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DEPARTMENT OF BUSINESS, INDUSTRY AND RESOURCE DEVELOPMENT
MINISTER: Hon Konstantine (Kon) Vatskalis, MLA
CHIEF EXECUTIVE OFFICER: Peter Blake

NORTHERN TERRITORY GEOLOGICAL SURVEY
DIRECTOR: Richard Brescianini

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EDITORS: TJ Munson and I Scrimgeour

For further information contact:
Geoscience Information
Northern Territory Geological Survey
GPO Box 3000
Darwin NT 0801
Phone: +61 8 8999 6443
Website: http://www.minerals.nt.gov.au/ntgs

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ESTABLISHING A REGOLITH-LANDFORM FRAMEWORK FOR THE NT

Chris Edgoose[1], Roger Clifton, Mike Craig[2], Ian Robertson[3, 4]

NTGS and CRC LEME have embarked on a collaborative project to establish a regional regolith-landform framework of the Northern Territory, to assist mineral exploration and land management. This is the first project focused on the regolith to be undertaken by NTGS, and is also unique in its scope in regolith studies in Australia. A considerable amount of detailed site-specific regolith work has been done in continental Australia, especially through CRC LEME. There has been few attempts, with the exception of the Gawler Craton regolith studies undertaken from 1998 to 2002, to extend these site-specific models to the extensive cratons of the Australian continent. The NTGS project is scheduled to run from late 2003 until June 2005.

The regolith is a product of the processes of physical and chemical weathering, erosion and deposition resulting in landform transformation. In the tropical, sub-tropical and arid environments of the Northern Territory, these processes are reflected in the landforms, desert sands and loams, internal and external drainage systems, and ancient weathering surfaces. An understanding of the regolith is necessary for effective mineral exploration, and provides a framework for understanding landscape evolution, extractive and placer mineral occurrences, groundwater potential, rangeland management, and environmental geoscience.

In 1975, BMR (now Geoscience Australia) produced a 1:2.5M-scale Cenozoic Geological Map of the Northern Territory, mostly based on surficial units as represented on First Edition 1:250 000-scale geological maps. The Regolith-landform Map of Australia (1:5M-scale) was produced in 1984. These two maps showed some of the major alluvial-colluvial systems, and major areas of ferruginous duricrust. However, it did not address the integrity of the palaeodrainage systems that are largely covered by aeolian sands, particularly in the southern and central parts of the Territory. Nor did it address the question of the evolution of landsurfaces and regolith materials. Since then, there have been considerable advances in understanding regolith processes and their relationship to mineral exploration. In addition, there is a wealth of new information provided by Second Edition geological mapping, Landsat 7, Aster, DEM, radiometric and magnetic data from high-resolution airborne surveys, and drill data from mineral exploration. These excellent regional and detailed datasets, coupled with field-based studies of four selected sites from across the state, will provide an extended basis for a regional regolith-landform framework for the Northern Territory.

The project will entail:

- the compilation of existing information from various datasets such as DEM, radiometrics, magnetics, Landsat, Aster, regional groundwater studies, and geological maps. This process should yield information regarding general landforms, regolith materials and palaeodrainages;
- the selection of four areas for detailed investigations on regolith-landform processes. These four type areas will be the focus of the following activities: regolith-landform mapping; establishing the 3D distribution of regolith from drilling and natural exposures; and the characterisation and geochronology of regolith materials;
- establishing the origin of ferruginous duricrusts and silcretes;
- identifying and classifying relicts of major palaeo-weathering surfaces;
- using drillhole and other data to make first-order estimates of the depths of transported overburden in depositional environments; and
- establishing the weathering history, and developing landscape evolution models.

The major product from this work will be a regolith-landform map of the Northern Territory at 1:2.5M-scale, forming a companion to other Territory-wide maps (such as Geology, TMI, DEM and Radiometrics). Other products include detailed maps and reports for the four study areas, and an Atlas of NT regolith materials. On a more conceptual level, developments resulting from this work are aimed at: testing the rival hypotheses of singular, episodic or continuous weathering; reconstructing palaeo-drainages; forming a regolith-landform model for a large part of northern Australia; making a major contribution to the understanding of the physical and chemical processes of regolith materials of arid to tropical environments; creating a first-order framework for guiding geochemical prospecting for minerals and diamonds; and developing a firmer basis for identifying and assessing regional groundwater provinces.

[1] Email: christine.edgoose@nt.gov.au
[2] Email: Mike.Craig@ga.gov.au
[3] CRC LEME – Geoscience Australia
[4] CRC LEME – CSIRO

Work on the project to date has comprised setting the parameters and scope of the program, and a 10 day reconnaissance field trip from south to north late in 2003. This trip was aimed at developing a familiarisation with Territory landscapes, completing further scoping in terms of selecting the four detailed study areas, and collecting some preliminary data.

GEOCHRONOLOGY IN THE PINE CREEK OROGEN – NEW RESULTS FROM NTGS

James Lally[1] and Kurt Worden[2]

Introduction

NTGS commenced a new project in mid-2003, to study the geological framework and mineral systems of the Pine Creek Orogen (PCO). A major part of this project is the collection of new geochronological data, aimed at solving problems with stratigraphic correlations and determining the timing of structural, metamorphic and mineralising events. Geochronology will also be used to place events in the PCO in the broader context of the Palaeoproterozoic evolution of the North Australian Craton. Zircons from several samples collected in 2003 were analysed using SHRIMP, and the new results are presented here.

Previous geochronology

Rb-Sr and U-Pb zircon dating of basement rocks in the Rum Jungle and Nanambu complexes gave Archaean ages in the range 2500–2540 Ma. One sample of metamorphic rocks from the Litchfield region gave a Rb-Sr age of 2002 ± 40 Ma, which was considered to date an early metamorphic event not recorded elsewhere (Pietsch and Edgoose 1988). 'Syntectonic' granites from the Nimbuwah Complex and Litchfield region yielded U-Pb zircon ages of 1866 Ma and 1850 Ma, respectively. Conventional and SHRIMP U-Pb zircon ages of post-tectonic granites lie in the range 1845–1810 Ma (OZCHRON). Samples from the Gerowie Tuff and Mount Bonnie Formation yielded a conventional U-Pb zircon age of 1885 ± 2 Ma, which was taken to be the depositional age of the South Alligator Group (Needham *et al* 1988). SHRIMP U-Pb zircon dating of Zamu Dolerite gave an age of 1870 Ma. SHRIMP U-Pb zircon dating of felsic volcanics of the El Sherana and Edith River groups gave ages of around 1830 Ma and 1822 Ma, respectively, which concurs with field evidence that they were coeval with some phases of post-tectonic granite intrusion. Annesley *et al* (2002) dated monazite in a post-metamorphic pegmatite dyke at Ranger uranium mine at 1847 ± 1 Ma, providing a minimum age for the Barramundi Orogeny in the eastern PCO. Tuffaceous mafic rock from the Stag Creek Volcanics (Namoona Group) yielded two groups of concordant analyses dated at 2548 ± 8 Ma and 2048 ± 13 Ma, but both ages were interpreted as inheritance (OZCHRON).

New samples and results

Priority was given to the following samples collected in the 2003 field season:

- Two samples of Gerowie Tuff from widely different locations, to check the existing 1885 Ma age for deposition of the South Alligator Group.
- Two samples of suspected tuffaceous sediment from the Wildman Siltstone, noted during detailed mapping of a cutting for the new Alice Springs-Darwin railway.
- A sample of the Warrs Volcanics, felsic-intermediate volcanic rocks in the Daly River area that host base metal mineralisation and occur near the base of the Burrell Creek Formation.

Gerowie Tuff samples from a quarry near Mount Bundey and a road cutting on the Stuart Highway give well defined SHRIMP U-Pb ages of 1864 ± 3 Ma and 1862 ± 3 Ma respectively, which are considered to be reliable estimates of the age of deposition of this unit. No inheritance was detected, except for one near-concordant grain in the Mount Bundey sample that had an age of 2030 Ma.

Wildman Siltstone samples were collected from a railway cutting about 8 km east of Batchelor. Both samples lie stratigraphically above the Acacia Gap Quartzite Member, which has a detrital zircon spectrum that consists entirely of Archaean grains. Sample A contains predominantly Archaean zircons, but included a minor population of 2029 ± 12 Ma age. Sample B contains a dominant component with an age of 2025 +8/-5 Ma, and a minor inherited Archaean component. However, the spread of data in the dominant component indicates that more than one population of zircons may be present, suggesting that some reworking has occurred. The absence of 2025 Ma zircons in the underlying Acacia Gap Quartzite Member suggests that, despite the evidence for minor reworking, 2025 Ma is a good estimate for the depositional age of the Wildman Siltstone and the Mount Partridge Group.

Zircons from the Stag Creek Volcanics, dated by BMR using SHRIMP, were re-assessed by Andrew Cross of Geoscience Australia. In his opinion, there was no reason to suspect that the younger 2048 Ma group of zircons was definitely inherited, and the date could reflect a depositional age for the rock. The Stag Creek Volcanics lies beneath the Mount Partridge Group, and a 2048 Ma age would be consistent with our new data.

[1] Email: james.lally@nt.gov.au
[2] Geoscience Australia

Data processing from the Warrs Volcanics sample is still underway, but initial indications are that the age of formation is about 1860 Ma, concurrent with its stratigraphic position near the base of the Burrell Creek Formation and slightly younger than the Gerowie Tuff.

A sample of Nimbuwah Complex granitoid was also collected, but zircons were all unsuitable for age determinations, being either too fractured or metamict. Alternative samples will be collected in 2004.

Implications

Deposition of the 'upper' PCO succession, comprising the South Alligator and Finniss River groups, occurred during 1870–1860 Ma, about 20 Ma younger than was previously thought. Existing ages of 1866 Ma and 1870 Ma for Nimbuwah Complex granitoid and Zamu Dolerite are incompatible with this new data, given geological evidence that their emplacement post-dated deposition of the South Alligator Group. It is possible that both ages reflect a significant inherited component from rocks of the same age as the South Alligator Group, and SHRIMP analysis of new samples is required to resolve the issue. Rocks of the same age as the South Alligator and Finniss River Groups are known across the North Australian Craton in the Halls Creek Orogen, Tanami Region, Tennant Creek Province and Mount Isa Inlier.

A 'lower' PCO succession, comprising the Kakadu, Namoona, Manton and Mount Partridge Groups, was deposited during the period 2050–2020 Ma. Polymetallic base-metal mineralisation at Browns is hosted by the Whites Formation, which is conformably overlain by Wildman Siltstone and which was interpreted by McCready *et al* (2004) to be syngenetic in origin. Assuming this interpretation is correct, mineralisation occurred at about 2030 Ma.

There is a major unconformity at the base of the South Alligator Group that represents a time gap of about 150 Ma. Early metamorphism and deformation in the Litchfield region at 2002 ± 40 Ma may be linked to an extended period of uplift and erosion that affected the entire PCO, although details of such an event are unclear. Sedimentary precursors to the Hermit Creek and Fog Bay Metamorphics may have been deposited at the same time as the lower PCO succession further east, and samples to be analysed in April 2004 will clarify this interpretation.

Separation of the PCO succession into two supergroups was proposed by Ahmad and McCready (2001), on the basis of contrasting rare earth element patterns and mineralisation styles. Geochronological data presented here supports this proposal, in which the lower and upper successions referred to above are named the Woodcutters and Cosmo Supergroups, respectively.

Regional deformation and high-grade metamorphism in the eastern PCO related to the Barramundi Orogeny is now bracketed in the range 1860–1847 Ma, instead of previous estimates of 1870–1850 Ma. It is hoped that further sampling will be able to accurately date metamorphism in this area and further constrain the timing of this orogenic event.

Future work

Future sampling in the PCO is aimed at defining the ages of key events, particularly the deposition of the lower PCO succession, and metamorphism and igneous activity in the Litchfield and Nimbuwah regions. Also of interest are detrital zircon studies of the Burrell Creek Formation, to determine if there are changes in the provenance characteristics of this extensive unit across the PCO.

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THE DALY RIVER MINERAL FIELD

Phil Ferenczi[1]

The Daly River Mineral Field (DRMF) is located about 120 km south of Darwin and lies within greenschist facies, submarine, mafic to felsic volcanics and interbedded sediments of the Finniss River Group, within the Pine Creek Orogen (PCO). The north-trending field is about 160 km^2 in area and contains 18 base metal occurrences. Fifteen of these can be classified as hydrothermal vein-type and three as volcanic-hosted massive sulfide (VHMS)-type. Small-scale mining on several copper-rich vein-type deposits (eg Daly River mine 6000 t @ 20% Cu) occurred between 1884 and 1918. Extensive exploration followed a semi-detailed (160 m line space) airborne magnetic survey in 1966 by the Bureau of Mineral Resources over the field, which revealed several significant bulls-eye anomalies.

Exploration work in 1967–77 by Western Nuclear Aust. Ltd in joint venture with Le Nickel Exploration Ltd, Aquitaine Minerals Ltd and Preussag Ltd included 59 diamond drillholes (totalling 12 000 m), soil geochemistry, auger drilling and ground geophysics on seven prospects. Most of the work was focused on the sub-surface Anomaly A deposit, where drilling delineated up to eight conformable stacked lenses of banded massive sulfides, within an altered submarine metavolcanic succession containing basalt, andesite and dacite (Brook 1975). A non-JORC resource of 213 000 t @ 18.7% Zn, 0.65% Cu (W26 Lens) and 550 000 t @ 6.6% Zn, 2.2% Cu, 19 g/t Ag (A26 Lens) has been estimated to a depth of 215 m (Pyper and Cotton 1977).

Regional geological mapping in the area (Dundas *et al* 1987, Edgoose *et al* 1988) has identified three felsic volcanic units within the lower Burrell Creek Formation: Berinka Volcanics, Mulluk Mulluk Volcanics and Warrs Volcanics. Known VHMS deposits are hosted in the Warrs Volcanics. These units form part of an extensive north-northeast-trending fault belt that contains numerous granitoid and mafic-ultramafic intrusives. This fault belt is the northern extension of the Palaeoproterozoic Halls Creek Orogen. The Halls Creek Orogen hosts a variety of ore deposit styles that make attractive exploration targets in the Daly River Mineral Field and the southerly fault belt extension. Exploration targets include Cu-Pb-Zn-Ag VHMS, orthomagmatic Cu-Ni or PGE, hydrothermal vein-type Au and volcanic-hosted REE.

The objectives of this project are to:

- properly define the nature and extent of volcanic packages related to and hosting polymetallic massive sulfide mineralisation;
- characterise massive sulfide and vein-type mineral systems and related wall rock alteration and develop a robust exploration model for the district; and
- examine potential for other mineral commodities (eg Cu-Ni and PGE in gabbros in the Wangi Basics and hydrothermal Au and REE).

The work program involves:

- whole rock geochemistry and petrology on unaltered host volcanics, mafic intrusives and alteration zones;
- geochronology (SHRIMP U/Pb zircon) of the host volcanics;
- sulfur isotope ($\delta^{34}S$) analyses on ore and alteration minerals;
- lead isotope analyses on galena samples;
- identifying geophysical signatures of known mineral systems and prospective host rocks; and
- publication of NTGS Record "The Daly River Mineral Field" in September 2004.

Preliminary results for this project:

- Preliminary SHRIMP U/Pb zircon data for the Warrs Volcanics suggest a likely age of 1860 Ma, which is consistent with new geochronology results for the PCO and regional geological interpretations.
- Interpretation of airborne magnetic data over the DRMF suggests that the Warrs and Mulluk Mulluk Volcanics are a single extensively faulted, geologic unit that occupies part of a large, north-plunging syncline,
- DRMF VHMS deposits are within submarine-altered andesitic to dacitic lavas, pyroclastics and volcaniclastics.
- A hangingwall alteration-mineral assemblage of chlorite-pyrrhotite-calcite-quartz and footwall assemblage containing disseminated magnetite enable effective use of magnetic methods to target VHMS mineralisation.
- Hydrothermal vein-type Cu (Zn-Pb-Ag) deposits in the DRMF do not have a distinct magnetic signature, but may represent structurally remobilised VHMS mineralisation.
- Sulfur isotope ($\delta^{34}SCDT$) analyses on sulfide ore from VHMS and hydrothermal vein-type mineralisation, and from disseminated sulfides in hangingwall volcanics range between –1.0 and +1.2‰ (with a mean of -0.23‰), suggesting a

[1] Email: Phil.Ferenczi@nt.gov.au

high S contribution from volcanic host rock or magmatic fluids, and is comparable to other Palaeoproterozoic VHMS deposits.
- VHMS deposits in the DRMF are very similar (in ore composition and grade, alteration style, host geology and deposit geometry) to larger-size VHMS deposits within the Koongie Park Formation (about 1845 Ma) in the Halls Creek Orogen.
- High grade (5–30 g/t Au) auriferous quartz vein mineralisation is present within the Ti Tree granophyre (Terrys A and D Prospects) and felsic Berinka Volcanics (Terrys B, C, F and G Prospects).
- Several layered gabbroic complexes with evidence of sulfur saturation during late stages of magma crystallisation exist in the fault belt (eg Gazelle Intrusive Complex); most of the mafic complexes remain untested for Ni, REE and PGE.
- REE occurrences (allanite-bearing veins) exist within the Ti Tree granophyre.

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WEST ARNHEM LAND AIRBORNE GRAVITY SURVEY

Mark Duffett[1], Mario Bacchin[2] and Richard Lane[2]

Introduction

A helicopter-borne ground gravity survey at 2 km x 2 km station spacing was originally planned for an area on the western edge of Arnhem Land adjoining Kakadu National Park in 2002 (**Figure 1**). This project was cancelled in late 2002, due to a lack of significant progress in land access negotiations. Development of the GT1-A airborne gravimeter for use in Australia, together with encouragement and support from industry, facilitated the project's revival in 2003. An airborne gravity survey was planned and executed for the same area, with specifications calculated to result in similar resolution levels, as the original ground survey proposal.

