resources Ltd, ASX release 29/1/09). Nupower’s Arganara prospect lies about 20 km northeast of the known Ammaroo prospect, and is also considered very prospective. Khan et al (2007) also identified phosphate mineralisation (2.28–16.9% $P_2O_5$) over a 45 m interval from a depth of 30 m in a water bore east of Ammaroo. Several prospective locations with elevated phosphate levels (up to 2%) in water bores drilled into the Georgina Basin on the eastern flank of the Tennant Region were also identified in this study.

![Figure 2. Model of Highland Plains Phosphate deposit (source: Phosphate Australia Ltd website).](image)
Wiso Basin
The Middle Cambrian Montejinni Limestone and overlying Hooker Creek Formation are the main phosphatic units in the Wiso Basin, and are stratigraphically equivalent to the major phosphatic intervals in the Georgina Basin.

The Lady Judith (Buchanan Hill) prospect is located on the western edge of the Wiso Basin and Howard (1990) has reported the presence of 31% P$_2$O$_5$ on the western edge of the Wiso Basin and Howard nodules. Wells coarser residual quartz, and phosphate pellets and concentrated by winnowing of finer material, leaving thin and thick bedded claystone. A recent NTGS investigation of a water bore in this area showed high-grade phosphate (up to 28.2% P$_2$O$_5$) at shallow depths. The Kunayangka phosphate occurrence is located about 52 km southwest of Tennant Creek and has a maximum grade of 2.43% P$_2$O$_5$ (Khan et al 2007).

Amadeus Basin
Sedimentary rocks within the Amadeus Basin contain pelletal phosphate rocks in a number of Neoproterozoic to Cambro-Ordovician units. The most promising stratigraphic unit is the Ordovician Stairway Sandstone, which records six occurrences that range in grade from 5 to 27% P$_2$O$_5$. The phosphate is predominantly pelletal, although nodular phosphate also occurs within interbedded shale and sandstone with minor carbonate rocks and phosphorite. The phosphorite is sometimes fissiliferous and includes numerous trace fossils and microfossils. The pelletal phosphate is believed to have originated from cold, upwelling, shallow-marine oceanic currents that impinged upon a submersed shelf (Wells et al 1970). The pellets are believed to be lag deposits, concentrated by winnowing of finer material, leaving coarser residual quartz, and phosphate pellets and nodules (Wells et al 1970). Although there are a number of phosphate beds in the Stairway Sandstone, they are not considered an economic resource; however, a total resource of 2.25 x 10$^{11}$ t P$_2$O$_5$ has been published for the unit (Cook 1972).

Rum Jungle
Phosphate rock was identified at 18 localities in the Rum Jungle area in the early 1960s from Government drilling (Pritchard et al 1966). The host unit for the phosphate rock is the Palaeoproterozoic Buckshee Breccia, a haematite-rich quartz breccia with interbeds of siltstone and rare shale breccia that overlies the Coomalie Dolostone. The principal mineral is microcrystalline fluorapatite enclosed in a haematite-rich breccia. Reserves of 5 x 10$^6$ t with a minimum grade of 10% P$_2$O$_5$ has been estimated for the deposits (Eupene 1991). The largest deposit is Geolsec, with recent exploration by Korab Resources Ltd resulting in drill intercepts of 37.2% P$_2$O$_5$ over 6.9 m to 14 m in DDH6; and 20.36% P$_2$O$_5$ over 7.6 m to 21 m in DDH1 (Korab Resources ASX release 29/12/08). Various interpretations of the origin of the Rum Jungle deposits include: hydrothermal deposits; secondary weathering of phosphatic rocks in the underlying Coomalie Dolostone; and metamorphosed phosphate-rich iron-bearing sediments. The last of these is the most widely accepted interpretation. The resources are considered suitable as ground-rock phosphate, but not for production of superphosphate, due to the very fine nature of the apatite and high iron and aluminium content (Eupene 1991).

Other deposit types

Vein - Nolans
A resource of 3.9 Mt @ 12.9% P$_2$O$_5$ has been identified at the Nolans deposit of Arafura Resources Ltd, located in the Aileron Province of the Arunta Region, approximately 150 km north of Alice Springs (Arafura Resources Ltd, ASX release 11/11/08). This deposit consists of REE, U, P and calcium carbonate contained in large fluorapatite veins within Palaeoproterozoic basement rocks.

Minor occurrences
Other phosphate occurrences are minor, but are worth noting, as they extend phosphate potential into other geological regions of the NT. These occurrences are recorded in Cretaceous sediments at Bathurst Island and near Darwin, in a phosphate crust at Ashmore Reef, in the McArthur Basin and in the Harts Range area in the Arunta Region (Eupene 1991).

References


GEOLOGY AND MINERAL POTENTIAL OF THE MURPHY INLIER REGION

Andrew S Wygralak1, 2, Terrence P Mernagh3, Julie A Hollis4 and Chris J Carson1

The Murphy area, located in CALVERT HILLS4, encompasses three geotectonic terranes. The central part comprises the Murphy Inlier. This least studied portion of the North Australian Craton forms an east-trending belt of Palaeoproterozoic, multideformed greenschist-facies metasedimentary rocks, including the Murphy Metamorphics, and also contains the Nicholson Granite Complex and comagmatic felsic Cliffdale Volcanics. It formed an intrabasinal high and separates the unconformably overlying McArthur Basin to the north from the South Nicholson Basin and Lawn Hill Platform successions to the south. The Tin Hole Hinge Line defines the northern boundary of the Murphy Inlier and separates it from the oldest formation of the McArthur Basin, the Westmoreland Conglomerate. The southern boundary of the Inlier is less well defined, but probably coincides with the Fish River Fault Zone. One hundred and four mineral occurrences are recorded in the Murphy area, including 38 uranium occurrences (some with gold) and 52 copper occurrences (NTGS MODAT database)5.

Several structural problems need to be addressed to better understand the deformational history of the Murphy Inlier and the nature of its contact with the McArthur Basin. The latter forms a hinge zone and a complex zone of reverse faulting associated with uranium mineralisation. There is an indication that the Murphy Inlier was uplifted after the deposition of the lower part of the Tawallah Group of the McArthur Basin.