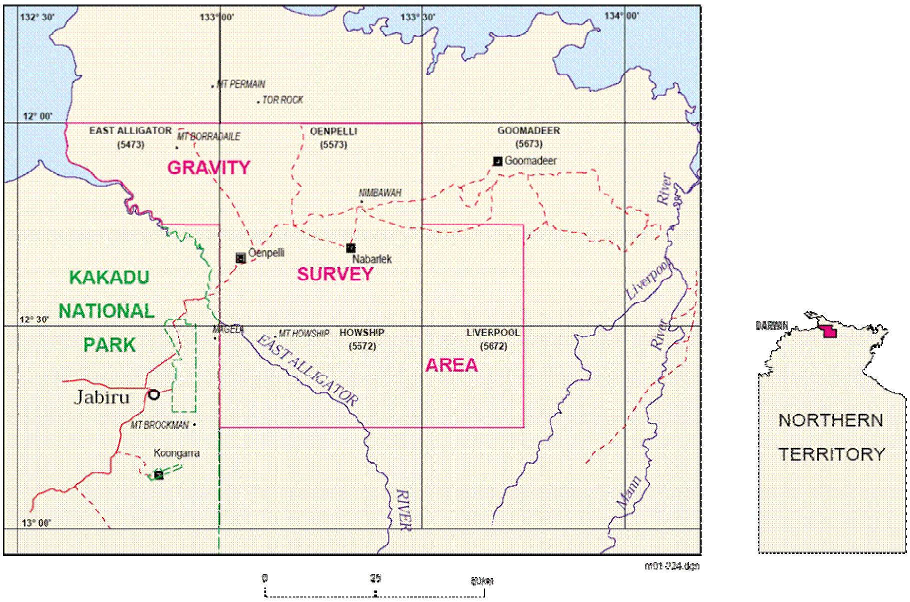

Figure 1. Gravity survey location.

Geology and topography

The survey area lies astride the northwestern edge of the McArthur Basin. Shallowly dipping sandstone and mafic volcanics of the Katherine River Group thicken southeastward towards the basin centre, but only form outliers in the northwest. They unconformably overlie Pine Creek Orogen basement comprising Archaean Nanambu Complex granite gneiss, Palaeoproterozoic metasediments of the Kakadu Group, the Nourlangie Schist and Cahill Formation, and granitoids (Nimbuwah Complex and small post-tectonic plutons). Both McArthur Basin and Pine Creek Orogen successions are intruded by mafic sills of the Oenpelli Dolerite. Flat veneers of Cretaceous mudstones and Cenozoic floodplain sediments cover large portions of the northern survey area, much of which is only a few metres above sea level. Katherine River Group sandstones form escarpments and deeply incised plateaux, rising up to 300 m above the floodplain, with highest elevations attained in the southeastern portion of the survey area.

Technology – the GT1-A system

The GT1-A system was originally developed in Russia by Gravimetric Technology Ltd. Its commercialisation in Australia has been undertaken by Canadian Micro Gravity Pty Ltd (CMG), who operated the instrument for the West Arnhem survey. The gravity sensor is an accelerometer mounted in an assembly that uses servo-motors and a rotating table to maintain the sensor in vertical orientation and constant heading. It was flown aboard a Shrike Commander (fixed-wing) aircraft, operated by Fugro Airborne Surveys. The gravity signal is recovered after the subtraction of accelerations due to aircraft motion, and is determined by post-processing of onboard dual frequency GPS data, coupled with that from a fixed ground base station. All GPS and gravity data processing was performed by CMG.

Acquisition

[1] Email: mark.duffett@nt.gov.au

[2] Geoscience Australia

East–west-oriented lines at 2 km spacing with north–south ties every 20 km were flown over 16 days in late August and early September, 2003. Flights commenced daily at first light; noise from the onset of thermal turbulence prevented their continuance beyond 9–9:30 am, local time. Surveys conducted under more optimal seasonal conditions, or at night may be able to achieve greater productivity. Data were acquired at a constant altitude of 650 m ASL, being approximately 250 m above the highest point in the survey area. Drift control was maintained by readings over the same point on the tarmac (10 cm tolerance) at the beginning and end of every flight. This point was subsequently tied via conventional ground gravity measurements to the national gravity network.

Processing

The raw gravity data were subjected to a complex filtering process in order to eliminate high-frequency noise. This was followed by application of microlevelling techniques and a DC shift, in order to honour absolute gravity values known from previous ground measurements in the area. The standard processing output is the relative free-air gravity signal. Considerable effort was expended on calculating Bouguer anomaly values with full terrain correction, utilising a detailed DEM sourced from the Department of Defence. This was in order to satisfy NTGS and GA requirements that the airborne data be fully compatible with the existing national ground gravity database. Terrain correction is the one aspect of gravity acquisition made easier from an airborne platform. The gravitational effect of topographic variation is generally both highest in magnitude and hardest to characterise in the zone closest to the measurement point. This would have been a significant source of noise in a ground-based survey, especially in the escarpment country of the survey area; airborne acquisition effectively eliminates it.

Results

Features revealed by the improved resolution of the airborne gravity data include indications of a north-plunging synform, superimposed on the gravity high associated with the Nourlangie Schist in the northwest, and more definitive characterisation of a low corresponding to outcropping late granitoids. The extent of the latter beneath McArthur Basin cover is defined more precisely, with indications that the intrusion geometry is partly controlled by later faults. Gravity signatures that are already known to be associated with features, such as the McArthur Basin, the Nimbuwah Complex and the Nungbalgarri Volcanics, are amplified and their geometries better defined.

Analysis

Examination of the differences between original and airborne Bouguer gravity data indicates that significant additional features have been revealed in the gravity field. While a component of this character may be due to remnant noise, confidence in its being mainly of geological origin is increased, by the coincidence of many revealed gravity features with magnetic anomalies and mapped units, such as Oenpelli Dolerite. The largest differences are in the areas of greatest topographic relief, commensurate with the elimination of terrain effects present in the original ground data. A 50-km gravity traverse, conducted in 1972 at 500 m station spacing, has been utilised as an additional basis for assessment of the airborne data. Many, though not all features in the gridded airborne Bouguer gravity are present in the ground profile. Whether these are due to errors in the airborne or (non-terrain-corrected) ground data is the subject of ongoing work.

Conclusion

While airborne gravity survey costs and data resolution are of similar magnitude to the ground survey initially proposed, avoidance of the requirement to obtain ground access to many hundreds of points spaced 2 km apart greatly expedited planning and execution. With extensive upgrading of our currently sparse gravity coverage a medium-term goal of NTGS, ease of access is a very important consideration. Preliminary indications of satisfactory performance in the challenging terrain of Arnhem Land give encouragement that this technique may be widely applicable in the development of improved gravity coverage for the Northern Territory at semi-regional to regional scales.

THE TANAMI 3D MODEL – 2004 UPDATE

Leon C Vandenberg[1] and Tony Meixner[2]

The Tanami 3D model

As part of a continuing collaborative project between NTGS and the North Australia Project of Geoscience Australia (GA), current efforts are focused on further developing the web-served 3D geological model of the Tanami region (Figures 1, 2). Version 1 of the model integrates serial structural cross-sections and gravity/magnetic forward modelling with other data (see below), to create 3D and 2D views of the geology in 3D space (Vandenberg and Meixner 2003). Version 1 is currently available on the internet via the link www.ga.gov.au/map/web3d. The format of the model enables simultaneous viewing and comparison of various datasets, and the model can evolve as new data is included. It is anticipated that an upgraded Tanami model (Version 2) will be available for internet release by July 2004. Version 2 aims to deliver to the geoscience community all available information relevant to the Tanami region in a internet-based simulated 3D environment. The upgrade will incorporate several new and revised sections based on recently completed field work, a significantly expanded range of datasets and interpretations, and internet links to other relevant databases and reports.

Version 1 Model: features

Basic features included in the Tanami 3D model are listed in the following:

- Fifteen 2-D structural cross-sections through the Tanami region (TANAMI and THE GRANITES) and part of Northern Arunta (HIGHLAND ROCKS).
- Fifteen 2.5-D modelled sections, derived from the integration of the structural sections with potential field forward modelling of regional gravity and magnetic data (GA and NTGS data).
- Several major fault surfaces and a granite body interpolated in 3D space.
- Regional gravity (11 km grid spacing, GA and NTGS data), regional magnetics (4 km grid spacing, NTGS and GA data).
- Surface outcrop and simplified basement geology.
- Digital elevation.
- Mineral occurrences.
- Geochronological data.
- Wormed gravity strings (multi-scale edge analysis, Archibald *et al* 1999).

Version 2 Model: additions

It is anticipated that the following features will be included in the upgraded Version 2 model:

- Fifteen revised structural and modelled cross-sections.
- Four additional structural and modelled sections.
- Radiometrics and interpretations.
- Radiometrics draped on elevation.
- Landsat images.
- Regolith maps.
- Updated and expanded basement interpretation maps.
- Second edition 250K surface maps (if available).
- Road and track maps.
- Drillcore-drillhole information (active pop-ups).
- Depth to basement information.
- Geochemical data (active pop-ups).
- Wormed gravity and magnetics.
- Interpolated fault surfaces.
- Interpolated surfaces of gravity and magnetic strings.
- Proposed transects for seismic reflection acquisition.

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[1] NTGS, Alice Springs. Email: leon.vandenberg@nt.gov.au

[2] Geoscience Australia, Canberra

To enhance and simplify manipulation of the model the following features may also be included:

- Location and scale references/tools.
- Improved menu and toolbar icons.
- Internet-linked active data fields accessible while navigating through the model.
- Internet links to existing databases and reports.
- Pre-set data and interpretation field views for immediate manipulation.
- Demonstration movie.

The serial geological sections and subsequent geophysical modelling using ModelVision have resulted in a model that displays a reasonable level of internal consistency (Vandenberg and Meixner 2003). The fact that many section lines intersect the same features at different angles and yield similar results encourages a reasonable level of confidence in modelled geometries. It should be noted that while the model has been constructed to 15 km depth, the ability to confidently model geometries below approximately 8 km depth rapidly diminishes and is dictated by the need to maintain geometric and stratigraphic consistency. In addition, whereas fault positions and offsets are reliable, fault geometries are largely hypothetical and additional information (eg seismic data) is needed to further constrain fault, stratigraphic and deep crustal architecture (for example, as with the Leonora-Laverton 3D model, Blewett *et al* 2002).

Possible future developments

- Incorporation of the proposed Tanami seismic reflection program.
- A magnetotelluric (MT) program along the same traverse as the seismic program.
- A 3.5D deformation model: a basement-cover interaction retro-deformation model, in which modelled geometries of the cover sequences (eg Birrindudu Group) undergo deconstruction modelling (eg. retro-deformation of the Lechtal Nappe, Tanner *et al* 2003). Deconstruction may then lead to the identification of potentially long-lived structures through the Tanami stratigraphy and basement that have influenced the development and mineralisation of the Tanami Region. The geometry of the underlying Tanami Palaeoproterozoic basement may be suitable for deconstruction, once seismic data has been acquired and modelled structural sections have been reinterpreted.

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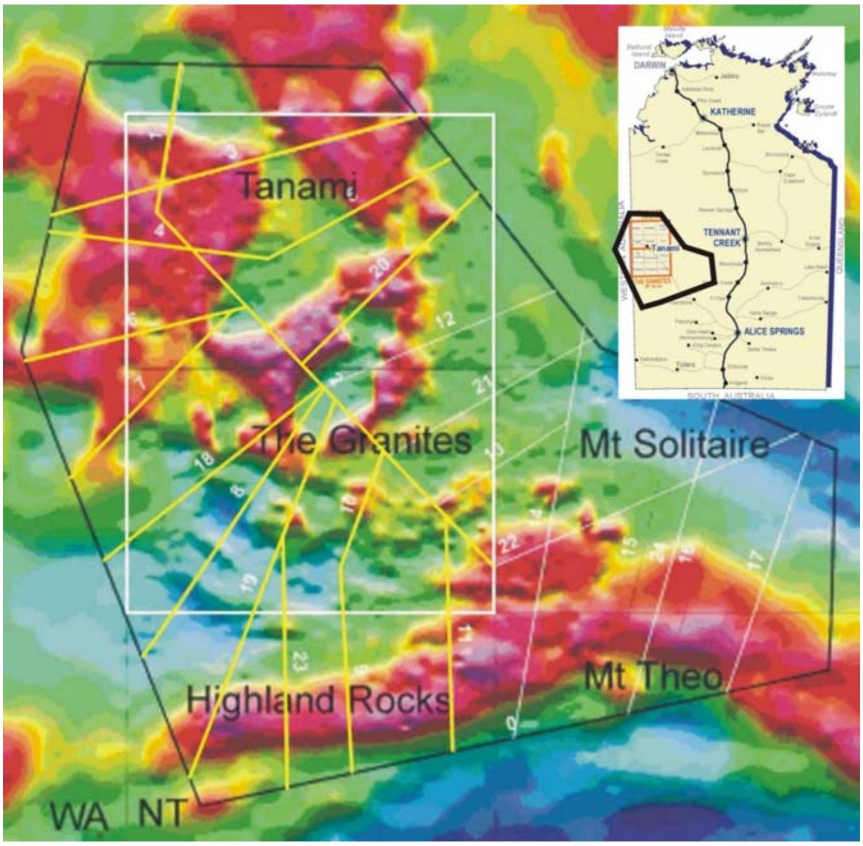

Figure 1. Tanami Region, regional gravity (Bouguer gravity; GA and NTGS data) showing positions of Version 1 modelled cross-section lines (yellow lines). TANAMI, THE GRANITES, MOUNT SOLITAIRE, HIGHLAND ROCKS, MOUNT THEO mapsheets indicated.

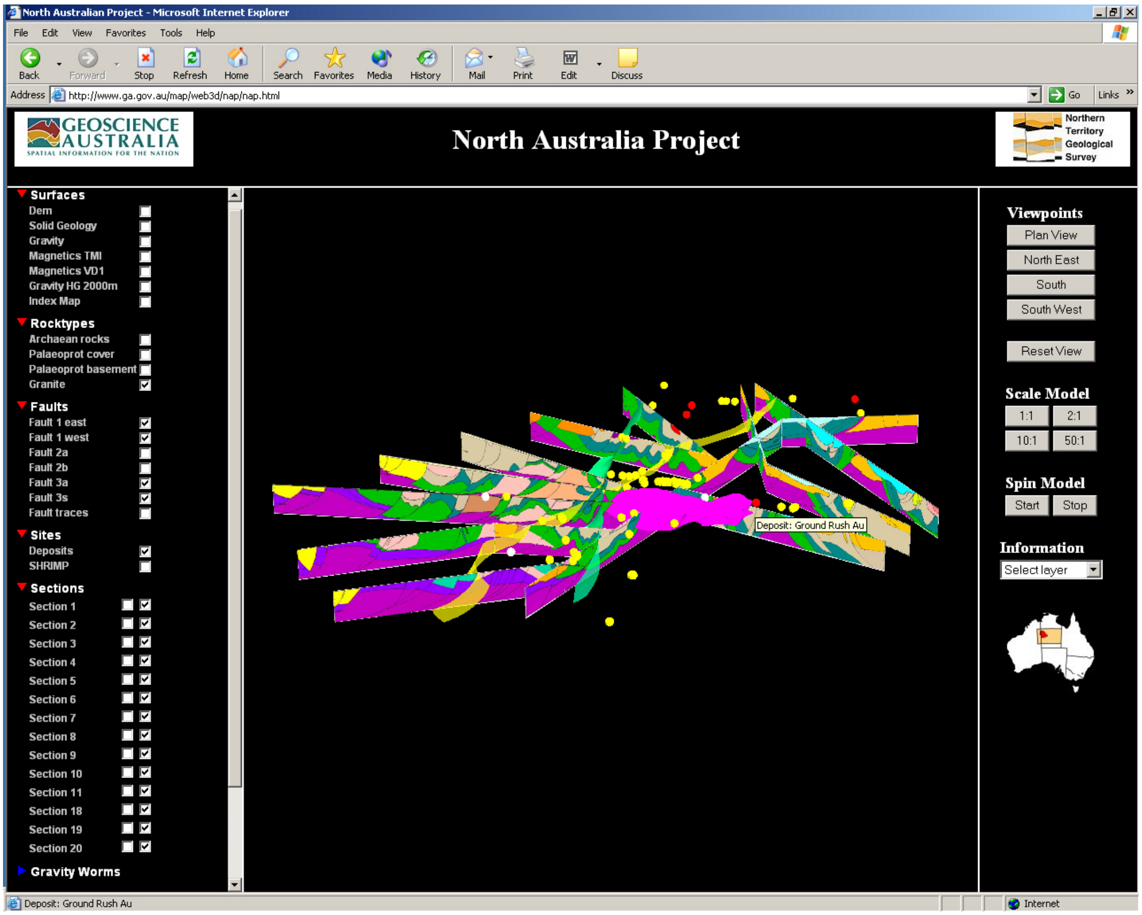

Figure 2. The Tanami 3D model Version 1 web-page view. Available from www.ga.gov.au/map/web3d

TANAMI SEISMIC ACQUISITION PROPOSAL (GA– NTGS– GSWA– ANSIR COLLABORATIVE)

Leon Vandenberg[1, 2], Tony Meixner[3], David Huston[3], Andrew Crispe[1], Leon Bagas[4], Tim Barton[5], Bruce Goleby[5], David Johnstone[5]

Introduction

A seismic reflection acquisition program across the Tanami region of the Northern Territory and Western Australia has been proposed by GA, NTGS, GSWA and ANSIR. The proposal forms part of ongoing collaborative NTGS-GA (and now GSWA) programs investigating geological controls on Palaeoproterozoic gold systems in the Tanami region. It is anticipated that seismic acquisition will take place in mid to late 2004.

Recent advances in our understanding of the Tanami region have been achieved through investigations associated with the NTGS Tanami–Tennant Link program and the GA North Australia Project. These programs have highlighted the importance of acquiring, interpreting and releasing high-quality regional geophysical data, in particular magnetic and gravity data, in regions viewed by industry as highly prospective, although poorly exposed. Similarly, GSWA have recently launched a series of programs aimed at investigating the adjoining WA portion of the Tanami Region. The acquisition of seismic reflection data will add value to our knowledge base by providing 2D velocity (depth/time) data and imaging constraints to crustal levels, beyond what is currently possible through drilling and modelling of existing geophysical data. The proposal would ensure comprehensive regional coverage of the major stratigraphic relationships, structures and deep crustal features that have influenced the development of the region, many of which may be directly related to mineralisation.

Figure 1 shows the positions of the proposed seismic lines across the NT. Note that these lines are subject to continuing review (current to 6/3/04), and line proposals in Western Australia are yet to be finalised. Transect selection is based on targeting fundamental scientific questions amenable to seismic investigation, while minimising social, environmental and economic impact by using (where possible) existing infrastructure.

Scientific questions to be tested via the acquisition of seismic data include:

- the scale and geometry of faults;
- stratigraphic thicknesses and the relationships of stratigraphic packages to controlling structures;
- the identification of crustal-scale structures and their relationship to mineralised domains;
- granite body geometry and relationships to mineralised domains;
- the identification of Archaean basement and its relationship to overlying Tanami Group and Lander Rock beds stratigraphy;
- the character of the Tanami–Arunta boundary; and
- deep-crustal structure and relationships to gravity features, such as the prominent east–west-trending Willowra Gravity Ridge.

The proposed lines also aim to test several sections that comprise the GA-NTGS Tanami 3D model (constructed via potential field modelling). As was found with the GA Leonora-Laverton 3D model, acquisition of seismic information can significantly enhance our understanding of the 3D architecture of a region, where an existing 3D framework is already in place. In addition, provision of seismic data and the revision of the regional 3D framework could provide further scientific infrastructure and impetus for the application of new or emerging technologies (for example magnetotelluric (MT) imaging).

Propososed Seismic Lines (current to 6/3/04)

Line 1a. A northwest to southeast transect along the Tanami Road. The northwest section of the line runs from the southern margin of the Coomarie Granite, cuts across the Frankenia Granite dome, and is aimed at defining the geometry and depth-extent of the granite. Between the two granite bodies, the line crosses the Tanami Mine district and would test relationships between mineralisation, northeast-trending structures and stratigraphy. Southeast of the Frankenia Granite, the line crosses Tanami Group stratigraphy and the Tanami Fault. Relationships between mineralisation and northwest-trending structures may also be targeted at The Granites Mine area. The southern section of the line crosses the east–west-trending Willowra Gravity Ridge, a prominent deep crustal feature. This section may test relationships related to the nature of the Tanami–

[1] NTGS, Alice Springs, NT
[2] Email: leon.vandenberg@nt.gov.au
[3] Geoscience Australia, Canberra
[4] GSWA, Perth, WA
[5] ANSIR, Canberra

Arunta boundary, and suggestions that the gravity ridge is off-set by several regional-scale mineralised east–west- and northeast-trending structures.

Line 1b. A west-striking transect along the Tanami Road from the southern margin of Coomarie Granite NT to Elsey Hills WA. Planning is currently under way for this line.

Line 2. A southwest–northeast-trending line passing through the Tanami and Groundrush goldfields. From the southwest, the line crosses a series of structures including the Tanami, MacFarlane Peak, Mongrel and older Bluebush Faults. Several of these faults are related to gold mineralisation and the line is ideally located to determine fault geometries.

The middle section of this line follows a haulage road network and crosses the Tanami Mine area (Mount Charles Formation), in an orientation favourable to image the deeper Frankenia Granite (shallower Mount Charles Formation-mineralisation relationships would be covered in line 1a). Further northeast, the line crosses favourably oriented Tanami Group stratigraphy, faulted against the Mount Charles Formation, a gravity low attributed to the northerly extension of the Frankenia Granite, the Groundrush Mine area and related structures. The line then crosses the north-striking Suplejack Fault Zone, a major structure which hosts significant gold mineralisation and which may have greatly influenced the tectono-stratigraphic development of the region.

Line 3. A north-trending line either side of the Tanami Road, passing to the west of the Coyote deposit, WA. Sections of this line would take advantage of an existing track network north from Coyote and passing over the Larrangianni prospect area. The line is still in the planning stage.

Line 4. A southwest–northeast-trending transect passing through The Granites and Windy Hill Mine areas. The southwest portion of the line crosses a series of northwesterly-trending structures and Tanami Group stratigraphy related to mineralisation (including the Granites Mine area). The southern section of the line crosses a number of major east–west-trending structures that dissect the interpreted position of the Tanami–Arunta boundary.

The northeast portion of this line crosses the Tanami Road and follows a haulage road northeast to the Windy Hill deposit. The line crosses an interpreted granitic body, the Tanami Fault and the interpreted southern extension of the Suplejack Fault Zone. Two options are canvassed for the far northeast section of this line that passes over the Suplejack Fault. The preferred option is for a continuation in the same trend as the haulage road, requiring line clearing. Alternatively, the line may follow an existing north-trending track.

Line 5. This line crosses outcrops of the Archaean Billabong Complex and may test the relationship of this Archaean complex to the Tanami Block. The line will require line significant clearing, so despite its considerable scientific value, is considered a lower priority.

Discussion

The proposed lines provide a comprehensive seismic program across the Tanami Region (*approximately 928 km total*). The provision of the long northwest-to-west-trending **line 1(a, b)** and two cross lines (**lines 2 and 3**) would ensure that most of the major regional structures are crossed and that most of the scientific objectives would be achieved (*approx. 677 km*). The addition of **line 4** would ensure crossing several of these structures more than once, facilitating three-dimensional seismic imaging and interpretation, as well as providing additional information from the Granites-Callie mineralised domain. Although **line 5** is considered a lower priority, it is the only line that may provide clear insights into the nature of the Tanami basement. While it is interpreted from potential field modelling that the outcropping Billabong Complex continues at depth southward, and may be imaged by **line 1a**, **line 5** is the only line which crosses the complex at the surface.

At the time of writing, funding and logistical arrangements are still being negotiated. A preliminary prioritisation of the lines, based on geoscientific merit has already been done (see Figure 1), but final selection of lines awaits the resolution of access negotiations and a precise knowledge of the funding available.

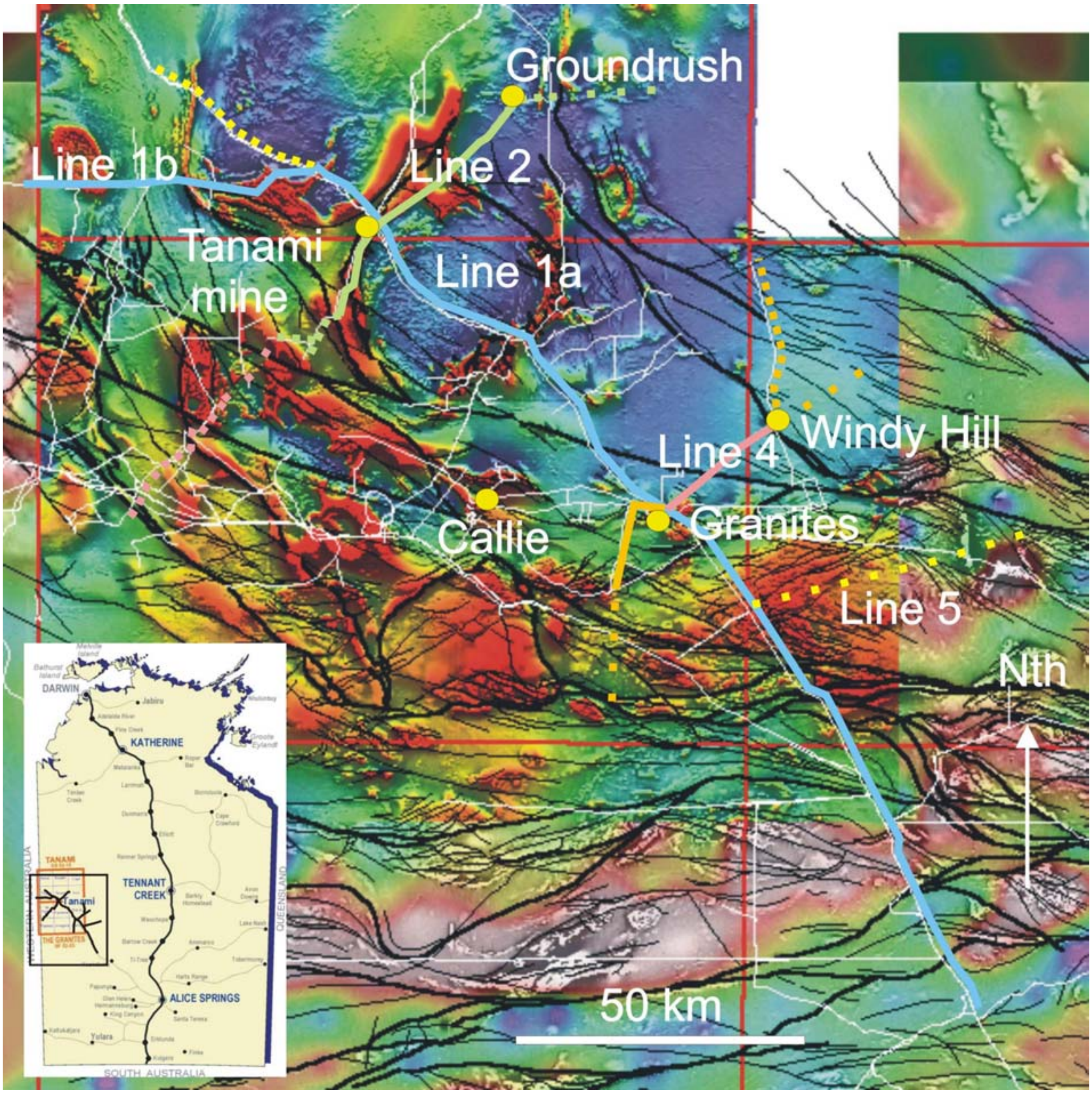

Figure 1. The proposed seismic lines overlying a gravity image with the known faults (black), existing roads and tracks (white) and major mineral deposits. Solid line – Tanami Road or major ore haulage road. Close-spaced dashes – existing track, track clearing maybe required. Sparsely dashed line – no track, line will require track clearing. Line colouring indicates line acquisition priority: *priority 1* (light blue), *priority 2* (green), *priority 3* (mauve), *priority 4* (pink) and *priority 5* (yellow). Line 3 (WA) not shown.

SEQUENCE STRATIGRAPHIC FRAMEWORK OF MINERALISED UNITS IN THE TANAMI REGION

Lex Lambeck[1]

The Tanami region in the Northern Territory and Western Australia is located 550 km northwest of Alice Springs. The Tanami is an important gold-producing province, with significant deposits including Dead Bullock Soak, The Granites and Titania. A new sequence stratigraphic study by Geoscience Australia aims to provide a better understanding of basin architecture and determine possible relations to fluid flows and the occurrence of ore-bearing bodies. Sequence stratigraphic concepts provide a methodology for recognising surfaces of chronostratigraphic significance in a sedimentary basin. Once these surfaces are recognised and facies are interpreted, it is possible to formulate a framework to understand basin evolution and predict the distribution of economically significant facies. The sequence stratigraphic approach combines mineral and petroleum exploration techniques, focusing on a number of key tasks such as grainsize and geochemistry. It has the potential to generate new understandings of controls on gold mineralisation in Palaeoproterozoic sedimentary basins.

Sequence stratigraphy relies on the integration of seismic, outcrop, drillhole and wire-line logs to provide an understanding of basin architecture. An absence of seismic data, coupled with poor exposure, has resulted in the need to integrate the drillcore logs from relatively shallow exploration holes to construct a 'composite' section of the stratigraphy at Dead Bullock Soak. The composite log has identified traps and vectors towards traps which cause gold to precipitate. The study has relied on drillcore from Newmont Australia to identify condensed sections formed during periods of marine transgressions. The condensed sections host the chemical traps for mineralisation. This body of knowledge will be combined with further work in the north and west of the Tanami Region, to further constrain basin evolution and fluid flow in the region.

The Dead Bullock Formation at the Callie Mine consists of a fining-upward sequence of siltstone, carbonaceous siltstone, chert and iron formation with minor sandstone. The formation incorporates the informally named Blake beds and Davidson beds of Smith *et al* (1998), as well as the former MacFarlane Peak Group and Twigg Formation of Hendrickx *et al* (2000) (**Table 1**). Based on the composite log, black carbonaceous and BIF units within this sequence are interpreted as forming condensed sections in deep water, during a period of marine transgression. Very little sediment was transported into deep-water shelf areas where these rocks were deposited, creating an anoxic environment. The highest grade gold occurs in well bedded carbonaceous horizons of the Lower Blake beds, Callie laminated beds and Magpie schist that form a chemical trap to the ore hosting fluids. Another condensed section is found within the Orac and SHIM members of the Davidson beds, which consist of iron-rich sediments. When the ore-bearing fluid reached this environment, gold was precipitated as a consequence of de-sulfidation reactions. It is postulated that fluid travelled along D_5 shears and deposited gold when condensed sections were encountered.

The Blake and Davidson Beds are deep water facies sediments that represent a condensed section followed by a period of aggradation. These beds contain higher-order maximum flooding surfaces, which contain significantly mineralised units. Poorly-sorted fine to medium sandstones of the Madigan Beds represent a basinward shift in facies, representing deepwater turbidites deposited landward of the carbonaceous facies.

Further composite cores are planned for the 2004 field season from Titania, Ground Rush and Coyote, and possibly from limited field exposures, in order to gain a regional overview of the area. It is planned to integrate this information with geochronology, in order to further constrain the timing of fluid flow. Fence diagrams can then be constructed, highlighting potential ore-hosting surfaces.

The Callie boudin chert forms a diagnostic marker at the Callie Mine and comprises a carbonaceous mudstone with extensive bands of chert nodules up to 5 cm in diameter. These chert nodules also exist throughout the Dead Bullock Formation in varying sizes and thicknesses. The nodules are interpreted to be of sedimentary origin, formed in deep water, below storm wave base. Concentric growth rings within nodules and enveloping laminations, which show evidence of compaction around the nodules, provide evidence that these features formed during early diagenesis. Similar nodules or concretions are common in deeper-water carbonate successions, where they form by the precipitation of carbonate and silica. The nodules also contain later evidence for shearing and folding, and they have possibly been altered by later boudinaging events.

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[1] Geoscience Australia

NTGS Stratigraphy	Newmont Stratigraphy	Lithology	Interpreted Environment
Killi Killi Formation	**Madigan beds** (only mineralised at Titania)	Medium sandstones to fine meta siltstones	Turbidites, Rapid uplift, proximal to basin fans, basin infilling
Dead Bullock Formation	**Davidson beds**		
	Manganiferous cherts, MCH Colgate schist, CS	Thinly bedded, non graphitic/ graphitic iron rich interbedded fine meta-siltstone	Condensed section, high chemical input
	* Schist Hills iron member, SHIM	Thinly bedded, non graphitic/ graphitic iron rich interbedded fine meta-siltstone	Condensed section, high iron input
	Dead Bullock member, DBM	Thinly bedded, non graphitic/ graphitic interbedded fine meta-siltstone	Condensed section
	Coora dolerite, CD	Medium- to coarse-grained dolerite	
	* Orac formation	Thinly bedded, non graphitic/ graphitic iron rich interbedded fine meta-siltstone	Condensed section, high iron input
	Blake Beds		
	Upper Blake beds, UBB	Fine meta-siltstone, occasional graphitic beds, rip-up features, soft sediment deformation	Condensed section
	Pip schist, PS Callie boudin chert, CBC * Magpie schist, MS * Callie laminated beds, CLB Lower Blake beds, LBB	Meta sandy siltstone grading up to mudstone	Condensed section within CLB, MS, CBC Proximal to basin fan

Table 1: Comparison between regional NTGS stratigraphy, and local stratigraphy recognised by Newmont at Dead Bullock Soak, in which further subdivisions are made on geochemical grounds and sedimentary features. * Mineralised beds.

PRELIMINARY FINDINGS FROM MAPPING IN THE NORTHERN TANAMI

Andrew Crispe[1], Leon Vandenberg

In 2003, NTGS commenced a project to undertake Second Edition mapping of the Birrindudu 1:250 000 mapsheet in the northern Tanami Region. Preliminary field observations have confirmed that this area is economically prospective, but has been relatively poorly understood, in terms of its relationship with better documented stratigraphy further south in TANAMI and THE GRANITES. The project is concentrating on the Palaeoproterozoic low-grade metasediments and metavolcanics of the Tanami and Ware Groups, with a view to extending our current understanding of Tanami stratigraphy to the north.

Fieldwork in 2003 consisted of one week of helicopter-based work and one week of vehicle-based traverses. The helicopter work aimed to provide first-order information about the rock types of remote outcrops in the area, particularly in the Browns Range Dome area and in an area mapped by the BMR as Nongra beds (Blake *et al* 1975). The vehicle-based component was aimed at assessing units of the Helena Creek beds, in terms of an updated Tanami stratigraphy, and at undertaking a geological reconnaissance of the Winnecke Range area.

Outcrop in the Browns Range Dome is poor, comprising deeply weathered granite. The granites are generally foliated with varying amounts of quartz veining and pegmatite intrusion, although intense weathering precludes further investigation without drilling. Granites were typically orange to white, muscovite-bearing, medium-grained and equigranular. They are likely to be weathered varieties of the renamed Grimwade Suite (previously known as the Coomarie Suite of Dean 2001).

Outcrop in an area dominated by the Nongra beds was found to be mostly Dead Bullock Formation, with less common, poorly exposed outcrops of possible Killi Killi Formation and even poorer outcrops of volcanic or volcaniclastic rocks. Heavily ferruginised, tightly folded siltstone of the Dead Bullock Formation contains subordinate chert bands and chert 'boudins', as are characteristic of the unit in THE GRANITES. In places, it is veined with 'dog-tooth'-quartz and haematite fracture-fill. Polydeformed, low metamorphic grade, interbedded psammite and pelite in the same region probably belongs to the Killi Killi Formation. An enigmatic group of outcrops to the west of the Nongra beds area may be a felsic volcanic package belonging to the Ware Group. These outcrops consist of a very fine-grained siliceous green rock of suspected volcanic origin. These are proximal to lithic arenite outcrops that were mapped by the BMR as Gardiner Sandstone, but which are now reinterpreted to be equivalents of the Winnecke Formation. Blake *et al* (1975) noted a 'porphyry' in the Nongra beds which, from his description, may be ignimbrite, and this will be investigated in upcoming fieldwork. This area is of high interest from both geological and economic perspectives, and will be a focus of studies during 2004.