New geochronological data from detrital zircons reveals a maximum depositional age of 1853 ± 4 Ma for the Murphy Metamorphics, 1865 ± 7 Ma for the lower section of the Westmoreland Conglomerate, 1843 ± 4 Ma for the upper section of the Westmoreland Conglomerate and 1853 ± 4 Ma for the Wire Creek Sandstone, which is a stratigraphic equivalent of the Westmoreland Conglomerate at the southern edge of the Murphy Inlier. However, the most interesting age was obtained from a thin horizon of pink silicified rock hosted by the Westmoreland Conglomerate, just 2 m above its contact with the Palaeoproterozoic basement (Figure 1). This rock was dated at 1830 ± 7 Ma. It may represent proximal volcaniclastic sediments most likely related to trachyandesite of the Bennara Intrusive Suite in CoanJula, dated at exactly the same age by Hanley (1996). The significance of this date is that it may reflect the true age of the beginning of sedimentation in the southern McArthur Basin.

Several issues need to be addressed in relation to mineralisation in this region.

5 Remaining occurrences include Sn, W, Mn and Zn.

Figure 1. Pink volcanoclastic sediment, dated at 1830 ± 7 Ma and occurring just 2 m above unconformity with Palaeoproterozoic basement might provide true age for beginning of sedimentation in McArthur Basin.
The provenance of copper mineralisation at Redbank is still unclear and models applied there range from carbonatite-related to a non-magmatic end member of Iron Oxide Copper Gold style (Hunt et al. 2007). Our stable isotope data of the ore-stage dolomitic vein indicate a range of $\delta^{18}O$ values from 16.5 to 17.5‰ and $\delta^{13}C$ values from -4.0 to -3.9‰. Such ranges are consistent with a carbonatitic or hydrothermal provenance. $\delta^{34}S$ values of chalcopyrite are in the range 5.6–5.7‰, which is consistent with the derivation of $H_2S$ from either magmatic or sedimentary sources. However, fluid inclusion data indicate the involvement of a low-temperature (120°C), high-salinity (22 wt% CaCl$_2$ eq) basinal brine.

One of the most important metallogenic problems in the project area is to answer the question of whether there is or isn’t a uranium-copper mineral system. Currently known indications of such a system include the following:

- A recent airborne radiometric survey by Redbank Mines Ltd has shown that the entire unit of the Gold Creek Volcanics, which is a major host of copper mineralisation, is also enriched in uranium.
- Pyrobitumen matrix from the Redbank deposit has elevated radioactivity.
- Grains of chalcopyrite occur in quartz-feldspar veins in the NE Westmoreland uranium prospect.
- Some copper prospects contain up to 102 ppm uranium.
- Copper mineralisation in the Cliffdale Volcanics is associated with similar fluids to those containing uranium mineralisation at the Eva uranium mine. These are: (1) CO$_2$- and CH$_4$-rich fluids homogenising at 230–370°C; and (2) a low-salinity gas-poor fluid homogenising at 100–300°C.

However, in spite of the above indications, at this stage of this project, it appears that copper and uranium mineralisation is largely separate. It is important to find out what separates these two metals at the precipitation stage.

Finally, it is suggested that future work should involve some geophysical studies designed to establish the depth to the basement unconformity and presence of potential packages of graphitic rock units under the cover of the Tawallah Group. This could lead to opening up new plays for uranium exploration.

References


INSIGHTS INTO ALTERATION AND MINERAL POTENTIAL OF VOLCANIC SUCCESSIONS OF THE MURPHY INLIER AND SURROUNDING AREAS

Karin Orth

The Murphy Inlier underlies the southern edge of the 5–10 km-thick McArthur Basin, which contains uranium+Au deposits and the rich McArthur River Pb-Zn and Redbank Cu deposits along its western edge. At the eastern edge of the McArthur Basin are the Westmoreland U deposits. South of the Murphy Inlier are Pb-Zn deposits of the Lawn Hill Platform. Within the Murphy Inlier are also old workings, such as the Norris Cu Mine and the granite-hosted Sn-W deposit of Crystal Hill (Ahmad and Wygralak 1989). Near the NT–Queensland border, the Murphy Inlier comprises the Palaeoproterozoic felsic Cliffdale Volcanics, intruded by the Nicholson Granite Complex. The basal McArthur Basin succession unconformably overlies the granite-volcanic complex and consists of the Westmoreland Conglomerate and the mafic Seigal Volcanics.

Cliffdale Volcanics

The Cliffdale Volcanics are an extensive, 4.5 km-thick volcanic complex, comprising dacitic and rhyolitic lavas, ignimbrites and intrusions. Minor andesite and a few sedimentary intervals punctuate the succession (Mitchell 1976). In the NT, a dacitic ignimbrite and later flow-banded rhyolite lava are the main components of the Cliffdale Volcanics, along with minor andesite near the top. Outliers of the volcanics are surrounded by the Nicholson Granite Complex. Complicated relationships exist between the Cliffdale Volcanics and the surrounding granite. Two of the southern outliers of the Cliffdale Volcanics are intruded by granite and even form roof pendants in the granite. East of Pandanus Creek, high-angle flow banding in rhyolite and the overall shape of a felsic body suggest that the volcanics could be intruding early phases of the granite. Near-flat contacts between the two units in the central region of the Cliffdale Volcanics are difficult to resolve as either nonconformities or sill-like intrusions. Numerous

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quartz-feldspar porphyry bodies and dykes intrude both the volcanics and the granite.

**Seigal Volcanics**

The initiation of sedimentation in the McArthur Basin over the eroded Murphy Inlier basement is marked by the Westmoreland Conglomerate and overlying mafic Seigal Volcanics. The Westmoreland Conglomerate was fed from quartz-rich continental rocks to the northeast of CALVERT HILLS¹ (Wygralak et al. 1988), but contains minor locally derived components. Basalt of the Seigal Volcanics comprises lower and upper units, divided by the quartz-rich Carolina Sandstone Member. The Seigal Volcanics are overlain by quartz-rich conglomerate and sandstone of the Rosie Creek Sandstone, limestone of the McDermott Formation and the Wunnumantyala Sandstone. The lower Seigal Volcanics unit comprises massive basalt to dolerite containing flow units demarcated by amygdaloidal zones. The upper basalt unit contains fine-grained, lithic-dominated inter-basalt sedimentary rocks. Many basalt-sedimentary rock contacts are peperitic, indicating basalt intrusion and burrowing. Rawlings (2002) has suggested growth of the basalt succession by inflation of shallow sills into unconsolidated sediments, similar to successions forming in the young rift in the Gulf of California (Einsele 1986). Samples from the Seigal Volcanics confirm that the upper and lower Seigal Volcanics are chemically distinct (Rawlings 2002). Basalt from the upper unit generally contains higher levels of TiO₂, P₂O₅, Y, Nb, Zr than basalt in the lower unit.

¹ Names of 1:250k mapsheets are in uppercase.

**Regional diagenesis and alteration**

Intrusion of high-level granites into the Cliffdale Volcanics has resulted in weak to moderate alteration and metamorphism. Mafic phenocrysts are altered to chlorite, illite, and Fe and Ti oxides. Feldspar crystals are pseudomorphed by illite, quartz and K-feldspar. Pink colours are also common in the Cliffdale Volcanics indicating weak potassic alteration of the groundmass. Veins and veinlets of epidote(?) with selvages of pink potassic alteration cut the grey feldspar-phryic ignimbrite in the west and pyrite is present in altered rhyolite in the Cripple Horse prospect area. North of the Eva Mine, the succession is marked by a network of quartz veins and faults, including the northwest-trending Calvert Hills Fault.

**U-Au mineralization at the Eva Mine occurs where the Cliffdale Volcanics are faulted against and unconformably overlain by the Westmoreland Conglomerate. A zoned alteration pattern is developed in the underlying rhyolite, varying with distance from the unconformity. White clay/sericite+haematite alteration is closest to the unconformity and is associated with veinlets of yellow autonite. A zone of yellow-green illite/muscovite alteration in granophyre is 30 m above the unconformity. Chlorite becomes more abundant further from the unconformity. An outer zone of chlorite±potassic alteration enhances primary textures. The alteration was not mapped in detail and it is uncertain whether the outer zone is related to mineralisation in the Eva Mine area, or to broader diagenesis/alteration of the Cliffdale Volcanics.**

**Only one sample of basalt collected from the Seigal Volcanics is unaffected by diagenesis. Amygdales include quartz, chlorite and commonly a green mix of white mica and illite, which has been called celadonite (Sweet et al. 1981). Potassic alteration of plagioclase is common, as is the alteration of olivine and some portions of pyroxene to chlorite and Fe and Ti oxides. Haematite+anatase replace some ilmenite.**

Pink potassically altered rocks form elongate north-northeast-trending dyke-like bodies within the Seigal Volcanics in the Doctors Creek area. The dyke-like bodies are associated with quartz±haematite veins and breccias and were originally designated as rhyolite dykes (Sweet et al. 1981). Immobile element geochemistry identifies them as basalt. Similar alteration is also in the long northeast-trending dyke intruding the Murphy Inlier. Pink, potassically altered basalt hosts copper workings at the NW prospect (B-4) at the top of the Seigal Volcanics.

Illite taken from the contact between the Seigal Volcanics and Westmoreland Conglomerate at the El Hussen prospect is more similar to the illite associated with U-mineralisation at Junnagunna and Redtree than to the diagenetic illite reported by Polito et al. (2005). El Hussen illite has slightly lower K⁺, suggesting that it may have formed at lower temperatures than the illite at Junnagunna or Redtree (Cathelinaeau 1988). The basalt host at El Hussen may have influenced higher FeO and MgO in this illite than the illite hosted in quartz sandstone of the Westmoreland Conglomerate.

**Geochemistry and mineral potential**

Rock samples taken throughout the study were also analysed for a range of elements including U, Au, Pt, W, Bi, Se, As, Cu, Pb, and Zn.

In the Cliffdale Volcanics, a sample from the Eva Mine area has elevated Bi, Cs, Se, Sn, W and slightly
higher U. Elevated U is also present in other samples with associated higher values of Th, Tl and Y. The most abundant REE are present in a rhyolite sample near to, but in the outer alteration zone of the Eva Mine. The rhyolite also exhibits elevated Be, Cu and U.

Some Seigal Volcanic samples have elevated Au, Pt, Pb and Cu. Elevated Cu is in the potassically altered basalt from the NW prospect at the contact between the upper Seigal Volcanics and the overlying McDermott Formation. The same sample is also anomalous in As, Ag, Pt, U and W. Elevated Pt is present in basalt found near the top and base of the Seigal Volcanics, not far from the type section, as well as in a dyke from Jumagunna and the altered dyke intruding the Murphy Inlier. Elevated Au is in a basalt sample from a locality near the Calvert Hills Fault.

Potential for different periods and styles of mineralization is evident from the rock types and associated alteration in the Murphy Inlier and overlying basal McArthur Basin succession. The complex relationships between the Nicholson Granite and the Cliffdale Volcanics indicate that the granite and many intrusions reached high crustal levels. Associated volcanism and high heat flow could have provided circulation for the development of fine-grained epithermal gold and possibly Mo deposits and has produced Sn and W deposits. A later, post- or syn-McArthur Basin fluid circulation system, postdating the McArthur River (HYC) deposit by MIM Holdings Pty Ltd.

References


THE MYRTLE ZINC DEPOSIT, NT: AN EXPLORATION CASE HISTORY

Ian R Mulholland

The Myrtle zinc deposit is located about 730 km southeast of Darwin in the Northern Territory, and 17 km south of the McArthur River zinc-lead mine (Figure 1).

Although exploration of the deposit is still at an early stage, an inferred mineral resource of 38 Mt grading 4.2% Zn and 1.0% Pb (5.2% combined Zn+Pb) has been estimated at 3% Zn+Pb cut-off, based on 11 out of 14 holes drilled. At a higher-grade cut-off of 5% Zn+Pb the resource is 15 Mt @ 5.5% Zn and 1.5% Pb (7.0% combined Zn+Pb).

Myrtle is probably the most significant zinc deposit discovered in Australia in the last 20 years or so, since the discovery of Century in 1991.

The Myrtle sub-basin was first identified as an area prospective for zinc-lead mineralisation of a style similar to the McArthur River (HYC) deposit by MIM Holdings

Managing Director, Rox Resources Limited.
Limd (MIM) and Carpentaria Exploration Company Pty Ltd (CEC) geologists in the mid 1960s. The first drillhole at Myrtle (MY1), drilled in 1967 by MIM, targeted an IP anomaly and intersected a 36 m interval containing about 20% pyrite and averaging 0.6% Zn from 56 m depth. A second hole (MY2), drilled in 1974 by CEC, was located 1.6 km to the west of MY1 (Figure 2). This hole intersected a stratigraphy similar to that in the first hole.

Hindsight shows that both of these holes were terminated short of the base metal mineralised horizon and the holes should have been drilled through to the footwall Teena Dolomite.

Subsequent exploration by a number of companies was patchy, with gravity and EM anomalies described as 'surficial'. History shows that they probably were not.

In 1997, the Myrtle prospect was pegged by North Ltd (North) and the tenement was granted in July 2002. In the intervening 5 year period, North was taken over by Rio Tinto Ltd (Rio), but some of the same geological team that had pegged the ground for North were retained. Rio proposed 3 drillholes at Myrtle, but for corporate reasons, they decided to farm out the tenement to Anglo American (Anglo). In 2004–2005,

Figure 1. Location of Myrtle Project.