A reconnaissance visit was made to the Winnecke Formation (Ware Group) in the Winnecke Range, which comprises sandstone interlayered with felsic volcanics. Initial observations revealed that the sandstone, although appearing quite siliceous, contains a substantial volcanic component. The volcanic layers contain up to 20% phenocrysts, comprising broken and euhedral terminating quartz crystals, < 1cm sericitised plagioclase laths, and chlorite and iron opaques replacing ferromagnesian minerals. Along with sandstone and felsic volcanics, the Winnecke Formation also contains a significant siltstone and mudstone component. The structurally simple dome and basin architecture of the area is dominated by north-trending fold axes. An area south of Mount Winnecke shows evidence for hydrothermal alteration, which remains uninvestigated.

The final area of investigation in 2003 was the Styles Creek area to the north, which was mapped as Helena Creek beds by the BMR. They placed this package in the "Tanami Complex", suggesting that they equated it with what is now recognised as Dead Bullock and Killi Killi Formations. The package comprises an association of fine-grained and altered mafic rocks, cleaved siltstone, and graded and cross-bedded coarse-grained sandstone, intruded by felsic dykes. Significantly, this package appears to have undergone only one major deformation, imparting a steep north-trending cleavage, which is axial-planar to tight folding. This observation suggests that the succession belongs to the Ware Group. This area is close to known gold mineralisation and represents an economically prospective area that is currently poorly understood.

Also during 2003, a visit was made to the Groundrush deposit to assess the host rocks within a regional stratigraphic context. The Dead Bullock Formation has not yet been unequivocally observed on the eastern side of the Suplejack shear, a major north-trending structure, thought to represent a crustal-scale shear in the eastern third of TANAMI. 3D geophysical modelling indicates that it dips moderately to the west, implying reverse net movement on the fault, as Tanami Group rocks outcrop immediately to the west at the Groundrush deposit. These sediments are upper greenschist to lower amphibolite facies metre-scale beds of arkosic conglomerate and coarse-grained sandstone, with siltstone and chert capping each bed. The siltstone is very reminiscent of the Dead Bullock Formation at Dead Bullock Soak. We postulate that the Groundrush sediment was deposited in a half-graben, formed through normal movement on the Suplejack shear during Dead Bullock deposition. The arkosic beds sourced immature detritus from nearby uplifted granitic/gneissic basement (to the east?) with each seismic disturbance, followed by a long period of little or no sedimentation, allowing pelagic sedimentation and chert layers to develop. Finer layer-parallel mafic rocks in these sediments may be derived from volcanic activity centred on, or

[1] Email: andrew.crispe@nt.gov.au

controlled by the Suplejack shear. This idea will be tested in the forthcoming months, using geochronology and possibly sequence stratigraphic studies by Geoscience Australia (see Lambeck, 2004).

In summary, the preliminary stage of the Birrindudu mapping project has identified areas previously mapped as Nongra beds that contain Tanami Group stratigraphy (including Dead Bullock Formation) and an unstudied felsic volcaniclastic package. To the north, the Helena Creek beds are a poorly understood association of rocks that may belong to the prospective Ware Group. Furthermore, our work on the Groundrush deposit may shed new insights on the depositional environment of the lower Tanami Group as well as the structural evolution of the Tanami.

Acknowledgments

The authors wish to thank Newmont Exploration and particularly the Groundrush Mine geologists, for their assistance and willingness to provide samples. We would also like to acknowledge the CLC and thank the Traditional Owners for allowing us to carry out geological studies on their land.

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STRIKE!

Tracey Rogers[1]

The Northern Territory Geological Survey has made geophysical imagery available over the web via the Image Web Server since 2000, but no other geoscientific data has been delivered through a web mapping interface, although as much information as possible has been made available via file downloading.

In 2002, it was decided to proceed with the purchase of appropriate web-mapping software and development of a web-based mapping interface to serve geoscientific GIS data and imagery. The tender was advertised and evaluated in 2003 and awarded to NGIS Australia. Development began in November 2003 and the first phase will be completed in March 2004.

The system has been named STRIKE, which nominally equates to Spatial Territory Information Kit for Exploration. It will enable explorers to display both imagery and vector-based geoscientific GIS data as a series of layers. Tenement and cadastral data will also be available, but at present will not be updated on a daily basis and therefore will not replace the Titles Information System (TIS) for tenement administration. Users of STRIKE will have the ability to:

- query data attributes via ad hoc queries eg mineral occurrences, geology;
- create user-defined maps with both imagery and vector-based data;
- drill down through all layers at a single point to determine what data elements exist at that point;
- manipulate transparency of images;
- select all data within the active layer (user-defined) by rectangle, circle or polygon select tools;
- select all the point data within a selected polygon boundary, eg all geochemical samples within a tenement boundary;
- select historical exploration tenements and retrieve relevant IRMS records;
- download data files;
- download all data in the map window clipped to the map window boundary and have it emailed to a specified address;
- export attribute data;
- view the metadata for all datasets; and
- show or hide the legend and overview map, and toggle between geographic and UTM coordinates

[1] Email: tracey.rogers@nt.gov.au

DEEP SEISMIC PROFILING OF THE SOUTHERN MCARTHUR BASIN: IMPLICATIONS FOR GEOLOGICAL EVOLUTION, MINERALISATION AND EXPLORATION

DJ Rawlings[1], RJ Korsch[2], B.R. Goleby[2], GM Gibson[2] and DW Johnstone[2]

The Palaeo- to Mesoproterozoic southern McArthur Basin contains an unmetamorphosed, relatively undeformed succession of carbonate, siliciclastic and volcanic rocks that host the world-class McArthur River Zn-Pb-Ag deposit. The one dataset with the potential to have the most significant impact on our understanding of the crustal architecture, in which this deposit formed, is reflection seismic data. To this end, a deep seismic reflection survey was undertaken in late 2002, to examine the fundamental basin architecture of the southern McArthur Basin, particularly the Batten Fault Zone, and the nature of the underlying basement. The Northern Territory Geological Survey (NTGS), Geoscience Australia (GA) and the Predictive Mineral Discovery Cooperative Research Centre (*pmd**CRC) combined to acquire an east–west deep seismic reflection profile, approximately 110 km long, that commenced 15 km west of Borroloola, and extended westwards along the Borroloola-Roper Bar road to the Bauhinia Downs region. A short 17 km north–south cross-line was also acquired, in collaboration with Anglo American. The seismic data were acquired through the Australian National Seismic Imaging Resource (ANSIR).

Key Findings and Implications for Geological Evolution

In terms of the basin stratigraphy, there is very little evidence in the seismic data for stratal growth and stratigraphic thickening, although in gross terms, the middle part of the succession (McArthur Group) thickens gradually towards the east, while the preserved thickness of the upper part (Roper Group) increases to the west. At the eastern end of the seismic profile, the entire succession is essentially horizontal and at least 8 km thick, including 3.2 km of McArthur Group and 1 km preserved of the lower part of the Roper Group. At the western end of the profile, there is also a thick succession of at least 9 km, of which about 1.3 km is McArthur Group and 5 km is Roper Group. We see no evidence in the seismic data for the Batten 'Trough' being a separate depocentre, or for asymmetric half grabens, because the sedimentary succession appears to continue in both directions away from the implied boundaries of the 'Trough'. A more likely palaeogeographic scenario appears to be of a gently east-dipping carbonate ramp at McArthur Group times, with third-order sub-basins generated along the Emu Fault at specific time intervals. This finding contrasts substantially with most previously proposed tectonic architectures (eg Plumb and Wellman 1987).

Most of the seismic profile is dominated by a series of west-dipping faults that we interpret as forming part of a major thrust belt that has propagated eastward, forming a forward-breaking sequence of thrusts. Within the section, displacement on the thrusts tends to be greatest in the west and diminishes to the east, with the frontal thrust of the system occurring 6 km west of the Emu Fault Zone, and having only minor displacement. The rock mass east of the Emu Fault is therefore interpreted to have acted as a structural buttress. In the west, the Roper Group forms the western limb of the Bauhinia monocline, which developed above the most western thrust ramp in the seismic data, and indicates a post-Roper Group timing for the thrust system. Deformation and fault geometry are consistent with a direction of tectonic transport towards the east. The thrusts continue at depth beyond the western limit of the seismic section, and this part of the thrust belt is now hidden beneath younger cover. Deformation and fault geometry are consistent with an east- to northeast-striking compressional axis.

We have interpreted the Emu Fault as a near-vertical strike-slip fault, containing an inverted flower structure along seismic Line 02GA-BT1. This is supported by the overall linear nature of the fault system in plan and rapid changes in geometry along strike. At least two episodes of fault activity are postulated. The first involved sinistral movement in middle McArthur Group times, leading to possible stratal growth on transtensional fault bends. The second involved dextral movement and postdates the Roper Group. It has inverted earlier transtensional zones to form positive flower structures. The Narwinbi Fault, a north-northeast-striking fault that kinks into the Emu Fault, is also interpreted as a positive flower structure, involving at least post-Roper movement.

Implications for Mineralisation and Fluid Flow Models

The seismic data support, to some extent, the genetic and fluid flow models for the McArthur River Zn-Pb-Ag deposit of Hinman (1995), Large *et al* (1998), Garven *et al* (2001), Simms *et al* (2001) and Yang *et al* (2001). The various cross-sections used for fluid flow modelling vary in their consistency with respect to the section derived from the seismic data. However, it must be acknowledged that alternative interpretations of the seismic are possible and an east–west section at the latitude of HYC may be somewhat different to that at Line 02GA-BT1.

Facets of the cross-sections used for genetic and fluid flow modelling that **are consistent** with the seismic cross-section include the following:

[1] Cameco Australia Pty Ltd, PO Box 35921, Winnellie NT 0821. Email: David_Rawlings@cameco.com

[2] Predictive Mineral Discovery Cooperative Research Centre, Geoscience Australia, GPO Box 378, Canberra ACT 2601, Australia

- Emu Fault geometry. The geometry used in the fluid flow models at HYC is deep-rooted and steeply west-dipping, as observed in the seismic data at Ryan Bend. In addition, the seismic data indicate a complex anastomosing strike-slip fault geometry, allowing access to deep basinal brines.
- Stratal growth at Emu Fault. The seismic data suggest that sedimentary growth took place within negative flower structures along the Emu Fault during middle McArthur Group times. Rapid local deposition and growth were probably facilitated by differential subsidence along transtensional releasing bends on the fault. The resulting sub-basins were inverted during post-Roper deformation, when these areas became transpressional restraining bends.
- 'Upper Tawallah Group aquifer'. In the seismic data, the aquifer system modelled to lie between the current positions of the Emu and Tawallah Faults (Garven *et al* 2001) takes the form of a more-or-less contiguous, 1500 m-thick, poorly reflective package in the postulated upper Tawallah Group. However, no porosity or permeability estimates can be inferred from the seismic data.
- Thickness changes in the lower Tawallah Group clastics (mainly Yiyintyi Sandstone). An increase in thickness across the Emu Fault from west to east, as shown in the models of Yang *et al* (2001), is supported to some extent by the seismic data (although not conclusively).

Facets of the fluid flow-derived cross-sections that **appear to be inconsistent** with the seismic include the following:

- McArthur Group, east of the Emu Fault. In the fluid flow models, this block is shown to be upthrown and thinned compared to west of the fault. In contrast, the seismic profile clearly shows a monoclinal structure with gross east-side-down movement and a continuation of thick McArthur Group to the east.
- McArthur Group between the Tawallah and Emu Faults. The overall geology is shown in the fluid flow models to dip eastward, when it actually youngs and dips to the west (this is also evident on geological maps).
- Geometry of the Tawallah Fault. Interpretation of the seismic data at the Tawallah Fault is not conclusive, due to areas of poor data quality, but there is no evidence for any steep deep-rooted west-dipping structure, as used in the fluid flow models. Instead, a shallowly west-dipping thrust is postulated. In any case, this fault postdates deposition of the McArthur Group and formation of the HYC ore body by at least 200 million years (unless structural reactivation or an unlikely 'late epigenetic' model is invoked). In addition, the current position of the Tawallah Fault reflects the current termination of a thrust sheet, not the architecture at McArthur Group times. However, it is important to note that the interpretation of Line 02GA-BT1 is two-dimensional, and therefore does not preclude the presence of another blind 'recharge' structure further to the south of the seismic line and west of HYC.
- Offset at the Tawallah Fault. This is shown in fluid-flow-derived cross-sections as an anticline, when it should show a substantial west-side-up reverse geometry (also evident on geological maps).

Implications for Mineral Potential and Exploration Philosophy

The new seismic data expand the potential for base metal deposits of various types within and beyond the Batten Fault Zone.

Covered segments of the Emu Fault north and south of HYC

The seismic data have strengthened the interpreted strike-slip geometry of the Emu Fault, with probable stratal growth of the upper McArthur Group within some flower structures (eg HYC and Ryan Bend). This means that other sub-basins must have developed along the 150 km length of the fault and are prospective for 'McArthur-style' SEDEX base metal deposits. The likely economics of any discoveries are also enhanced by the possibility that mineralised sub-basins (typically subsidence features and therefore structurally 'deep') have been later inverted to sit at structurally 'neutral' or 'shallow' positions.

Covered areas east of the Emu Fault

Contrary to most literature, the McArthur Group continues east of the Emu Fault with considerable thickness and largely parallel reflections, indicating that this fault did not have first-order control on deposition or post-deformational distribution. Therefore, the exploration potential of covered area to the east is improved, as there is a much broader distribution of appropriate and thick trap rocks (Barney Creek Formation appears to be a wide high-amplitude reflection set) and other blind synsedimentary structures like the Emu Fault could be present. The Narwinbi Fault, for example, is relatively subtle on geological maps, but is shown to be a significant strike-slip fault in the seismic data.

Within the Batten Fault Zone

The current structure and thickness estimates of packages in the Batten Fault Zone do not reflect the architecture at Barney Creek time. Thrust sheets elsewhere in the fault zone may thus contain a thicker McArthur Group succession or may conceal an Emu-like strike-slip fault that had earlier tapped fluids from deep in the basin. There is thus potential to discover 'blind' structurally-transported SEDEX deposits within the main thrust belt.

MVT, petroleum play and thrust belt-associated deposits

The development of a fold and thrust belt within and west of the Batten Fault Zone also provides potential for a second major topographically-driven fluid flow event, some time after deposition of the Roper Group. This increases the exploration potential for epigenetic 'Mississippi Valley-Type' (MVT) or petroleum-play 'Century-style' deposits, in appropriate lithologic and structural settings in the broader McArthur Basin. This fluid flow event may have been responsible for numerous epigenetic base metal occurrences within the McArthur Basin (eg Redbank, Eastern Creek, Thor). Appropriate carbonaceous units occur throughout the succession and include the Wollogorang Formation (Tawallah Group), Barney Creek Formation, Caranbirini Member (McArthur Group), Mainoru Formation and Velkerri Formation (Roper Group). Well-developed karstic carbonate units include the Emmerugga Dolomite (McArthur Group), Balbirini Dolomite (Nathan Group) and Karns Dolomite. Importantly, MVTs have two distinct exploration advantages over SEDEX deposits in the Carpentaria Zinc Belt: (**1**) their overall distribution is much wider; and (**2**) they have better metallurgical properties.

Deposit remobilisation

Any HYC-aged SEDEX deposits involved in thrusting within the central Batten Fault Zone may have been hydrothermally remobilised and manifested as widespread diffuse anomalism, or fault-associated 'late' epigenetic occurrences. A potential example is Bulman on the Arnhem Shelf.

Direct detection of SEDEX deposits

Seismic acquisition and processing proved to be successful in the region and, therefore, SEDEX deposits may be detectable with shallow (1 second) reflection seismic techniques. This may be an economically viable option for explorers along the length of the Emu Fault Zone, particularly under thin cover.

Data release

A complete description of the seismic survey and the key scientific results will be published shortly as a Geoscience Australia Record.

The seismic data are available through ANSIR @ GA (contact Tim Barton on +61 2 62499625 or email Tim.Barton@da.gov.au).

For more information phone Russell Korsch at *pmd**CRC @ GA on +61 2 6249 9495 or email russell.korsch@ga.ov.au or Richard Brescianini at NTGS on + 61 8 8999 5377 or email richard.brescianini@nt.gov.au

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NEW ADVANCES IN THE AMADEUS BASIN

Torey Marshall[1] and John Dunster

The Amadeus Basin has not been the subject of any extended NTGS program in the last twenty years. Geoscience Australia, (then Bureau of Mineral Resources) undertook work on the basin during the 1980s, and their insights pushed the boundaries of economic understanding and had major implications for exploration within the basin. The current NTGS study aims to use new techniques and methods to provide important new insights to aid mineral and petroleum exploration in the Amadeus Basin.

The Amadeus Basin is currently the focus of an NTGS multi-commodity study in the same vein as that done for the Georgina Basin (Dunster *et al* 2004, in prep). In the past, exploration has taken place, with mixed success, for numerous commodities including hydrocarbons, evaporites, zeolites, copper, gold, uranium, phosphate and manganese. The occurrence of gold on the northern margin of the basin is well known (eg Arltunga and Winnecke Goldfields), as are copper shows around Waterhouse Range, zeolites and evaporites (KULGERA), and uranium in Devonian rocks of the northern basin.

During the past 18 months, the Petroleum Branch of NTGS has been active in attempting to answer some questions relating to the possible accumulation of hydrocarbons basinwide. Our studies will have five main outputs, which will include:

- a source rock review – to delineate potential hydrocarbon producing intervals, generally organic-rich shales, which in turn has implications for the host stratigraphy for mineral deposits;
- a petroleum systems evaluation – to understand the working petroleum systems in the basin, where each system is more likely to be present, what is likely to have been produced (oil/gas), and so on;
- structural history/halotectonic modelling – to understand the structural evolution of the basin, which is extremely important, as mineral and petroleum occurrences in the Amadeus are typically structurally controlled;
- thermal history modelling – the thermal history of the basin is derived from the results of structural modelling, conventional fluid inclusion analysis and other techniques of assessing thermal maturity. This has implications on the presence/charge/accumulation of commodities, ranging from petroleum to base metals; and
- a leads and prospects inventory – primarily with a petroleum focus, but as the name suggests, this will document all known, and a large number of new leads and prospects within the Amadeus.