Figure 2. Myrtle prospect plan showing resource outline, soil anomalies and surface geology (interpreted).
Anglo drilled a number of holes (Figure 2), resulting in the intersection of significant thicknesses of zinc mineralisation (Figure 3):

- MY6: 06.7 m @ 5.7% Zn, 1.8% Pb from 473.5 m
- MY7: 02.0 m @ 4.1% Zn, 0.5% Pb from 389.4 m
- MY8: 06.4 m @ 3.8% Zn, 0.4% Pb from 240.6 m
- MY10: 25.0 m @ 4.8% Zn, 1.4% Pb from 216.0 m.

Anglo should therefore be credited with the discovery of the Myrtle zinc deposit, but for corporate reasons of their own, they withdrew from the JV with Rio in 2006.

Rox Resources Ltd (Rox) signed an Option to Purchase agreement with Rio in January 2008. Rox has since exercised the Option, and now owns 100% of the deposit, subject to a royalties and other amounts payable to Rio upon the commencement of production.

During 2008, Rox continued exploration drilling at Myrtle and recorded the following results:

- MY16: 19.0 m @ 4.1% Zn, 1.3% Pb from 179.0 m
- MY17: 09.3 m @ 4.1% Zn, 1.0% Pb from 407.8 m
- MY19: 12.0 m @ 4.0% Zn, 0.6% Pb from 149.0 m
- MY20: 08.9 m @ 5.3% Zn, 1.3% Pb from 363.1 m
- MYR22: 11.0 m @ 3.2% Zn, 1.1% Pb from 060.0 m
- MYR23: 06.0 m @ 3.3% Zn, 0.3% Pb from 115.0 m.

The zinc-anomalous interval drilled in holes MY1 and 2 is present in every hole subsequently drilled and is about 80 m above the base metal interval.

Soil sampling and geological interpretation has demonstrated that the mineralised zone comes to the surface (Figures 2, 3), so both open pit and underground mining potential exist. Geochemical indicators are subtle, with a peak zinc-in-soil value of about 580 ppm, and 0.24% in rock chips. The deepest mineralisation so far intersected is at about 500 m depth in hole MY6; this is interpreted to be the deepest part of the sub-basin.

Mineralogical analysis has shown the host rocks at Myrtle to be tuffite (containing K-feldspar), in comparison to shale host rocks at McArthur River. They are both units of the Barney Creek Formation. However, the geological setting and deposit-forming processes at Myrtle and McArthur River are believed to be similar. Both rock assemblages have been subjected to a later carbonate overprint with accompanying replacive sulfide mineralisation.

In the case of Myrtle, it appears that this replacive mineralisation has produced coarse-grained sulfides that should be much more amenable to metallurgical recovery than the extremely fine-grained sulfides at McArthur River (which require ultra-fine grinding to 7 μm). In the samples examined from Myrtle, the majority of the sphalerite occurs as grains greater than 100 μm in size, without pyrite or galena inclusions or attachments.

The Zn to Pb ratio at Myrtle of 4:1 is higher than the 2 to 1 ratio at McArthur River and this higher Zn:Pb will also enable higher metallurgical recoveries. Test work is planned to evaluate metallurgical recoveries.

The mineral resource size at Myrtle is currently constrained by the limits of drilling and it is likely that the resource will increase significantly with further drilling, especially in the area of an untested zinc-in-soil anomaly that indicates a possible 1 km extension to the mineralised zone.

Based on the current resource, Myrtle falls into the top ten Sedex zinc deposits in Australia (Table 1), and

Figure 3. Drill cross-section A–A’ at 8167000mN. Location shown in Figure 2.
when exploration and resource definition drilling is complete, it will probably exceed 100 Mt in size.

Rox is now looking for a significantly sized and resourced corporate partner to help it progress the Myrtle deposit through feasibility studies to production, and in November 2008, the company signed an MOU with a major Chinese Government-owned company to acquire 80% of the project for $12.5 million.

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<th>Deposit</th>
<th>Mt Ore *</th>
<th>Mt Zn + Pb</th>
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<td>Broken Hill</td>
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<td>3.1</td>
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</table>

Table 1. Giant Sedex Zinc deposits in Australia. * Based on published pre-mining resources as listed in Leach et al (2000).

Reference


MAGMATISM IN THE EASTERN ARUNTA REGION: IMPLICATIONS FOR NI, CU AND AU MINERALISATION

Jo Whelan¹,², Lachlan Hallett⁴ and Dorothy Close⁴

The Arunta Region extends over an area of approximately 180 000 km² and has undergone multiple tectonothermal events in a period spanning the Palaeoproterozoic to the Carboniferous. The region is divided into the Palaeoproterozoic to Mesoproterozoic Warumpi and Aileron provinces and the Neoproterozoic to Palaeozoic 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 high frequency of deformation of variable intensity, high-grade metamorphism and an abundance of granitoids that distinguishes it from many of the other Proterozoic provinces in northern Australia (Shaw et al 1984, Hoatson et al 2005, Scrimgeour 2009).

In the eastern Arunta Region, the Irindina Province comprises a thick basin succession with stratigraphic affinities to the Neoproterozoic to Palaeozoic Amadeus Basin (Buick et al 2001, Maidment 2005). The province has undergone Palaeozoic granulite-facies metamorphism and extension-related mafic and ultramafic magmatism that are 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.

Recent mapping and geochemical studies by NTGS have identified: (1) shear zone-hosted Au and Cu mineralisation in a predominantly igneous basement terrane; and (2) several plug-like mafic bodies intruding the Irindina Province with visible primary and secondary copper mineralisation. Subsequent work by Mithril Resources Ltd has led to further discoveries of mafic intrusive rocks associated with Ni and Cu mineralisation in the area including the Blackadder, Baldrick and Edmund prospects (Mithril Resources Ltd, ASX announcements, 8 September 2008; 17 November 2008). Here, we discuss the origin and tectonic setting of mafic to intermediate magmas associated with mineralisation and the role that post-emplacement deformation and fluid flow in an intraplate setting may have had on mineralisation in the eastern Arunta Region.