The source rock review (Marshall 2004a, *in press*) synthesised previous work done on source rocks in the Amadeus, but also included significant new information and further interpretation. The assumption that the source rocks in the basin were always gas-prone is likely to be incorrect. Pristane/Phytane ratios indicate that the original kerogen character was most likely to be type 2, producing oil and gas. The general assumption is that various stratigraphic intervals have most likely produced oil previously, which further degrades their present organic character/production indices. Equally, previous interpretations of maturity data indicated that the basin source sequences, as a whole, were overmature for the generation of hydrocarbons (perhaps just gas). New information (MPI) shows that the southern parts of the Amadeus appear to be subjected to a much lower maturity gradient.

Following on from the source rock study was the utilisation of CSIRO Petroleum's patented Fluid History Analytical techniques (FHA). The techniques chosen were Grains containing Oil Inclusions (GOI), Quantity of Grain Fluorescence (QGF), and Quantity of Grain Fluorescence Extract (QGFE). These measure the presence of oil directly; QGF, which is based on fluorescence, can be affected by the presence of other contaminants, such as drilling mud chemistry, whereas GOI is a counting method, whereby the actual quantity of grains containing oil inclusions are counted from thin sections. The presence of palaeo-oil was noted in all but one of the wells measured by QGF, and a residual oil column was found in the Finke-1 well (Marshall 2004b). The Finke 'accumulation' is important, as it is reservoired in a Neoproterozoic unit, the Finke beds. This raises the potential for finding oil in units of equivalent ages within the Amadeus, and potentially, surrounding basins.

After much research, the structuring of the basin, specifically the relative timing of movement on faults, is expected to be the single most important control on the distribution of economic deposits. The current phase of the project is examining the structural history of the basin. In order to do this, NTGS has embarked on two major techniques, the first of which is the SRK-patented SEEBASE-style of interpretation. This method has the advantages of creating a basin container shape, GIS recognition and a fault-movement history, as applied from a basement point of view. The second is the sequential balancing and restoration of cross-sections intra-basinally, via a software package called 2Dmove™. Initially, the backstripping of sections will take place, based on the interpretation of seismic sections. Preference will be given to spatial location, as opposed to data quality as a whole, and 5 regional cross-sections, oriented approximately north–south, will be constructed and restored. Well-documented salt/evaporitic horizons in Late Proterozoic units (Bitter Springs and Chandler Formations) are a complicating factor. Halotectonics is an important basin driver in terms of preferential activation/reactivation of older

[1] Email: torey.marshall@nt.gov.au

structures, and its importance in understanding movement history cannot be understated. Basin/thermal modelling will take place in parallel with the structural research.

Preliminary interpretations and insights are as follows:

- Salt bodies that are present in the basin were initially driven by tectonism during the onset of the Petermann Orogeny. This created the void space for the evaporites to occupy. The southern part of the basin, having been relatively tectonically inactive, has autochthonous salt present, indicating a high degree of preservation. These diapiric-style intrusives have been at buoyant equilibrium for a substantial period of time.
- Most structures that are seen in the basin were nucleated during the Petermann Orogeny. Sequential transpressive and compressive forces have acted through the late Neoproterozoic and Early Cambrian time to give the basin its current configuration.
- The central ridge is likely to be a basement-derived feature, dating back to the original extensional events that lead to initial basin formation/rifting. It has a very important role in the accommodation of strain during large tectonic events. During the first phases of compressive events, older normal faults were reactivated in a reverse sense, creating a horst block. The accumulation of salt, particularly on the southern flank, provided a detachment surface for very large-scale movements. Because the central ridge has been able to accommodate large amounts of strain, the southern parts of the basin saw relatively little deformation associated with the Alice Springs Orogeny.
- To be most accurate, and to delineate the most applicable exploration models, the basin should be broken into separate structural sub-domains, as each is geometrically and thermally unique. The most obvious division would be separation into a northern thick molasse domain and a southern stable zone that includes the southwestern margin of the basin adjacent to the Musgrave Block, where it has been shown that high metamorphic temperatures existed (Close *et al* 2003).

The current program is in progress and structural products are expected to be available during 2004/05.

We feel that through a solid understanding of the intra-basinal effects of structural and thermal events, it is possible to be able to devise successful exploration models for a number of commodities likely to be present in the Amadeus Basin.

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INDUSTRY INFORMATION SERVICES

Tracey Rogers[1]

All industry information services in the Northern Territory Geological Survey (NTGS) are provided through the Minerals and Energy Information Centre. Services include product distribution, access to, and distribution of open file company reports, reference queries and data delivery through the web.

In the past 12 months, several major information projects have commenced and several others have progressed significantly since AGES 2003. Those of particular interest to industry include: Pine Creek Orogen (PCO) geochemistry data capture; upgrades to both IRMS and the core library database records; and the completion of the web mapping interface for geoscientific GIS data.

The Pine Creek Orogen open file geochemistry data capture project, covering thirty-nine 1:100 000-scale mapsheets, commenced in September 2003. Data collected for the western PCO module consists of 487 drillholes, 744 rock chip and 4064 stream sediment samples, as at the end of February. The data will be released in MapInfo and Excel formats later in 2004, as part of an updated Digital Information Package (DIP 5). Work on the other modules is also continuing.

The IRMS minerals database has many incomplete or inconsistent records as a result of limited information systems and management practices. It is estimated that between 6000 and 7000 records need to be substantially improved to enable efficient and consistent data retrieval. A project to upgrade the worst records commenced in January 2004 and will continue for 18 months to two years. Over the first six weeks, 448 reports were reindexed and IRMS updated. The first focus of the project is records with no subject keywords, and to-date, work has concentrated on the Pine Creek region, to help support PCO geochemical data capture and other PCO projects. Updated records are available via the IRMS searching interface on the website, which is updated monthly.

The core library database, COREDAT, also has incomplete records, including 1562 without coordinates, as of 7th January 2004. A project commenced in late January to locate these drillholes and update the database. As of 1st March, 302 holes had been located and COREDAT records updated. During this process, duplicate records have also been discovered and removed, and other information updated.

The current GIS datasets for 1:250 000 geological mapsheets produced by NTGS are very basic and do not contain attributes for structural elements. In late 2003, a pilot project to produce a comprehensive GIS dataset for a 1:250 000 mapsheet was initiated. The map chosen for the pilot project was Tobermorey and it is due for release in June 2004. The dataset will be comprised of 17 layers and will be fully attributed. Once released, every new map will have the same GIS dataset format and back-capture of older mapsheets will begin.

Data from many onshore petroleum wells in the NT is being entered into the Geoscience Australia databases ORGCHEM, RESFACS and STRATDAT. ORGCHEM is a petroleum source-rock database containing, among other things, organic carbon, extracted organic matter, thermal alteration indices and natural gas composition data. RESFACS is a petroleum reservoir database containing reservoir, facies and hydrocarbon data including location, permeability, porosity, water saturation and depositional environment. STRATDAT contains interpretive biostratigraphic data, relating fossil zones to absolute time scales in selected wells. The database also contains sequence boundaries, formation tops and other log pick data. All three databases can be accessed through the Australian Petroleum Cooperative Research Centre-sponsored and Geoscience Australia-built website at www.ga.gov.au/oracle/apcrc. The website uses a combination of textual and spatial selection tools to identify datasets for downloading as ASCII text files, and has the facility to graph data online for a preview, before downloading. The NT data will be available via the website in July 2004.

A tender for a web mapping system was evaluated in 2003 and awarded to NGIS Australia. Development work commenced in November and the system will be available on the website late March 2004. The system has been named STRIKE: Spatial Territory Information Kit for Exploration and will allow explorers to query geoscientific data and create maps on the fly. Further details of STRIKE are given in a separate paper.

[1] Email: tracey.rogers@nt.gov.au

INDIGENOUS LIAISON

Chris Lee[1]

The Indigenous Mining and Industry Services (IMIS) Branch of the Department of Business, Industry and Resource Development (DBIRD) is the NT Government's specialist resource industry and Aboriginal community liaison service.

The IMIS Branch offers specialist skills and experience in land access strategies and programs exclusive to the Northern Territory. It includes three regional offices (Darwin, Tennant Creek and Alice Springs), skilled and experienced Aboriginal and non-Aboriginal staff, and a range of models, posters and career guides to assist in educating communities and industry groups.

IMIS uses a range of tools and products to explain some of the more complex and technical aspects of mining, exploration and extractive operations to Aboriginal people and communities. This ensures that Aboriginal community members have all the necessary information to make informed decisions.

IMIS has also taken on more of the NT Government's enterprise development focus. IMIS staff encounter many Aboriginal community members who are ready to establish micro-enterprises on outstations and communities. The Branch facilitates business development, training and, sometimes, funding, and coordinates access to knowledge and information, to help create employment and business opportunities. IMIS resources and assistance are also available to industry, to aid in community consultation meetings and negotiations with communities and regional stakeholders, and to facilitate access to key stakeholders and NT Government programs.

As part of the IMIS information program development, the branch has commenced work on a Land Access CD-ROM, aimed at the exploration industry executive. This CD will contain all the necessary information essential to exploration and extractive activities in the NT, particularly in relation to Aboriginal-owned land and resources. IMIS is building two versions of the CD. The first instalment is aimed at the Industry executive who has some idea of what their company wants to do in the NT, but needs a few directions on how to best achieve the required results. The second version will target Aboriginal communities and stakeholders. A simpler version of language will be used, as well as more photographs and diagrams, and embedded videos explaining more technical processes.

IMIS will continue to deliver physical face-to-face workshops, as the best method of maintaining our close relationships with Aboriginal communities, and to reach those communities who don't have CD/IT technology.

[1] Indigenous Mining and Industry Services branch, DBIRD. Email: chris.lee@nt.gov.au

NORTHERN TERRITORY TENURE UPDATE

Jerry Whitfield[1]

Steady progress has been made over the past twelve months on the grant of exploration and mining titles in the Northern Territory.

Significant developments include the:

- completion of a number of agreements between industry and Native Title claimants;
- negotiation of various Indigenous Land Use Agreements (ILUAs);
- implementation of administrative reforms to processes associated with the *Aboriginal Land Rights (Northern Territory) Act;* and
- commencement of a review of the Northern Territory *Mining Act.*

To further progress title issues, a number of Departmental staff will be attending AGES. Participants are encouraged to take the opportunity to discuss titles issues with these Departmental representatives.

Native Title

The grant of exploration licences on land subject to Native Title, is now a routine and timely process. The Northern Territory Government has well established conditions of title that are aimed at protecting Native Title rights and interests. In addition, stakeholders are entering into ILUAs and other forms of agreements, to provide for the grant of title.

Aboriginal Freehold Land

To progress title applications on Aboriginal freehold land, the Northern Territory Government and stakeholders have proposed legislative and administrative reforms to the *Aboriginal Land Rights (Northern Territory) Act.*

Legislative reforms to the *Act* are currently before the Federal Government for consideration.

Initiatives to improve administrative processes related to the *Act* include the placing of conditions on the consent to negotiate, holding consultative forums, conducting regular meetings between the Northern Territory Government and Land Councils, and producing a user-friendly guide for the *Act.*

One initiative is the 'New Perspectives' workshop which will be held at the end of AGES. The aim of this workshop is to cultivate a better understanding of issues faced by stakeholders.

Mining Act Review

The Northern Territory Government has commenced a review of the *Mining Act*, with the aim of developing a discussion paper for circulation to stakeholders by the middle of the year.

The review of the Act is timely, as there has been substantial change within the mining industry since the commencement of the *Act* in 1982. These changes include the globalisation of the industry, the advent of technology and the introduction of the *Native Title Act*.

[1] Director of Titles, Department of Business, Industry and Resource Development. Email: jerry.whitfield@nt.gov.au

PROGRESS IN THE ARUNTA

Ian Scrimgeour[1]

At AGES 2003, a revised geological framework for the Arunta was presented, which outlined a large number of sedimentary packages and tectonomagmatic events, stretching from the Palaeoproterozoic to the Palaeozoic (Scrimgeour 2003). In the past year, NTGS work in the Arunta has focused on the completion of the Arunta North and Arunta South projects, along with continuing mineral deposit studies in various parts of the region. On the basis of mapping and new geophysical interpretations, a completely revised 1:2 500 000-scale map of the Arunta has been made for the new Geological Map of the Northern Territory (Ahmad and Scrimgeour 2004). This will lead towards the production of a new 1:1 000 000-scale interpreted map of the Arunta that contains more detail on the individual sedimentary packages and granite suites.

A revised province subdivision of the Arunta has been defined in the past year, with three named provinces. The oldest province in the Arunta Region, the *Aileron Province*, forms part of the North Australian Craton, and is geologically contiguous with the Tanami and Tennant Creek Regions. Sedimentary protolith ages in this province are restricted to the period 1865–1740 Ma, with the intensity of deformation and metamorphism increasing to the southeast, reflecting likely proximity to a Palaeoproterozoic plate margin. In the southwestern Arunta, the *Warumpi Province* has sedimentary and igneous protoliths in the range 1690–1600 Ma, and is interpreted to be a terrane that accreted onto the craton at 1640 Ma (see Close *et al* 2004). In the eastern Arunta, a third, fault-bounded terrane, named the *Irindina Province*, incorporates Neoproterozoic to Cambrian sediments and mafic rocks of the Harts Range Metamorphic Complex (Maidment *et al* 2004) that were metamorphosed during the Ordovician Larapinta Event.

Our understanding of the Arunta is continually evolving, and changes to our understanding of the geological framework over the past year include:

- the recognition of previously unknown 1530 Ma magmatism in the western Arunta (Close *et al* 2004);
- the identification of a thermal and magmatic event at 520 Ma in the Irindina Province (*Stanovos Event*, Maidment *et al* 2004);
- the recognition by Jon Claoué-Long [Geoscience Australia (GA)] and Matt Cobb (Curtin University) that the Strangways Orogeny spanned the interval 1730–1700 Ma, and may comprise two discrete events; and
- the dating of the metasediments hosting mineralisation at the Oonagalabi Deposit, which shows that they are younger than most of the Strangways Metamorphic Complex, with an age of 1760–1750 Ma (Hussey *et al*, 2004).

Upcoming work by NTGS in the Arunta in 2004 includes:

- the mapping of the southeastern margin of the Arunta, including the Todd 1:100k map in northeastern HALE RIVER;
- the interpretation of recently flown airborne geophysics in the poorly exposed far eastern and southeastern Arunta (HAY RIVER, HALE RIVER, ILLOGWA CREEK, SIMPSON DESERT NORTH).
- a magnetotelluric geophysical traverse to examine deep crustal structure across the eastern Arunta (Kate Broxholme, University of Adelaide);
- a study of metamorphism across the western and northern Arunta, including a new interpreted metamorphic facies distribution map;
- a study of the metallogenic potential of granites in the Warumpi Province, in collaboration with Lesley Wyborn (GA); and
- the mapping of the Jervois Range 1:100 000 mapsheet, from a geological and metallogenic perspective, including the interpretation of new high-resolution airborne geophysics over the sheet.

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[1] Email: ian.scrimgeour@nt.gov.au

THE HARTS RANGE METAMORPHIC COMPLEX – A NEOPROTEROZOIC TO CAMBRIAN METAMORPHOSED RIFT SEQUENCE IN THE EASTERN ARUNTA REGION

DW Maidment[1, 2], IS Williams[1] and M Hand[3]

The Harts Range Metamorphic Complex (HRMC) in the eastern Arunta Region [comprising the Irinidina Province of Scrimgeour (2003)] is a distinctive sequence of supracrustal rocks metamorphosed at amphibolite- to granulite-facies that structurally overlies the Palaeoproterozoic Strangways Metamorphic Complex (SMC). The HRMC has long been considered to have been deformed and metamorphosed in the Palaeoproterozoic, at a similar time the SMC; however, relatively recent Sm-Nd and U-Pb isotopic data for the HRMC show that high-grade metamorphism took place in the Early Ordovician at 475–460 Ma, a time previously considered to be tectonically inactive in the central Australian region (Hand *et al* 1999; Mawby *et al* 1999; Buick *et al* 2001). This tectonism has been termed the Larapinta Event. It took place under high-temperature, moderate-pressure conditions, consisting of a peak metamorphic phase at 800˚C, 10–12 kbar, and a retrograde phase at 700˚C, 7 kbar (Miller *et al* 1997, Mawby *et al* 1999). Perhaps even more unexpected are initial detrital zircon data that indicate that the sedimentary protoliths to the HRMC were deposited as recently as the Cambrian, with no evidence of a Palaeoproterozoic history (Buick *et al* 2001). These data raise the possibility that the protoliths to the HRMC were deposited within a sub-basin between the Amadeus and Georgina Basins, as part of the greater Centralian Superbasin.

SHRIMP U-Pb detrital zircon data have been collected for sediments in the Georgina and Amadeus Basins to provide a reference, against which detrital zircon populations from the HRMC can be compared, in order to evaluate how the highly metamorphosed supracrustal rocks in the Harts Range relate to the Centralian Superbasin. U-Pb zircon isotopic data have also been collected for metasediments, metavolcanics and felsic intrusives of the HRMC to delineate: (**1**) the extent of Neoproterozoic-Cambrian metasediments; (**2**) the timing of the Larapinta Event; and (**3**) changes in sediment provenance of the supracrustal sequences in the HRMC.

Detrital zircon data for the Amadeus and Georgina Basins show that for much of the Neoproterozoic, sediments were sourced from the Palaeo–Mesoproterozoic Arunta basement and the broader North Australian Craton. The data also indicate a variable, but generally lesser input from the Musgrave Block in southern central Australia. The similarity between detrital zircon populations of late Neoproterozoic sedimentary rocks, coupled with stratigraphic arguments (Shaw 1991), suggests that the Georgina and Amadeus Basins were still linked at this time. Latest Neoproterozoic sedimentary rocks from the Amadeus Basin are dominated by Grenvillean-age zircons, interpreted to reflect uplift and erosion of the Musgrave Block during the 560–520 Ma Petermann Orogeny. A more complex detrital spectrum from a similarly aged unit in the Georgina Basin has a higher proportion of Meso- to Palaeoproterozoic ages, suggesting a larger component of sediment sourced from the North Australian Craton. Conceivably, this difference reflects the formation of deeper sub-basins along the northern margin of the Amadeus Basin and the initiation of rifting between the two basins, which formed a barrier to sediment transport. An influx of Pan-African-age zircons (650–500 Ma), beginning in the latest Cambrian, appears to be related to the formation of the northwest-trending Larapintine Seaway, which connected the eastern and western margins of Palaeozoic Australia. Latest Cambrian to Early Ordovician sediments deposited in the seaway have very similar detrital signatures to those of Cambro-Ordovician sedimentary rocks in southern and southeastern Australia, New Zealand, the Transantarctic Mountains and South Africa. The consistency of the detrital signature over such an extensive area suggests a distal source, possibly the Mozambique Belt of the East African Orogen. The lack of a Palaeo-Mesoproterozoic Arunta component in Early Ordovician sediments of the Amadeus and Georgina Basins and the presence of the seaway strongly implies that there was no significant positive topography during the high-grade Early-Mid Ordovician Larapinta Event. Basin inversion took place from 450 Ma, and included numerous phases of convergence and extension during the Alice Springs Orogeny (450–300 Ma). Syn-Alice Springs Orogeny sediments of the Silurian to Early Devonian Mereenie Sandstone and Early Devonian Dulcie Sandstone have detrital signatures similar to those of Cambro-Ordovician sediments, suggesting that uplift of the northeastern Amadeus Basin had not yet exposed the lower parts of the cover sequence or Arunta basement at this time. This implies that the bulk of uplift associated with the Alice Springs Orogeny took place after 380 Ma.

Detrital zircon data from the HRMC indicate that high-grade Neoproterozoic-Cambrian metasediments extend as far east as the Atula Homestead area, 100 km east of the Harts Range. Metasediments of the HRMC have similar maximum depositional ages, provenances and evolving provenance patterns to the Amadeus and Georgina Basins, and thus appear to be the highly metamorphosed equivalents of the Amadeus-Georgina sequences. Some metasedimentary units in the HRMC have distinctive detrital signatures that closely match those of the adjacent basins, and appear to be direct correlatives (eg Brady Gneiss and Pacoota Sandstone/Tomahawk Formation). Similarities between the detrital age signature of quartzite from the Stanovos Gneiss in the HRMC and the Heavitree Quartzite, the lowermost unit of the Amadeus Basin, suggests that the complete Neoproterozoic to Cambro-Ordovician sequence of the Centralian Superbasin is likely to be represented in the

[1] Research School of Earth Sciences, Australian National University, Canberra ACT 0200
[2] Geoscience Australia, GPO Box 378, Canberra, ACT 2601
[3] Department of Geology and Geophysics, Adelaide University, Adelaide SA 2002

HRMC. Zircon overgrowths on detrital cores in the HRMC have ages of 470–460 Ma, which appears to be consistent across the province, including metasediments of slightly lower metamorphic grade in the easternmost HRMC.

While the bulk of the interpreted zircon growth in the HRMC points to high-grade Early to Mid-Ordovician metamorphism, the apparently lowest parts of the HRMC stratigraphy have layer-parallel granites that give ages of 520 Ma, which are significantly older than the Larapinta Event. Significantly, these zircons are overgrown by 460 Ma zircon, confirming the existence of a distinct, high-T event in the Mid-Cambrian. Based on field relationships and limited inherited zircon data, these granites appear to have been generated by partial melting of the Stanovos Gneiss, and have not been observed in the structurally overlying units. In addition, structurally segregated granitic melt in the Stanovos Gneiss also has an age of 520 Ma. This implies that significant deformation accompanied partial melting of the Neoproterozoic-Cambrian supracrustals, and we have informally termed this the Stanovos Event. The existence of a tectonothermal event at 520 Ma is supported by garnet Sm-Nd ages of 515 Ma from the basement that structurally underlies the HRMC. Based on the minimum ages of detrital zircons and comparisons with detrital age signatures of the Centralian Superbasin, the inferred depositional ages of the overlying Irindina and Brady Gneisses are similar to, or less than the age of crystallisation of the 520 Ma granitic rocks. This implies that sedimentation continued in the upper parts of the basin, while at deeper levels, partial melting and deformation was taking place. The Stanovos Event is broadly coeval with mafic volcanism with rift-like geochemistry in the HRMC and the Antrim Plateau Volcanics flood basalt of northern Australia at 513 ± 12 Ma (Hanley and Wingate 2000), and possibly occurred in an extensional tectonic setting, with crustal and lithospheric thinning leading to partial melting of the lowest parts of the HRMC sequence.

Isopach data, sedimentological studies and detrital zircon data indicate that metamorphism during the Larapinta Event took place beneath the deepest part of a shallow intracontinental seaway, with no evidence of positive topographic development or coarse syn-orogenic sedimentation, similar to that which accompanied crustal shortening during the compressional Alice Springs Orogeny. A pervasive, recumbent, layer-parallel fabric with no evidence of folding formed at mid- to lower-crustal depths, during both peak metamorphism and rapid, near-isothermal decompression as part of the retrograde phase. Syn-tectonic mafic dykes, with MORB-like geochemical signatures were intruded into the HRMC at this time and metamorphosed under amphibolite facies conditions (Lee *et al* 2002). These observations are consistent with an extensional environment for the Larapinta Event, whose peak metamorphic pressure estimates indicate a burial depth of 30–35 km. The suggestion of Early-Mid Ordovician extension is also supported by the presence of the narrow marine corridor of the Larapintine Seaway, which connected the central Australian region in the northwest to the Canning Basin, which was initiated by rifting in the Early Ordovician. If the Larapinta Event took place in an extensional or transtensional setting, then burial may have been achieved largely by sediment loading, and the Mid-Cambrian to Early Ordovician sequence in the Irindina sub-basin would therefore have been 30 km thick, making this basin the deepest known in Earth history. This would require average subsidence and sedimentation rates of 600 m/Ma over 50 Ma, or 1000 m/Ma if subsidence mainly took place during the formation of the Larapinta Seaway, during the latest Cambrian to Early Ordovician. The fact that Early-Mid Ordovician metamorphism has been found only in the HRMC and not the adjacent SMC is consistent with a sediment burial mechanism, which would not be expected to significantly affect the unburied basin margins. A prominent broad linear magnetic feature on the magnetic map of Australia can be traced northwest to the Canning Basin, and southeast to the Warburton Basin, which contains rift-related Cambrian volcanics of similar age to the Stanovos Event (Sun and Purvis 2002). This magnetic feature coincides with the position of the Larapintine Seaway and possibly represents a significant continental-scale structure, which localised extension or strike-slip movement during the Cambrian and Early Ordovician.

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METALLOGENY IN THE EASTERN ARUNTA REGION AND THE POTENTIAL OF ITS PALAEOPROTEROZOIC ROCKS

Kelvin Hussey[1], David Huston[2] and Max Frater

This project is exploring the context of various mineral deposits within a developing conceptual geological framework, to better understand the mineral potential of the eastern Arunta Region. Investigations have concentrated on constraining the geological relationships of selected mineral deposits and their host rocks, through detailed mapping, geochemistry and geochronology. To date, work has mainly focused on base-metal prospects in the Strangways Metamorphic Complex, and more recently, on deposits in the Jervois Mineral Field.

Unravelling genetic models for mineralisation is a difficult task in intensely metamorphosed and deformed rocks. In many cases, the depositional setting of the host rocks is difficult to determine and a variety of options arise, based on rock types and associations. The timing of mineralisation, for example, is also extremely difficult to prove in complex granulite facies rocks, and in most cases, it is only possible to establish whether mineralisation predates or postdates metamorphism and deformation. Therefore to develop a genetic model for mineralisation, it is critical to know precise time constraints on the age of the host rocks and also the age of mineralisation. The latter is often difficult to precisely constrain and one must be aware of the limitations imposed by different geochronological techniques and analytical errors in determining these ages. Nevertheless, it is usually possible to construct one or more geologically plausible models that can be evaluated and tested by other means.

The eastern Arunta Region contains multiply deformed greenschist to granulite facies sedimentary and igneous rocks, with a complex geological history. Numerous small- to medium-sized mineral prospects occur throughout this region, but to date, no large mineable economic deposits have been found. Similar deposit types appear to be present in different areas at different metamorphic grades. This suggests that areas with untested potential may exist, and could shed further light on the tectonic development and regional geological framework. The geology of the eastern Arunta Region appears to be largely represented by the same, or similar chronostratigraphic interval of rocks, but at varying metamorphic grades. Most Palaeoproterozoic rocks in the eastern Arunta Region therefore appear to be chronostratigraphic equivalents of the Strangways Metamorphic Complex. In places, stratigraphic units are up to at least 1820 Ma in age and may be as young as 1750 Ma. Younger igneous rocks are locally present. A similar chronostratigraphic interval also occurs in the nearby Davenport Province of the Tennant Region. Unfortunately the degree of deformation and metamorphism means it is often difficult to determine the depositional setting of rocks throughout the Arunta Region. However, the less deformed Davenport Province provides clues that suggest the Arunta Region may also be an active continental rift setting. The abundance of 1810–1800 Ma (Stafford Event) zircons in the eastern Arunta Region stratigraphy suggests abundant felsic volcanic activity and associated detritus contemporaneous with the Stafford Event. Probable VMS mineralisation in the Strangways Metamorphic Complex appears to be contemporaneous with deformation and emplacement of high-level mafic and felsic magmas, along with localised HT-LP metamorphism in the northern Arunta Region. This association is consistent with an overall continental rift setting.

Several small- to medium-sized, sub-economic Zn-Cu prospects, interpreted as variably retrogressed, granulite facies metamorphosed VMS deposits, occur in the Strangways Metamorphic Complex. These are referred to as Utnalanama-type deposits and appear to be mostly Zn or Zn-Cu prospects, with low Pb, Ag and Au contents. They are hosted by compositionally layered quartz-cordierite-orthopyroxene-biotite ± garnet granulites with localised silica-poor lenses or layers of cordierite-orthopyroxene-biotite or cordierite-spinel ± sillimanite ± garnet granulite. These host units typically form a mappable stratiform footwall layer that can be up to several hundred meters thick, and in some cases appears to be regionally extensive. SHRIMP U-Pb zircon ages for the host rock units show a single detrital/igneous zircon population at 1810–1800 Ma for each of Edwards Creek, Harry Creek and Utnalanama (Johannsens Phlogopite Mine) prospects. Geochemically, the host rock precursors are consistent with an assemblage of quartz-Mg chlorite ± sericite, and subsequently, they are interpreted as altered felsic volcaniclastic rocks, based on their single detrital/igneous zircon population and whole geochemistry. Variably mineralised stratiform Mg-Al-Fe-rich assemblages occur above these quartz-cordierite-orthopyroxene-biotite granulites. These assemblages are predominantly composed of various amphiboles and spinels, orthopyroxene and phlogopite, along with localised cordierite, sapphirine, plagioclase, corundum, rutile and rare staurolite. Lenses of magnetite-rich rocks also occur. Rocks in this zone also appear to have anomalous Cu, Pb, Zn, Ag, Au, Bi, Cd, Sn and F signatures. Anomalous Mo and W are also present at some prospects. It should be noted that subsequent overprinting might have influenced this signature. Sphalerite and chalcopyrite are the main sulfide phases seen in these rocks, along with lesser galena, pyrite and pyrrhotite. Sulfides occur as segregations and in veins. Mineralisation appears to be patchy and disseminated or slightly remobilised in this zone. No massive sulfide bodies are known. The highest grades to date (17.5% Zn) have been found in amphibole-spinel rocks at Edwards Creek, where Zn-spinel can form up to 40% of the rock. Högbomite is also locally present at Utnalanama. Lesser amounts of weakly mineralised marble are present in most instances. Migmatitic metapelite and psammopelite also often occur near these deposits, but they tend to be spatially outside

[1] Email: kelvin.hussey@nt.gov.au
[2] Geoscience Australia

of the metamorphosed alteration system. The metal associations, whole rock geochemistry and asymmetric stratiform nature of these mineral systems and associated rock types are all consistent with metamorphosed VMS systems. The whole rock oxygen isotope signature of these rocks are low (mostly 1.8–4.4‰). These values are typical of proximal alteration zones to VMS deposits, suggesting that the precursors interacted with evolved heated seawater and further supporting a VMS mineralisation model.

Granulite facies, migmatitic quartzofeldspathic gneiss and metasediment-hosted, magnetite-associated Cu-Au-Ag-Pb-Zn-Bi-Mo-F (-LREE?) mineral deposits occur in the Strangways Metamorphic Complex. Examples include the Johnnies Reward and Gumtree Prospects. The Johnnies-type deposits have different host rock associations and a different metal content and character compared to the Utnalanama-type deposits. Johnnies-type deposits and associated host rocks contain K-feldspar and tend to be much more Fe-rich, compared to the Utnalanama-type. Mn is also elevated in the ore zone. The ores appear to be zoned at Johnnies Reward based on systematic drillcore geochemistry. From structural base to top, it is tentatively suggested that the zoning is Au (Cu-Bi-S ± Mo) → Cu-Pb-S (Zn-Ag-Au) → Pb-Mn (Cu-S ± Ca) → REEs-HFSEs → Ca, with Fe- and Mg-enrichment present through much of the mineralised interval. Similar mineral deposits also occur in the Jervois region, but these are located in much lower metamorphic grade rocks. The Jervois deposits are hosted by amphibolite facies Fe-rich (magnetite-bearing) metasediments in the 1805 Ma Bonya Schist and have a similar metal association. Mineralisation appears to be both podiform and fault-controlled and is clearly epigenetic. The Cu-(Au-Ag) ores are associated with magnetite at Jervois and appear to be separate from the Pb-Zn-Ag ores. Fe-Cu-W-Mo-(Bi-Ag-Au?) skarn and replacement deposits also occur in the Jervois Mineral Field, and may also be genetically related. Johnnies-type deposits have affinities with iron oxide-copper-gold (IOCG) deposits. The recognition of IOCG deposits is economically interesting, as this type of mineralisation often tends to be widely distributed. Despite the absence of known deposits, several other areas in the Arunta Region also appear to have potential for this style of mineralisation.

Base-metal mineralisation at Oonagalabi occurs in marble, calcsilicate and amphibole-rich rocks. Mineralisation is mostly Zn>Cu>Pb. Mineralisation can be Ag-rich and also has anomalous Bi, Cd, Sn and W. Trace amounts of Au have been reported. This metamorphosed deposit is most probably either a skarn or carbonate replacement deposit, or possibly a VMS deposit. A maximum SHRIMP U-Pb age of 1767 Ma was obtained from the Oonagalabi host rocks, indicating that it is significantly younger than the host rocks to the Utnalanama- and Johnnies-type deposits, with which it was first associated. Lithological and compositional differences, in particular, also indicate that this deposit is considerably different to the Utnalanama- and Johnnies-type deposits. The Oonagalabi Package contains several smaller deposits similar to Oonagalabi itself. These intensely reworked and variably retrogressed granulite facies rocks appear to be considerably younger than the other parts of the Strangways Metamorphic Complex, and it is suspected that Oonagalabi-type mineralisation may be related to the Inkamulla Igneous Event.

Recent high-precision Pb isotope data indicates that there may have been several periods of mineralisation within the Palaeoproterozoic eastern Arunta Region. Calculated model Pb ages indicate that the probable VMS mineral systems formed predominantly at 1810–1800 Ma. Despite having a similar upper crustal source of Pb, the probable VMS deposits are slightly older than 1800–1780 Ma Johnnies-type deposits in the same region. Pb isotope data also indicates that several Pb introduction events are present at some deposits, suggesting that new Pb may be introduced coincident with igneous activity in the region. Deposits in the younger Oonagalabi Package have a different (mid-crustal?) source of lead, compared to the other deposits in the Strangways Metamorphic Complex and appear to be related to the Inkamulla Igneous Event. Skarns and other igneous-related mineral deposits also appear to be associated with felsic igneous activity throughout the eastern Arunta Region at various times, although the ages of these are yet to be precisely constrained. Collectively, these suggest that the mineral systems evolved during progressive burial of the Strangways Metamorphic Complex and its equivalents, prior to the 1730–1700 Ma Strangways Orogeny.

Despite the above, it should be noted that precise geological constraints are limited in the eastern Arunta Region and much of our geological understanding is based on correlation and geophysical interpretation. It is therefore important to realise that the geological framework of the Arunta Region is constantly evolving with each new geological constraint. Current geological models or ideas should therefore not hinder new ideas. Geological models must be constantly tested and evaluated. This is particularly important when evaluating mineral systems in a complex region, and has been our approach.

DEFINING THE "FOOTPRINT" OF TECTONOTHERMAL EVENTS IN THE NORTH AUSTRALIAN CRATON: RECENT ^{40}AR/^{39}AR RESULTS FROM THE DAVENPORT RANGES AND BARROW CREEK REGIONS

Geoff Fraser[1]

Much of Proterozoic Australia has experienced multiple metamorphic and deformational events. Field-based correlation of structural or metamorphic features across large regions is commonly hampered by sparse outcrop, and the age of thermal and deformation features remains poorly constrained over much of the continent. This is well illustrated by the dramatic changes in event histories revealed by geochronological studies over the past decade, for example, the recognition of the Mesoproterozoic Chewings Event (1590–1570 Ma) in the Reynolds Range, and the Palaeozoic Larapinta Event in the eastern Arunta, both in regions that had previously been considered much older. In both these examples, U-Pb geochronology has been the tool that has provided new insights into the event histories. Indeed, our current understanding of the temporal framework for tectonic events in central and northern Australia is largely based on U-Pb geochronology, particularly using zircon, whether it be magmatic, detrital or metamorphic. However, it is well known that zircon is relatively insensitive to metamorphism at grades of less than uppermost-amphibolite or migmatite facies. This means that the timing of metamorphism over large tracts of greenschist to mid-amphibolite facies rocks remains poorly constrained. For such rocks, ^{40}Ar/^{39}Ar geochronology provides an ideal complement to U-Pb data and it is a tool that has been under-utilised in Australia.