Geological setting

The eastern Arunta region has been affected by numerous tectonothermal events (Scrimgeour 2003, Hand and Maidment 2007), including the Yambah Event, Larapinta Event and Alice Springs Orogeny. The 1780–1770 Ma Yambah Event, which is associated with the emplacement of voluminous felsic and lesser mafic intrusive rocks. Granitoids and orthogneiss of the Ambulbinya Igneous Suite (Whelan et al 2008) form part of the calc-alkaline-trondhjemite (CAT) suite of Zhao and McCulloch (1995). These rocks have arc-like affinities and have been interpreted to have been generated in a subduction-zone setting (Foden et al 1998, Zhao and McCulloch 1993, Zhao and McCulloch 1995), through either fractionation and/or partial melting of arc related magmas, or underplating. Magmatism was accompanied by compressional deformation interpreted to reflect the closure of a back-arc basin and the development of a continental arc (Scrimgeour 2006).
The 480–460 Ma Larapinta Event has currently only been recognised in the Irindina Province. It is characterised by granulite-facies metamorphism (Miller et al 1997, Mawby et al 1999, Buick et al 2005, Maidment 2005) and was accompanied by the intrusion of mafic to ultramafic dykes and plugs, and by the deposition of fine-grained sediments in an extensional setting (Mawby et al 1999, Hand and Maidment 2007).

The 450–300 Ma Alice Springs Orogeny is divided into the Late Ordovician Rodingan Event, the Devonian Pertnjara-Brewer events and the Carboniferous Eclipse Event. This multiphase orogeny began with basin inversion of the Irindina Province, followed by thick-skinned deformation and exhumation along major crustal-scale structures and amphibolite-facies metamorphism and felsic magmatism, including the intrusion of voluminous pegmatites. Large-scale fluid flow was responsible for widespread REE mineralisation (Hussey 2004).

Field observations and petrography

Recent field mapping, focused on the Harts Range Metamorphic Complex (Irindina Province) in ILLOGWA CREEK, has identified several occurrences of plug-like intrusions of olivine-bearing gabbroic rocks (Figure 1), which intrude granulite-grade metapelites and metapsammopelites of the Irindina Gneiss. Contacts between the intrusions and host rocks are generally sheared and these shear zones contain visible chalcopyrite, malachite and azurite. The olivine gabbro and gabbronorite display primary igneous textures and consist of olivine + orthopyroxene + plagioclase ± clinopyroxene. Petrographic studies reveal the presence of blebbly sulfides. Plagioclase is interstitial.

The Illogwa Schist Zone is a major 3–4 km-wide, north-dipping shear zone that strikes east to southeast over a distance of more than 25 km, south of Harts Range (Figure 1). The shear zone is hosted by Palaeoproterozoic basement and interpreted to have been active during the Alice Springs Orogeny. It is characterised by discrete zones of chloride and muscovite alteration. Magnetite is prevalent through most rock types and layered quartz magnetite rocks containing up to 60% magnetite are present. Igneous rocks in the zone range in composition from mafic varieties through to granodiorite and are referred to the Aremra Suite (Figure 1). Vein- and shear zone-hosted copper mineralisation is present at a number of localities (eg IC08JAW1027 and IC08LJH616, Figure 1). Shear zone-hosted mineralisation consists of chalcopyrite + djurleite + covellite + malachite + goethite (and other secondary copper minerals) and is interpreted to represent original massive chalcopyrite ‘ore’, which has been protomylonitised and oxidised (Pontifex Mineralogical Report 9488). Mineral paragenesis studies suggest that chalcopyrite formed pre- to syn-deformation and defines the regional shear fabric in the area.

Igneous Geochemistry

Olivine gabbro/gabbronorite (Blackadder-type)

Field observations have identified a number of plug-like mafic bodies intruding the Irindina Gneiss and the Huckitta Bore Boudin. These consist of olivine-bearing gabbro and gabbronorite with primary igneous textures. Constituent minerals range from olivine + plagioclase to olivine + orthopyroxene + plagioclase + pigeonite + chromite. These intrusions have high MgO contents (17 to 24 wt%) and elevated Ni, Cu, Cr and Co. La/Sm ratios range from 1.9 to 2.2, which may suggest a small amount of crustal contamination. Primitive mantle-normalised, incompatible trace-element diagrams show relatively featureless sloping trends with some scatter in the more mobile elements.

Aremra Suite

The Aremra Suite outcrops within and extends south of the Illogwa Schist Zone (Figure 1). Diorite and granodiorite the most abundant rock types. SiO₂ contents are in the range 50.8–63.1 wt%. These rocks are also characterised by high Fe₂O₃, Al₂O₃, and Cu, and contain trace Au, F and S. The Aremra Suite is characterised by steep REE patterns, where La/Yb ratios range from 3 to 4.8, and shows some evidence of fractionation.

Field observations have identified small, discrete shear zones and quartz veins containing visible mineralisation within the Illogwa Schist Zone proximal to the Aremra Suite. Grab samples from one shear zone returned 35.4% Cu and 0.12 ppm Au and elevated PGE, Ag, Mo and U. A grab sample from a quartz vein at the Hale River Prospect, 7 km along strike from the mineralised shear zones, displays a similar pattern of enrichment with 2.94 ppm Au, 13% Cu and elevated Ag.

Mineralisation styles

The Northern Territory has historically had few identified economic nickel sulfide resources, in spite of the recognised prospectivity of the Arunta Region for mafic-hosted mineralisation (Hoatson et al 2005). This study has identified two types of mineralisation in the eastern Arunta Region: a mafic/ultramafic nickel association and an intermediate copper/gold association.

The newly identified Blackadder-type intrusive rocks described here are associated with mafic magmas intruding granulite-facies pelitic and psammitic metasedimentary rocks of the older stratigraphic units of the Irindina Province. The intrusions are

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1 Names of 1:250k mapsheets are in uppercase.
unmetamorphosed and display primary igneous textures. Field relationships suggest that they are Palaeozoic. Mineralisation occurs as blebby sulfides in the mafic intrusions and as disseminated sulfides along the sheared contacts with country rocks. Slightly elevated, light rare earth element contents suggest that some crustal contamination has taken place, likely the result of assimilation of surrounding gneiss or metasedimentary rocks at the time of intrusion.

Igneous rocks of the Aremra Suite are geochemically similar to granites from the Entia Dome which are dated at ca 1770 Ma (Maidment 2005). They are slightly fractionated I-type granitoids that have crystallised from an oxidised magma and they contain elevated Cu and trace Au. Shear zones and quartz veins in the vicinity of the suite contain high abundances of Cu + Au + U ± PGEs. Mineral paragenesis suggests that, at the very least, chalcopyrite growth occurred pre- to syn deformation, ie, prior to the Alice Springs Orogeny. Large-scale fluid flow through the Illogwa Schist Zone may have remobilised metals, depositing them in discrete shear zones and quartz veins proximal to the Aremra Suite.

Figure 1. ALOS satellite imagery of the Quartz 1:100 000 mapsheet area showing the location of the Blackadder and Baldrick Ni+Cu+PGEs prospects (data from; Mithril Resources ASX releases 15th September 2008 and 17th November 2008) and the Hale River (IC08LJH616) and shear zone hosted (IC08JAW1027) Cu + Au mineralisation (samples collected by NTGS during 2008 field season) along with the location of the Illogwa Schist Zone (Green shading) and the Aremra Suite (pink shading). Olivine-bearing gabbroic rocks are identified by red dots.
Discussion

The eastern Arunta is a highly prospective under-explored region that 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 eastern Arunta Region has identified new mineralisation styles associated with diverse magmatic events. In the Irindina Province, Ni-Cu sulfide mineralisation is associated with Palaeozoic, rift-related mafic magmatism. In contrast, mineralisation in the Aremra Suite is interpreted to be related to Palaeoproterozoic arc-related magmatism at ca 1770 Ma and to have been remobilised during Palaeozoic intraplate tectonism.

References


BLACKADDER GOES FORTH: NICKEL SULFIDES IN THE IRINDINA PROVINCE

Jim McKinnon-Mathews

Executive summary

- Mithril Resources Ltd (Mithril) has discovered significant Ni-Cu-PGE mineralisation at three locations within the Harts Range Alliance project area. Rock chip samples have assayed up to 3.8% Ni, 9.6% Cu and 1.7 g/t Pt+Pd+Au at the Blackadder Prospect, on the contact between an olivine-bearing norite and a felsic gneiss (Figure 1).
- Mithril targeted the region on a conceptual basis as it presents a favourable environment for the formation of significant nickel sulfides. The area has not seen any historical nickel sulfide exploration, nor had any nickel sulfide mineralisation been identified until Mithril’s recent discovery of Blackadder.
- Recent geological mapping and sampling has identified over 25 gabbroic bodies interpreted to be the same generation of mafic intrusive as that at Blackadder within an area of >1000 km². Many of these bodies contain disseminated and blebby magmatic sulfides.
- The prospective gabbroic intrusions are undeformed and vary in size, with some as large as 600 m x 2000 m.
- Much of the project area is covered by thin (<100 m) alluvium and/or colluvium and it is suspected that further targets exist beneath cover that would be readably detectable using geophysical methods.
- Mithril has consolidated a 4335 km² land package of tenements through three joint ventures and one tenement that is held 100% by Mithril.

Introduction

In September 2008, Mithril announced the discovery of nickel-copper-bearing gossans at the Blackadder Prospect, where rock chip assays returned high-grade values of up to 3.8% nickel, 9.6% copper and 1.7 g/t platinum + palladium + gold. The mineralized horizon was mapped over a strike length of 180 m (Figure 1) before it plunged beneath thin sand cover. This discovery was the result of Mithril geologists following up a report by the Northern Territory Geological Survey (NTGS) of some minor secondary malachite staining near the contact of a mafic and felsic gneiss identified during the course of remapping the Quartz 100K sheet. Significantly, this is the first occurrence of nickel sulfide mineralisation identified in the region, where Mithril has consolidated a leading tenement position referred to as the Harts Range Alliance Project. Subsequent to this discovery, further work has identified a number of other prospects (eg Baldrick and Edmund), which have returned highly anomalous Ni-Cu-PGE analytical results, and many other mineralised gabbroic intrusions.

The project is located approximately 150 km northeast of Alice Springs in the Northern Territory of central Australia (Figure 2) and comprises 4335 km². It is located entirely within pastoral lease and consists

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of five granted Exploration Licences, where Mithril is earning an 80% interest under three joint ventures, and one Exploration Licence Application, of which Mithril has 100% of the exploration rights. The area is situated within the highly deformed Neoproterozoic–Cambrian Irindina Province in the eastern portion of the Arunta Region.

Mithril acquired the project as a conceptual target for magmatic nickel, copper and platinum group (‘Ni-Cu-PGE’) sulfide mineralisation associated with mafic and ultramafic intrusions. The targeting focused on a number of continental-scale structures interpreted from regional gravity, magnetic and geological data that intersect on the interpreted southern edge of the North Australian Craton.

**Geology**

The project straddles the contact between the Neoproterozoic–Palaeozoic Irindina Province and Mesoproterozoic rocks of the Arunta Region, between the Georgina and Eromanga Basins (**Figure 2**). The Irindina Province consists of a package of rapidly buried rift-related sediments and mafic to ultramafic intrusive rocks that were metamorphosed to upper amphibolite and granulite facies during the 480–460 Ma Larapinta Event (Scrimgeour 2003).

Regional geological mapping by various government organisations has identified outcropping and subcropping metasediments including calc-silicates, amphibolites and metamorphosed carbonate rocks throughout the project area. The available published geology is from mapping in the late 1970s and early 1980s, and the area is currently being re-mapped by NTGS. These packages of basement rocks are commonly covered by a thin veneer of alluvium and/or colluvium, and drilling to the north suggests that the cover is typically very shallow (10–100 m thick).

Historically, there are a number of locations where mafic rocks have been identified within the project area (**Figure 3**). It is only recently that more attention has been paid to these and from Mithril’s recent field activities, it appears there are at least three different generations of mafic intrusive events. It appears that only one generation of these intrusive rocks is undeformed and these host the Ni-Cu-PGE mineralisation identified to date. Mithril refers to this generation of mafic intrusive rocks as the Blackadder Intrusive Event (BIE).

The BIE intrusives range from leucogabbro to sulfide-bearing olivine norite with a picritic composition. The presence of blebby and disseminated pyrrhotite, pentlandite and chalcopyrite mineralisation has been confirmed through the petrology of the host mafic unit at Blackadder and Baldrick, and at a number

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**Figure 2.** Harts Range Alliance tenements and Mithril’s Huckitta Project.
of other locations (Figure 3). At three locations, the Blackadder, Baldrick and Edmund prospects, assays that are highly anomalous in nickel, copper, platinum, palladium and cobalt values have been returned from gossanous material on the contact between the mafic intrusive rocks and felsic gneiss.

The larger of the BIE bodies identified to date are often geologically complex, with both textural and compositional variations common. It is also apparent that there are multiple pulses of the BIE within these larger bodies. The bodies associated with the BIE are interpreted to be feeders from a large fertile magmatic event and have been the subject of little or no systematic exploration.