Previous results from a reconnaissance-scale ^{40}Ar/^{39}Ar traverse across the Tanami and north Arunta Regions have revealed the effects of successively younger tectonic events from north to south (Fraser 2003). Specifically, ^{40}Ar/^{39}Ar mica ages are in the range 1810–1750 Ma in the Tanami region (post-Tanami Event cooling), 1570–1550 Ma in the HIGHLAND ROCKS and MOUNT THEO region (post-Chewings Event cooling), to Palaeozoic in the MOUNT DOREEN region (Alice Springs Orogeny), with subtle evidence for thermal effects at 1100 Ma (Musgrave Orogeny/Teapot Event) and 800 Ma (probably related to Ngalia Basin initiation).

A similar-scale geochronological sampling traverse is currently in progress between the Davenport Ranges, through Barrow Creek, and south to the ALCOOTA mapsheet. Part of the rationale for this is to track the distribution of thermal, deformational and/or mineralisation activity of broadly Strangways Orogeny age (i.e. 1730–1700 Ma). This follows the measurement of mica ages in the range 1735–1705 Ma from ore-stage quartz veins at the Callie gold deposit in the Tanami (Fraser 2002), leading to speculation that low-grade deformation and hydrothermal activity in the Tanami may have been related to high-grade metamorphism and deformation further south on the Palaeoproterozoic plate margin, during the Strangways Orogeny.

In the Davenport Ranges, coarse-grained muscovite selvages on quartz veins that host Sn-W mineralisation in the Hatches Creek area yield ^{40}Ar/^{39}Ar ages of 1700 Ma. These ages are consistent with field interpretations (K Hussey, pers comm) that relate Sn-W mineralisation to local granites, that are, in turn, interpreted to be of similar age to the Elkedra Granite (U-Pb zircon age of 1720 ± 6 Ma) and the Devils Marbles Granite (U-Pb zircon age of 1711 ± 11 Ma). Similarly, a muscovite selvage on a quartz vein from the Black Hills gold prospect in the Kurinelli goldfield yielded an ^{40}Ar/^{39}Ar age of 1700 Ma. Further south, in the Barrow Creek area, mica from the Ooralingee granite (U-Pb zircon age 1809 ± 5 Ma) and from pegmatites in the Bullion Schist also yielded ^{40}Ar/^{39}Ar ages of 1700 Ma. A thermal disturbance of this age has also been documented further north at Tennant Creek, both as late granites (Compston 1995), and as a thermal overprint in metasediments (Compston 1994).

As well as indicating the age of Sn-W and gold mineralisation in the Davenport region, the mica ages reported above indicate that subsequent events, such as the Chewings Event, Teapot Event and Alice Springs Orogeny have not thermally disturbed the Davenport and Barrow Creek regions. This contrasts with results from further west, where Chewings Orogeny ages were recorded from as far north as the southern margin of the Tanami.

In summary, regional ^{40}Ar/^{39}Ar data indicate that a thermal "event", represented by volumetrically minor magmas, pegmatites, and both Au and Sn-W mineralisation, affected a very broad region of the North Australian Craton including the Tanami, Tennant Creek, Davenport and Barrow Creek regions, broadly contemporaneous with the Strangways Orogeny in the Arunta. This evidence, together with stratigraphic correlations between the Ooradigee Group, Lander Rock beds, and Killi Killi Formation (Donnellan and Johnston 2003, Green *et al* 2003) tends to increase the mineral prospectivity of the region between the Tanami and Davenport/Barrow Creek region, although it is noted that the Dead Bullock Formation, host to the majority of gold in the Tanami, has not been traced south and east (Green *et al* 2003).

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[1] Email: geoff.fraser@ga.gov.au

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LEGISLATION AND LAND ACCESS

Bob Adams[1]

A review of land access for mineral exploration has led to calls to amend the *Native Title Act* (*NTA*) and *Aboriginal Land Rights (NT) Act* (*ALRA*), to make them more amendable to facilitating the grant of exploration and mining tenure.

A number of major reviews were conclude in 2003; they included:

- **The Bowler Inquiry**. An inquiry by the Western Australian Government into the reasons for the decrease in exploration expenditure, which included a review of land tenure difficulties in Western Australia flowing from the *NTA*.
- **The Prosser Inquiry**. An Inquiry by the House of Representatives Standing Committee on Industry and Resources into any impediments to increasing investment in mineral and petroleum exploration, chaired by the Hon Geoffrey Prosser. The report included a chapter on the impact of the *NTA* and *ALRA* on the grant of exploration tenure.
- **The report of the Mineral Exploration Action Agenda**. The Mineral Exploration Action Agenda was initiated by the Federal Minister for Industry, Tourism and Resources. Land access was recognised as a critical issue that impeded exploration expenditure, due to the excessive time taken to grant tenure and the high cost to the industry of complying with the legislative procedure of both the *NTA* and *ALRA*.

In addition the Federal Minister for Immigration and Multicultural and Indigenous Affairs sought information from stakeholders about the operation of the *ALRA*. The mining industry, including the Northern Territory Minerals Council (NTMC), NT Land Councils and the Territory Government made submissions.

The Territory Government, via the Office of Indigenous Policy, initiated a dialogue with Land Councils and contracted Mr Bill Gray and Dr Ian Manning to coordinate a review of mining issues associated with the *ALRA*. This review culminated in a “forum “ to determine the Territory Government’s recommendations for amendments to the *ALRA*.

These recommendations were then discussed with the NTMC, which expressed concerns about the procedure for developing the recommendations and proposed some amendments to the proposals.

After discussions with Land Councils, the NT Government finalised submissions to the Commonwealth Minister.

Proposals for amendments to the *ALRA* were forwarded to the Commonwealth on 22 June 2003, as a joint proposal from the Northern Territory Government and the four Territory Land Councils.

Recommendations from the Prosser Inquiry and the Report of the Mineral Exploration Action Agenda seek amendments to the *ALRA* to simplify and accelerate the grant of mineral exploration title, speed up ratification of Traditional Owner’s decisions and reduce the cost to explorers. The inquiries did not develop specific recommendation for amendments of the *Act*.

The Commonwealth Minister for Immigration and Multicultural and Indigenous Affairs changed from Nick Minchin to Amanda Vanstone in a Federal Cabinet reshuffle in December 2003.

There has been no comment from Amanda Vanstone regarding the progress or possibility of amendments to the *ALRA*, and certainly in this election year, I suspect that there will be no action taken to amend the *ALRA*, and even less the *NTA*.

[1] **Email**: bob.adams@nt.gov.au

NEW INSIGHTS INTO GEOLOGY AND PROSPECTIVITY OF THE SOUTHWESTERN ARUNTA REGION

Dorothy Close[1], Ian Scrimgeour, Chris Edgoose, Max Frater, Andrew Cross[2]

Introduction

The Arunta South project commenced in 2000 as a greenfields mapping project to undertake a comprehensive geoscientific investigation into an area of the Arunta Region that had had no geological survey or exploration analysis since the original 1:250k maps produced by the BMR in the 1960s. The 1:250k maps that form the basis of the Arunta South project are MOUNT LIEBIG[3], MOUNT RENNIE and LAKE MACKAY. Subsequent to the commencement of this project, Newmont Australia, BHP-Billiton and Tanami Gold have successfully negotiated access to, and have been exploring the LAKE MACKAY and northern MOUNT RENNIE area. Outputs from the Arunta South project include outcrop and basement interpretation maps and accompanying notes for these three mapsheet areas.

The area of investigation covers two very different geological provinces of the Arunta Region. All of LAKE MACKAY and the northern sections of MOUNT LIEBIG and MOUNT RENNIE lie within the Aileron Province and thus belong to the North Australian Craton (NAC), whereas the middle sections of MOUNT LIEBIG and MOUNT RENNIE incorporate outcropping areas of the younger Warumpi Province (**Figure 1**).

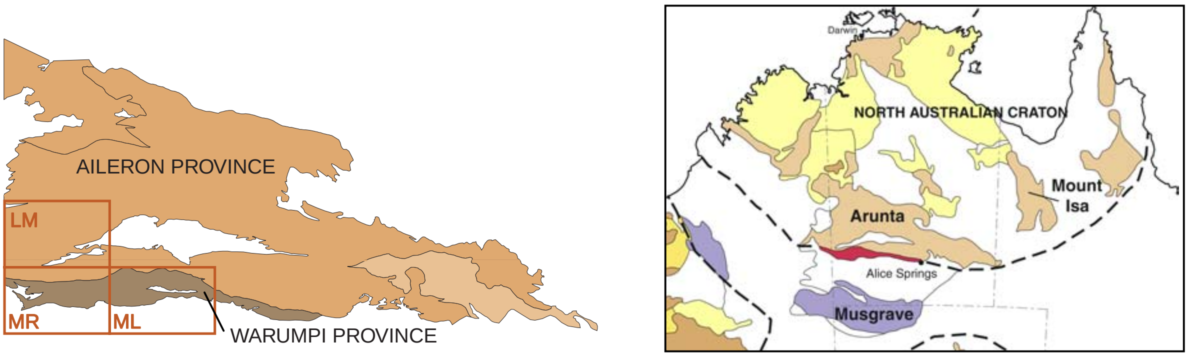

Figure 1. Location of area of study in southwestern Arunta Region (left) and location of Warumpi Province (red) on southern margin of North Australian Craton (right).

Palaeoproterozoic evolution of southwestern area of the Aileron Province

The basal succession exposed in the southwestern Aileron Province comprises siltstones, quartz arenites, quartzo-feldspathic sandstones and minor greywackes. U-Pb SHRIMP detrital zircon analysis of these sediments at different metamorphic grades from three locations across LAKE MACKAY and northern MOUNT RENNIE have yielded consistent maximum deposition ages of 1860 Ma (Scrimgeour *et al* 2002), with detrital histogram patterns similar to sediments elsewhere in the Aileron Province. Therefore, this succession is interpreted to form part of the broadly defined Lander Rock beds package, a flysch succession that is widespread over this area of the NAC. Intruding the Lander Rock beds is a suite of dolerite sills and minor pyroxenites of the newly recognised Dufaur Suite. Geochemically, these comprise low-K tholeiites, suggesting emplacement in a thinning crust/extensional environment, and they have an εNd value of +4.7, indicating a primitive, depleted mantle source. The age of these mafic intrusives is as yet unknown, but they may have intruded at 1805 Ma (Stafford Event), synchronous with high-grade metamorphism in northeastern LAKE MACKAY. Deposition of quartzite, calcarenites, pelites and rare volcanics was widespread across central and northern LAKE MACKAY at around 1780 Ma. During the 1780–1760 Ma Yambah Event, a series of porphyritic biotite granites intruded the southwestern Aileron Province. Subsequent to this intrusive event, the southwestern Aileron Province was pervasively overprinted by regional-scale deformation at lower amphibolite grade. This deformation produced isoclinal folding with associated bedding-parallel andalusite-muscovite-biotite foliation in the Lander Rock beds, hornblende-actinolite foliation in mafic sills, and biotite foliation in Yambah Event granites. The interpreted age of this deformation is late in the Yambah Event.

Palaeoproterozoic evolution of the Warumpi Province

The earliest identified event in the Warumpi Province was the 1690–1660 Ma Argilke Igneous Event, which produced voluminous felsic extrusive and intrusive magmatism (Close *et al* 2003). Minor laminated chemical sediments are

[1] Email: dorothy.close@nt.gov.au
[2] Geoscience Australia
[3] Names of 1:250 000 mapsheets are in CAPITALS

intercalated with felsic volcanics with a SHRIMP U-Pb zircon age of 1680 ± 4 Ma. This package of rocks was previously recognised in the eastern Warumpi Province and has been named the Madderns Yard Metamorphic Complex. We interpret this magmatism to have occurred outboard of the NAC in a pre-existing fragment of continental crust, and no magmatism of this age has been identified in adjacent regions of the Aileron Province. Post-dating the Argilke Igneous Event was a period of sedimentation, with the deposition of a succession of mudstones, sandstones and calcarenites (Yaya Metamorphic Complex) occurring north of the Madderns Yard Metamorphics within the Warumpi Province. U-Pb SHRIMP zircon analysis of the succession indicates a maximum deposition age of 1661 Ma for these sediments and a large component of 1690–1660 Ma zircons suggests that the Madderns Yard Metamorphic Complex was exposed and provided a source region for these sediments. Again, no sediments of an equivalent age have been identified in the adjacent NAC, suggesting that the Warumpi Province was still developing in isolation.

Effects of the 1640–1630 Ma Liebig Orogeny on the southwestern Aileron Province and Warumpi Province

The 1640–1630 Ma Liebig Orogeny is the first time that there is evidence that both the Warumpi Province and the southwest margin of the NAC were involved in similar geological evolution. At this time, the Yaya Metamorphic Complex (YMC)of the Warumpi Province underwent regional-scale granulite metamorphism as a result of burial to 30 km depth (Scrimgeour *et al* 2002). Synchronous with this regional high P and T metamorphism of the YMC was large-scale lower crustal melting, resulting in voluminous felsic magmatism. This produced granites, granodiorites and charnockites, and less abundant gabbros, which intruded the YMC. Geochemically, these felsic magmas are high-K, calc alkaline in nature. Metamorphic reaction textures suggest the YMC was exhumed rapidly after peak metamorphism. In adjacent regions of the Aileron Province, at 1640–1630 Ma, mafics, ultramafics, cumulates and granite of the Andrew Young Complex (AYC) intrude the southwestern margin of the Aileron Province. The geophysical signature of the AYC suggests the complex is layered in part and is assumed to have intruded in an extensional environment. Immediately adjacent to the AYC, metasediments with a maximum deposition age of 1860 Ma have undergone high-T, low-P metamorphism and partial melting, at conditions of 3–4 kbar and >750°C. U-Pb SHRIMP dating of metamorphic zircon rims from these metasediments gives an age of 1635 Ma. The Liebig Orogeny is interpreted to be the event that juxtaposed the Warumpi Province and the NAC. This is consistent with other indicators, such as the hairpin bend in the apparent polar wander path for northern Australia at 1640 Ma (Scrimgeour *et al* 2002). Following the Liebig Orogeny, the Warumpi Province was rapidly exhumed and within 20 million years, sections the Madderns Yard Metamorphic Complex were exposed and unconformably overlain by a succession of siltstones and arkoses grading up to quartz sandstones (Iwupataka Metamorphic Complex). Deposition of these sediments probably occurred around 1620–1610 Ma.

Sm-Nd isotopic data from the southwestern Aileron Province and Warumpi Province

New Sm-Nd data from the Warumpi Province and adjacent regions of the NAC appears to confirm that they are different fragments of continental crust. In the Warumpi Province, granitic rocks typically have low negative εNd value of –2.3 and depleted mantle model ages of around 2.2 billion years. This model age suggests that the Warumpi Province was not primitive continental crust formed outboard of the NAC, but was a pre-existing fragment of Palaeoproterozoic crust. In comparison, granites in the southwestern NAC have a much lower εNd value of –5.7, and a depleted mantle model age (T_{DM}) of 2.7 Ga, suggesting at least some component of Archean basement. Similarly, mafic rocks of the same age (1640–1630 Ma) in the two provinces show differing Nd isotopic characteristics: εNd = –0.01 and T_{DM} = 2.13 Ga for the Warumpi Province; εNd = –5.1 and T_{DM} = 2.49 Ga for the southwestern region of the Aileron Province. This again suggests that the Warumpi Province comprises younger and less evolved crust than the adjacent NAC. This Nd isotopic evidence is supported by Pb isotope data, interpreted by David Huston at Geoscience Australia as suggesting a more primitive source of Pb in the Warumpi Province (Huston *et al* 2003)

Mesoproterozoic development of the southwestern Aileron Province and Warumpi Province

Deformation associated with the Chewings Orogeny at 1590 Ma pervasively overprinted both the Warumpi Province and the southwestern NAC at different crustal levels. Deformation of the Warumpi Province took the form of south-vergent, non-coaxial strain fabrics developing under lower to upper amphibolite facies conditions. Within the southwestern NAC, deformation during the Chewings Orogeny was occurring at higher crustal levels, resulting in folding of the earlier S_0-parallel fabric. There is no known magmatism associated with the Chewings Orogeny within either the Warumpi Province or the southwestern NAC. The Chewings Orogeny is interpreted to represent a response to tectonism at a plate boundary further to the south, leading to south-directed deformation, metamorphism and crustal thickening in both the Warumpi Province and southwestern Aileron Province. Fundamental reworking of the suture zone that separated the two provinces occurred at this time and initiated the north-dipping structures, which are preserved today. A large undeformed granite pluton in LAKE MACKAY has a SHRIMP U-Pb age of 1533 ± 5 Ma, reflecting a previously unknown period of early Mesoproterozoic magmatism in the Arunta.

The 1150 Ma Teapot Event is the next major thermal event that affected the Warumpi Province. This event led to widespread isotopic resetting, pegmatite intrusion and localised upper amphibolite facies migmatisation accompanied by zircon rim growth. This isotopic resetting is likely to have extended north into the southern Aileron Province (Fraser 2003).

Metallogenic Potential of the Warumpi and southwestern Aileron Provinces

The potential for mineral deposits in this area of the Arunta Region is poorly known, due to largely unexplored nature of the area. However, there is recognised potential for a variety of mineralising systems.

Orogenic gold

The southwestern Aileron Province in LAKE MACKAY and northern MOUNT RENNIE has sedimentary precursors with chronological and lithological affinities to parts of the Tanami Group (Tanami Region) and Warramunga Formation (Tennant Region). This package was intruded by mafic sills and later granites, and subsequently deformed under metamorphic conditions ranging from greenschist to mid-amphibolite grades. These factors are consistent with this region being prospective for orogenic-style Au mineralisation, particularly if reactive lithologies can be identified.