**Mithril exploration**

Following the discovery of magmatic Ni-Cu-PGE mineralisation at the Blackadder Prospect in late August 2008, exploration efforts by Mithril focused on the distribution of the BIE. Systematic field checking over a ten-day period in October 2008 identified more than 25 additional BIE bodies within the project area. Of these, approximately 10 were found to contain disseminated and/or blebby magmatic sulfides in minor amounts (trace–1%) and a further two contain secondary copper and nickel mineralisation on the contact between the mafic intrusive rocks and felsic gneiss (Baldrick and Edmund Prospects; Figure 3). The Baldrick Prospect is about 1.2 km to the northeast of Blackadder and gossans very similar to those identified at Blackadder have been identified over approximately 25 m. Assay results have returned highly anomalous nickel, copper, PGEs and silver (Figure 4).

Recent desktop studies have revealed a number of further compelling targets to be field mapped and prospected in the coming months. In addition to this, ground and/or airborne electromagnetic surveys are planned, as well as drilling of the Blackadder and Baldrick prospects.

**Conclusions**

Through conceptual targeting, using continental scale datasets and published geological information, Mithril has discovered a fertile magmatic event hosting nickel-copper and PGE sulfides over a wide area in an underexplored region of the eastern Arunta Region of the Northern Territory.

Geological mapping and sampling to date over the largely sand/colluvium-covered project has identified over 25 bodies from the fertile event within the project area, with many containing evidence of nickel-copper sulfide mineralisation. This mapping has also identified the presence of large BIE bodies that have undergone no systematic exploration. Given the extent of the BIE and the presence of significant mineralisation, Mithril believes the area is an emerging nickel–copper sulfide province capable of hosting a large deposit.

The next phase of exploration will include further geological mapping, systematic geophysical surveys and drill testing of prospective targets.

![Figure 3. Prospect and mineralised BIE locations from mapping to date by Mithril.](image)
DEEP SEATED STRUCTURES AND MINERALISATION IN THE ARUNTA REGION

Dorothy Close and Ian Scrimgeour

The Arunta Region of the Northern Territory comprises complex Palaeoproterozoic to Palaeozoic provinces that have experienced multiple cycles of deposition, mafic and felsic magmatism, deformation and fluid flow. This prolonged activity has resulted in terranes that host an abundant and diverse range of metallogenic systems. Mineral systems that developed during the Palaeoproterozoic include VHMS and carbonate-replacement Zn-Cu-Pb, pegmatite-hosted Sn-Ta-W, IOCG, mafic magmatic-hosted Ni-Cu sulfide and V-Ti magnetite, and felsic magmatic-related Mo-W, REE and U. The Meso–Neoproterozoic was characterised by mesothermal W, REE, P, U, Th, Cu and Ag mineralisation.

During widespread intraplate deformation during the Palaeozoic, mineralisation styles include intrusion-related REE, U, Th and Ni-Cu, shear zone-hosted Cu and mesothermal Au. These mineralisation styles are spatially and temporally variable in their distribution, and the dominant style of mineralisation often changes across major regional structures.

The diversity of metallogenic styles is especially evident in the southeastern Arunta Region, which has been interpreted to be proximal to a late Palaeoproterozoic plate margin (Zhao and McCulloch 1995, Scrimgeour 2006). This tectonic setting led to the development of back-arc basins and interpreted VHMS deposits that are apparently absent inboard, in the northern Arunta, Tanami and Tennant regions. A recent compilation of Sm-Nd isotopic data confirms the input of younger crust from a depleted mantle source in the southeastern section of the Arunta Region and this is roughly coincident with the distribution of calc-alkaline-trondjhemitic arc-related magmatism (Zhao and McCulloch 1995). It therefore appears likely that there is an unexposed fundamental tectonic boundary in the southeastern Arunta Region, which defines a change in crustal signature and interpreted tectonic environments. This more complex setting has resulted in a greater diversity of mineralising systems during the Palaeoproterozoic.

Acquisition of improved resolution gravity data in the central Arunta Region during 2008, under the NT Government’s Bringing Forward Discovery initiative,
has provided greater delineation of regional-scale northeast- and northwest–southeast-trending structures. These structures are interpreted to be the result of phases of deformation during the Devonian to Carboniferous phase of the intraplate 450–300 Ma Alice Springs Orogeny, although many are likely to be reactivated, earlier, long-lived structures.

The Woolanga Lineament is a major northwest-trending structure that extends from the Casey Inlier in the southeast, through the Strangways Range into the northern Arunta Region. This lineament has possible economic significance and it has been interpreted to link with the Trans-Tanami fault system that extends to the gold deposits of the Tanami Region. The 2008 Central Arunta Gravity Survey has clearly delineated this structure, which is associated with substantial gravity gradients. Although the Woolanga Lineament does not appear to define fundamental differences in crustal ages and composition, it does define a trend of Meso–Neo-proterozoic, anomalous alkaline igneous and hydrothermal activity, including the 1300–1200 Ma Nolans REE-P-U deposit (Korsch et al 2009), 1130 Ma Mordor Complex, 732 ± 5 Ma Mud Tank Carbonatite, and undated Cu-REE veins in the Casey Inlier. This suggests that, although the Woolanga Lineament was active during the Alice Springs Orogeny, it is a long-lived crustal-scale structure that was a conduit for magmatism and mineralisation throughout much of the Proterozoic.

Integration of the new gravity data with existing magnetic, radiometric, geological and geochemical data suggests that the major crustal blocks, which are separated by significant gravity features, have differing geological and metallogenic characteristics. The discovery of new outcropping Cu-Au mineralisation in the Illogwa Shear Zone (Whelan et al 2009) highlights the under-explored mineral potential of these major reactivated structures, many of which have never been subjected to modern systematic exploration.

References


PROTEROZOIC NI-PGE EXPLORATION: MAFIC-ULTRAMAFIC MAGMATIC EVENTS

Jon Claoué-Long¹; 2, Dean Hoatson¹ and Subhash Jaireth¹

Worldwide, the discovered very large Nickel and Platinum Group Element (PGE) sulfide deposits are strongly concentrated in mafic igneous rocks of Proterozoic age. The rich Proterozoic Ni-PGE endowment of other countries – Canada, Africa, China, Russia – contrasts with the record of discovery in Australia, where only one world-class example has been found so far (Nebo-Babel in the Musgrave Province, ca 1080 Ma, ca 1.2 Mt Ni). The deficit of discoveries in Australia, relative to other continents, is unlikely to reflect real geological differences. Rather, it points to the difficulty of identifying settings for mineralisation in intrusions that are under cover. This presents a major opportunity for exploration that can use the knowledge gained from other continents to predict which magmatic events and intrusions may be most prospective.

Based on the settings of known very large Ni-PGE deposits, four questions can be used to distinguish highly prospective magma provinces and intrusions from others:

- **Where are the mafic-ultramafic magmatic systems?** Requires spatial / temporal correlation, under cover.
- **Which are the very large magmatic systems?** Requires spatial / temporal correlation, under cover.
- **Which magmatic events include ultramafic magmas?** Requires spatial / temporal correlation, under cover.
- **Can crustal structure narrow the exploration focus?** For example, to feeder zones, metallogenic belts.

To address these guiding questions, Geoscience Australia, in collaboration with the State and Northern Territory geological surveys, has produced a new ‘Map of Australian Proterozoic Mafic-Ultramafic Magmatic Events’ (Figure 1). It compiles the available solid geology of mafic-ultramafic magmatic rocks across

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the continent, and links to the extensive knowledge of geochronology gained in recent years. Solid geology gives insights into the total areal extent of magmatic systems, which is an important criterion when assessing mineral potential. An overlay of the Australian Crustal Elements Map provides a province framework for the location of the Magmatic Events.

The event chronology of Proterozoic mafic-ultramafic rocks in Australia resolves into thirty newly defined Magmatic Events which range in age from ca 2455 Ma to 510 Ma. The events are presented in a 1:5 000 000 national map with rock units of different ages colour-coded; as a large format Time-Space-Event chart; and as derivative maps that show Large Igneous Provinces (LIPs) and associated mineral deposits.

The new map and Time–Space–Event chart highlight important periods of mafic-dominated tholeiitic magmatism and the concentration of mafic-ultramafic magmatism during the period ca 1870 Ma to ca 1590 Ma (about 35% of all events). Nine of the thirty Magmatic Events are mineralised in Australia with known deposits or occurrences of Ni, Cu, and/or PGEs. Six Magmatic Events are coeval with major Ni-Cu ± PGE deposits in other continents (eg ca 2440 Ma Penikat in Finland; ca 1918 Ma Raglan, ca 1880 Ma Thompson and ca 1850 Ma Sudbury, all in Canada; ca 1403 Ma Kabanga in Tanzania; and ca 827 Ma Jinchuan in China). There are important correlations of these mineralised magmatic systems in Australia, under shallow cover and in under-explored provinces. The full geographic extent of the mafic-ultramafic magmatic systems is shown and significant extensions to some igneous provinces are evident.

In northern Australia, locally known mafic intrusions can now be seen as belonging to major continent-scale correlations of mafic-ultramafic magmatic systems which include ultramafic components or mineralisation elsewhere. The Arunta Region stands out as the location of repeated mafic and ultramafic magmatism in nine distinct Proterozoic Magmatic Events, reflecting its relationship with central Australian crustal elements. It includes mafic-ultramafic magmatic rocks from three extensive LIPs that may be prospective for mineralisation.

Map users are encouraged to overlay and integrate their own datasets, and to evaluate:

- the spatial distribution of Proterozoic mafic and ultramafic rocks, their geological settings, the frequency of emplacement and potential coeval relationships

Figure 1. The new 1:5 000 000 Map of Australian Proterozoic Mafic-Ultramafic Magmatic Events. Map can be downloaded at http://www.ga.gov.au/map/index.jsp/#mum.
the secular variation of mafic and ultramafic magmatism, such as mafic-dominated systems versus ultramafic-dominated systems

- the magnitude of each magmatic system (including LIPs), which has implications for structural frameworks, tectonic settings, and metallogenesis

- correlatives of magmatic units that are mineralised elsewhere in the Australian continent, and in other continents

- relationships with favourable reactive (eg carbonaceous, sulfur-bearing) country rocks that may potentially induce contamination and sulfur saturation of mafic-ultramafic magmatic systems during emplacement

- the spatial distribution of extrusive versus intrusive magmatic components within each Magmatic Event, as an indication of erosional levels and potential vectors to favourable mineralised environments, such as feeder conduits and basal contacts of intrusive bodies.

Calibrated Radiometrics and Threshold Images.

Roger Clifton¹

Under the Onshore Energy Security Program, Geoscience Australia completed an airborne geophysical tie-line survey (AWAGS2) around the entire country in 2007. This survey resulted in a radioelement datum enabling the calibration of all radiometrics surveys that overlapped the flight lines, or that overlapped other surveys which did.

Consequently, all major radiometrics surveys in the Northern Territory are now calibrated. As a result, the images of the individual grids and stitches now have Z-scales. Quantitative values estimated from the grids can now be quoted in reports with a reasonable prediction of ground values. Certainty is within 20%, a considerable improvement over the factor of two previously available.

Calibrated grids and images are available on disk free of charge from the NT Minerals and Energy InfoCentre (geoscience.info@nt.gov.au).

The NT-wide stitches have also benefited considerably. The values in each stitch now conform to values across the whole of the NT. The images are visibly improved. For example, survey boundaries no longer form steps in the data.

Ratios of radiometric values are now possible across the entire NT. In particular, the grids are now quantities, rather than qualitative images. Consequently, functions of these quantities can be defined, applied, and quoted in publications.

A simple example of functions of radiometric quantities are the principal components of thorium and potassium, shown in red and green in Figure 1.

Functions of related variables, such as geochemical data, can now be correlated reliably. Where a relationship can be predicted as a function, its image can similarly be projected and recurrences of the same relationship located.

Thresholding is an immediate value of the calibrated grids. In Figure 2, the total count is thresholded at 1.2 millisseivert per annum. Uranium miners will recognise that the value of two millisseivert per annum, familiar to them as the maximum public exposure permitted by their operations, is exceeded frequently in the images.

Areas of high radioactivity can be located and average values of each of potassium, uranium and thorium estimated from their respective images. In an image processor, the grids themselves can be interrogated and more detailed areas obtained directly from the grids.

Figure 1. Linear function of two radiometric quantities, thorium and potassium. First principle component is red, second principle component is green. Box shows location of Figure 2.

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However the grids too, are themselves highly smoothed from the line data.

When an explorer has located such an area of interest, it is recommended that the line data be obtained for a closer look at the localities concerned in graphs of the respective flight lines. Even in the individual measurements, the gamma ray intensity has been averaged over the footprint of the instrument, itself smoothed across a hundred seconds of the aircraft’s flight. Subsequent field investigation would certainly lead to higher values in detailed expressions on the ground.

Line data can be obtained on disk from the Minerals and Energy InfoCentre (geoscience.info@nt.gov.au). The line data is not yet calibrated, but a user can make the necessary corrections by comparing the mean values of the line dataset with its respective calibrated grid.

**Figure 2.** Total count over central highlands in southern NT; thresholded. Isolated values exceed the top of the scale. Location shown in Figure 1.