Base metals and copper ± gold (Stokes Yard, Ulpuruta and Haast Bluff prospects)

At AGES 2003, the base metal prospectivity of the Iwupataka Metamorphic Complex of the Warumpi Province was highlighted. This has now been followed-up by Max Frater, with work on the prospects at Stokes Yard, Ulpuruta and Haast Bluff, involving detailed mapping and surface or drillcore geochemical sampling. Geochemical analyses have returned promising results from each of the three prospects. The highest values attained from samples across drillcore at Stokes Yard were 12.2% Pb, 13.3% Zn, 49.5 ppm Ag, 91 ppb Au and 6450 ppm Cu, with mineralisation hosted within a calcsilicate. From Ulpuruta, maximum values were 4.04% Pb, 19.7% Zn, 8.5 ppm Ag, 3.03% Cu and 62 ppb Au, with mineralisation localised within a calcsilicate from a succession of marble, calcsilicate and volcanigenic rocks. The Haast Bluff geochemical traverse produced maximum values of 7600 ppm Pb, 1.85% Zn, 22.5 ppm Ag, 11.5% Cu and 770 ppb Au, with mineralisation localised within a calcsilicate in a succession of amphibolite, psammite and marble. Preliminary results of follow-up work suggest that two styles of stratigraphically controlled mineralisation are present: Cu-Au-Fe (Ag-Bi-Pb-Zn-Te-Se-Mn) shear-related (Haast Bluff); and Pb-Zn (Cu-Ag-Bi-Mg-Ca) skarn-type, localised in fault and breccia zones (Stokes Yard and Ulpuruta). Mineralisation styles are similar to those in the Cloncurry ore system and the succession is of similar age (<1680 Ma). Mineralisation has not been adequately tested and although the three prospects appear to be sub-economic, they significantly increase the potential for a sizeable mineral field in the Warumpi Province.

Nickel-Copper-Cobalt

The Andrew Young Complex (AYC) that lies on the southwestern margin of the Aileron Province has been recognised as prospective for Ni. These large mafic intrusions outcrop in the Andrew Young Hills (MOUNT DOREEN) and in scattered areas in northern MOUNT RENNIE, with a much more extensive extent beneath cover. Geochemical and geophysical analyses by Dean Hoatson and Tony Meixner confirm that the AYC forms part of a S-rich group (300–1200 ppm S) of mafic intrusives from the western and central Arunta Region, which has potential for orthomagmatic Ni-Cu-Co sulfide associations (Hoatson *et al* 2002).

Diamonds (Nickel, PGE?)

Rare outcrops of undeformed ultramafic intrusives have been identified within the Warumpi Province in MOUNT RENNIE. Mineralogically, these mafics are identified to be plagioclase-phlogopite-wehrlite, or lherzolite comprising olivine, clinopyroxene, orthopyroxene, and phlogopite. They have a mantle geochemical signature that includes values of 850 ppm Ni, 1950 ppm Cr, 83 ppm Co and 18.1% MgO. These ultramafics coincide with distinctive, small, rounded to elongate, remnantly magnetic features, clearly visible on regional-scale aeromagnetic images. This suggests that plug-shaped bodies of mantle material intruded relatively late in the geological evolution, and may be prospective for diamonds or possibly Ni, Cr and/or PGE mineralisation. Elsewhere in the Warumpi Province in MOUNT RENNIE, low outcrops of chlorite-tremolite schist have been identified, and elevated levels of Ni and Cr suggest that they may have an ultramafic origin.

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FLUID CONDITIONS AND TIMING OF QUARTZ VEINING ON LAKE MACKAY AND MOUNT RENNIE 1:250K MAPSHEETS

Andrew S Wygralak[1] and Terrence P Mernagh[2]

Earlier metallogenic work (Wygralak and Mernagh 2001) on the study of physico-chemical characteristics, and the origin and evolution of hydrothermal fluids within the Tanami Region concentrated on areas of known gold mineralisation in TANAMI and THE GRANITES. Subsequently, this work was extended to HIGHLAND ROCKS, MOUNT SOLITAIRE, and MOUNT THEO. It was found that the nature of fluids and timing of quartz veining differs on both sides of the inferred boundary between the Tanami and the Aileron Province of the Arunta Region (Wygralak and Mernagh 2002). In the Tanami Region, ore-stage fluids are of moderate–high temperature, low salinity, and usually contain varying proportions of $CO_2 \pm CH_4 \pm N_2$. The $^{40}Ar/^{39}Ar$ age of quartz veining (1720 Ma) coincides with the Strangways Event. In the northwestern Aileron Province, fluids differ markedly from the Tanami Region; they have lower temperatures, are highly saline and are gas-poor. Quartz veining there is younger, ranging from 1432 to 1518 Ma.

During the 2003 field season, the study was extended further south, to include LAKE MACKAY and MOUNT RENNIE. In the northeastern part of LAKE MACKAY (area 1 on **Figure 1**), quartz veins are also gas-poor, but a second, hotter fluid (220–280ºC), with low to moderate salinity, was also identified. $^{40}Ar/^{39}Ar$ dating[3] of muscovite from a wall-rock sample of one of the quartz veins (at 0624503mE 7521260mN) yielded an age of 1528 ± 6 Ma. This higher temperature, low salinity, gas-poor fluid resembles the fluids in the Tanami Region, and thus, could carry Tanami goldfield-style mineralisation.

A large portion of the southeastern quarter of LAKE MACKAY (area 2), located close to the structural boundary between the Aileron Province and the northern Ngalia Basin, is characterised by saline to very saline[4] fluids, with a temperature range of 200–290ºC. Depressed temperatures of first ice melting indicate the presence of salts of Na, K, Ca and Mg. A characteristic feature of this fluid is a relatively constant CO_2/N_2 ratio. Such a stable proportion may indicate that the fluid passed through either a non-reactive or lithologically monotonous rock package. Alternatively, it could imply limited water–rock interaction due to a low fluid flow, or that the fluid formed an impermeable selvage envelope around the veins, which prevented further fluid–rock interaction. Hydrothermal muscovite in the quartz vein (at 0587581mE 7486320mN) has yielded an $^{40}Ar/^{39}Ar$ age of 1478 ± 17 Ma.

Further southwest, in area 3, the fluid has a temperature range of 230–450ºC and high salinity. Unlike the fluid in area 2, it contains varying proportions of $CO_2 \pm CH_4 \pm N_2$, suggesting greater fluid–rock interaction. Due to the presence of CH_4, which in some cases is the only gas in the vapour phase of the fluid inclusions, this fluid is also more reduced. The reduced nature of the fluid and its chemical interaction with the rocks could provide a favourable environment for deposition of gold. $^{40}Ar/^{39}Ar$ dating of muscovite in a quartz vein located at 0558578mE 7479172mN returned an age of 1636 ± 4 Ma, synchronous with the Liebig Orogeny in the Warumpi Province.

Several samples taken from the central part of LAKE MACKAY (area 4) represent quartz veins hosted by the Mount Thomas Quartzite (Reynolds Range Group) and pegmatitic veins hosted by strongly silicified granite. Fluid inclusions from these veins are characterised by temperatures of 200–280ºC and low to high salinities, indicating the presence of two fluids. Low salinity inclusions are characterised by an abundance of high-density CO_2-bearing inclusions (ie low CO_2 homogenisation temperatures) and varying proportions of CH_4.

$^{40}Ar/^{39}Ar$ dating of hydrothermal muscovite from quartz veins in this area has returned unusually young ages. Muscovite from a quartz vein, located at 0596187mE 7522135mN and hosted by the Mount Thomas Quartzite, returned an age of 1005 ± 10 Ma. Muscovite from a pegmatitic quartz vein at 0593794mE 7522214mN, hosted by heavily silicified granite, yielded an age of 947 ± 4 Ma. Muscovite from a pegmatitic quartz vein hosted by silicified granite at 0600713mE 7506503mN gave an age of 1172 ± 7 Ma. Further south, in the Warumpi Province in MOUNT RENNIE, similar young ages of 918 ± 9 Ma and 1100 ± 5 Ma were obtained from muscovite in a quartz vein, hosted by the Sandy Blight Quartzite at 0556845mE 7228330mN, and from a granite-hosted pegmatitic vein at 0561704mE 7404224mN.

Such young ages reflect a previously unknown event involving extensive silicification by a fluid containing significant amounts of $CO_2 \pm CH_4$. Further work is needed to recognise the extent of this event, and to establish whether or not these $^{40}Ar/^{39}Ar$ ages have any relationship to regional cooling from the 1140 Ma Teapot Event. Its significance for gold mineralisation is unknown, but young ages indicate that hydrothermal activity may have continued until at least during the initial part of sedimentation in the Centralian Superbasin.

It is proposed that the silicification event took place between 1005 and 918 Ma, as reflected by the formation of hydrothermal mica in quartz veins hosted by the Mount Thomas and Sandy Blight Quartzites. The wider spread of ages of muscovite in granite-hosted pegmatitic quartz veins probably reflects a varying degree of age resetting of previously existing muscovite.

[1] Email: andrew.wygralak@nt.gov.au
[2] Geoscience Australia (GA)
[3] Ar-Ar data presented here (**Table 1**) were obtained from the Western Australian Argon Isotope Facility, operated by a consortium of Curtin University and the University of Western Australia
[4] soluble cubic daughter mineral, probably halite

Limited work on fluid inclusions from the Warumpi Province (area 5) in MOUNT RENNIE indicated the existence of at least two fluids, including a very high temperature (up to 540ºC), CO_2-bearing fluid. The lower temperature fluid (70–230ºC) is highly saline. Inclusions in the hot fluid (330–540ºC) are of small size and did not allow salinity measurements. The gold potential of the Warumpi Province remains unknown, but such high temperature fluids are rather uncommon in hydrothermal lode gold deposits.

Location	**Sample**	**$^{40}Ar/^{39}Ar$ age (Ma)**	**Comments**
LAKE MACKAY 0558578mE 7479172mN	12128	1636 ± 4	Quartz vein in Palaeoproterozoic micaceous greywacke
LAKE MACKAY 0624503mE 7537120mN	12094	1528 ± 6	Quartz vein in Palaeoproterozoic micaceous greywacke
LAKE MACKAY 0587581mE 7486320mN	12123	1478 ± 17	Quartz vein in Palaeoproterozoic micaceous greywacke
LAKE MACKAY 0600713mE 7506503mN	12114	1172 ± 7	Quartz vein in strongly silicified gneissic granite
MOUNT RENNIE 0561704mE 7404224mN	12135	1100 ± 5	Quartz in granite-hosted pegmatitic vein.
LAKE MACKAY 0596187mE 7522135mN	12112	1005 ± 10	Quartz vein in Mount Thomas Quartzite (reflects silicification)
LAKE MACKAY 0593794mE 7522214mN	12110	947 ± 4	Quartz vein in silicified granite
MOUNT RENNIE 0556845mE 7228330mN	12141	918 ± 9	Quartz vein in Sandy Blight Quartzite (reflects silicification)

Table 1. $^{40}Ar/^{39}Ar$ ages of muscovites obtained during 2003 work.

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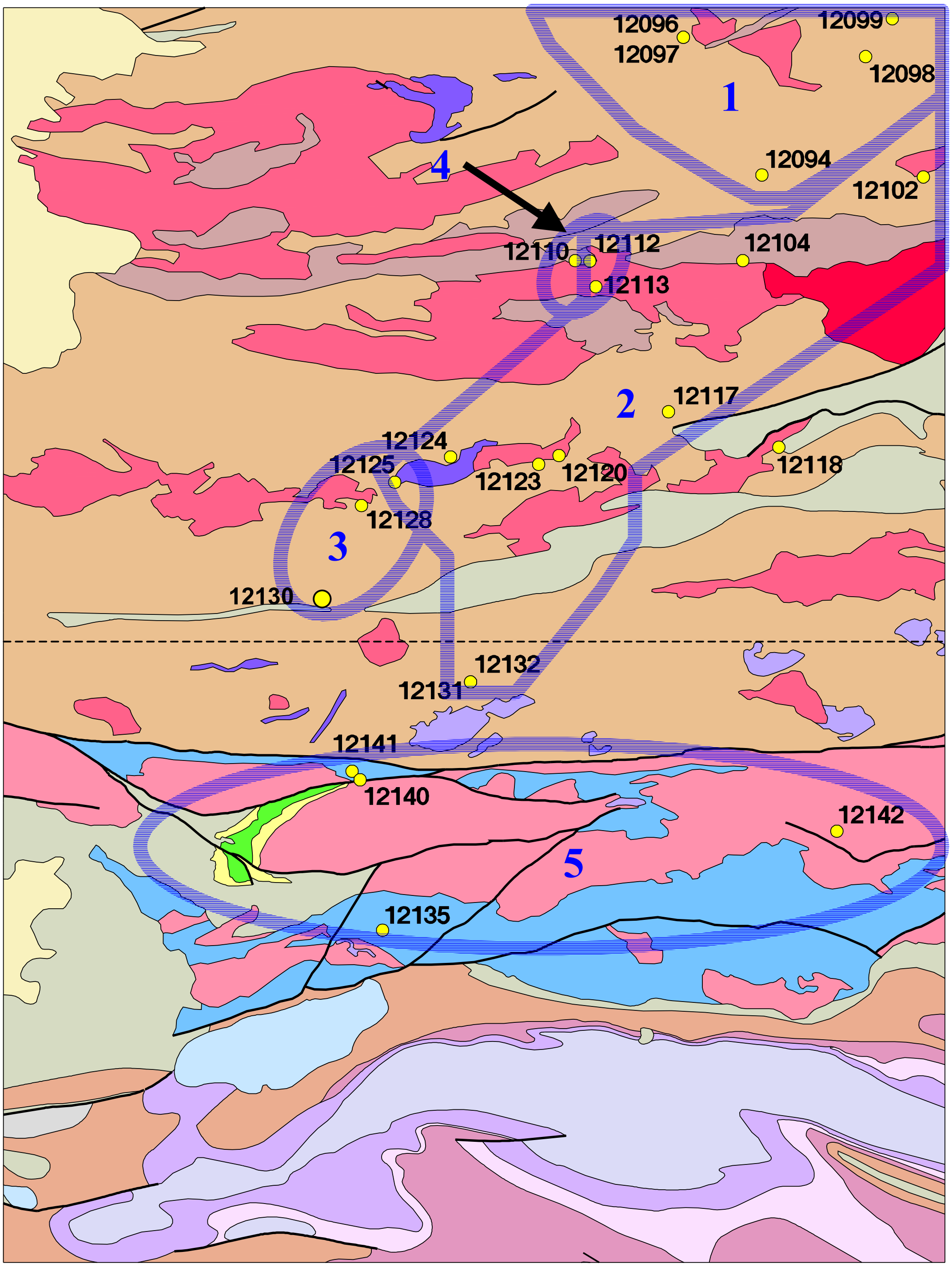

Figure 1. Sampling points on LAKE MACKAY and MOUNT RENNIE.

GOLD PROSPECTIVITY IN THE NORTHERN ARUNTA REGION: EXTRAPOLATING FROM THE TANAMI DEPOSITS

Michael G Green

"the intensity of conviction that a hypothesis is true has no bearing on whether it is true or not." Sir PB Medawar (1979)

Ore genesis models are vital tools when evaluating prospectivity, as without defined criteria about how prospective orebodies formed, target definition becomes rather *ad hoc*. Conversely, too narrow a focus on an individual criterion may lead to precluding areas where other equally valid models may be applicable. Given the wide range of known mineralisation styles, a narrow focus is probably more detrimental than a broader perspective. However, deep pockets are required to fund exploration when using multiple models. Compromise is usually established, as it seems logical that models which closely reflect nearby deposits are likely to be the most relevant, although experience may suggest otherwise. Nevertheless, the prospectivity of the northern Arunta region can be evaluated by looking for analogues of known Tanami deposits. In brief, there is significant probability that the northern Arunta region hosts economic gold deposits.

Prospectivity maps show areas where criteria deemed important to exploration models are satisfied, for instance, tight folding of a specific stratigraphic unit at a given metamorphic grade. Hence, the production of prospectivity maps requires that the geology of predicted deposits and target areas is satisfactorily known. For most of the Tanami deposits, geological summaries are available, although there may be important unknown criteria. Furthermore, recent NTGS mapping has greatly improved the understanding of the northern Arunta region. By fusing these data, it is possible to produce prospectivity maps of the northern Arunta region, looking for Tanami-style gold deposits. Ideally, such mapping systems would incorporate robust digital databases within GIS systems.

The Tanami region hosts five major gold deposits, all of which are quite different (**Table 1**), and some smaller deposits that are even more removed (eg, gold-bearing quartz veins in granite at Twin Bonanza, Happy Jack). Given such variety, what criteria should be used to evaluate prospectivity? Can criteria be ranked from universally important to specifically interesting? Can selected criteria be readily identified in the exploration area?

The three criteria described in **Table 1** represent information that may or may not have a bearing on discovering gold deposits in the northern Arunta. The only constant appears to be that mineralisation in intimately related to quartz veining. Other criteria may just be incidental. However, such an assessment is of little use, as prospective quartz veins have not been clearly identified from existing Arunta datasets. Instead, it is more useful to group criteria that can be discriminated together. Hence, host lithology can be divided into mafic rocks (Tanami corridor, Groundrush), fine-grained clastic sediments (Callie, Coyote) and Fe-rich cherts (The Granites). In this scenario, the lithology alone is considered important, and not necessarily the stratigraphic position. Moreover, lithology can be readily identified from regional geological and geophysical datasets. Additional refinement can then be made since the evidence suggests that metamorphic grade is critical when exploring for Callie and Coyote analogues, but not so, for mafic-hosted deposits.

With these few criteria, large areas of the northern Arunta region are considered highly prospective for Callie-Coyote analogues as they comprise greenschist-facies, fine-grained clastic rocks. Moreover, these regions record a near-identical tectonic and magmatic history to the Tanami region, providing additional favourable exploration criteria. In contrast, high-grade metamorphic rocks in HIGHLAND ROCKS are probably not particularly favourable for Callie-Coyote analogues, but could be prospective for mafic-hosted deposits. Targeting such mafic rocks should be straightforward as they are readily identified in geophysical datasets.

Deposit	Host lithology	Metamorphic grade	Mineralisation
The Granites	Fe-rich chert, calcsilicates, pelitic schist	amphibolite	quartz veins
Callie	thinly bedded graphitic mudstone	lower greenschist	sheeted quartz veins, Au in anticlines
Coyote	wackes, siltstone	lower greenschist	quartz veins with Au envelopes
Tanami corridor	Mount Charles basalt and medium- to coarse-grained clastic sediment	subgreenschist to lower greenschist	quartz-carbonate veins and breccias
Groundrush	metamorphosed dolerite dyke	greenschist to amphibolite	quartz-carbonate veins and breccias

Table 1. Summary of major gold deposits in the Tanami region.