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NEW PERSPECTIVES OF THE EVOLUTION OF THE AMADEUS BASIN

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The last major period of study in the Amadeus Basin was lead by oil industry activity in the early 1980's and culminated in the publishing of government agency studies in 1991. Not only have there been some significant studies of the Amadeus Basin since this time but the technology available to geoscientists has also improved considerably. A program of acquisition of high resolution airborne geophysics over the Amadeus Basin by the NT Geological Survey has updated datasets in some areas where the only previously available geoscientific data was several decades old. The aims of this present NTGS study are based broadly upon the principles of basin analysis, an update and review of knowledge with incorporation of new geophysical and geochemical data.

Three principal things have changed with respect to non-seismic geophysics since the last major period of study in the Amadeus Basin concluded 10 years ago, these are 1, the accuracy with which instrumentation measures 2, the data processing or computing power and 3, the way in which this data is enhanced and displayed. Apart from a limited number of exclusive oil company commissioned surveys conducted in the 1980's, the most recent high resolution airborne geophysical surveys conducted by the NT Geological Survey have been the first such programs to specifically target the full resource potential of the Amadeus Basin.

The predominating influence of the Alice Springs Orogeny on the Amadeus Basin is reflected in the consolidation of basin fill into resistive mountain forming rock like that of the MacDonnell Homocline. By comparison, outcrop of sedimentary rocks in the areas extending west of the Gardiner Range and south and west of the George Gill Range (King's Canyon area) is intermittent and sparse. It is then clear that away from areas covered by seismic data near the northern margin, much interpolation between these intermittent outcrops has been necessary to produce previous map versions of the basin's bedrock geology (Stewart 1992). Comprehensive coverage of these areas with modern airborne magnetics has given unprecedented vision into near surface geology throughout the greater basin.

From observation of the first vertical derivative (1VD) of the total magnetic intensity (TMI) data over the Amadeus Basin it is evident that much information may be obtained from the somewhat translucent character of the sedimentary rocks. The existence of high wavelength magnetic anomalies in the Ayers Rock-Lake Amadeus area was first noted from a BMR airborne survey conducted in 1965. Subsequent investigation of these anomalies many years later via a 2 hole drilling program revealed intra-Bitter Springs Formation extrusive volcanics in this area (Bladon and Davies 1982). Thin amygdaloidal spilites were only previously reported in the Loves Creek Member of the Bitter Springs Formation east of Alice Springs by Wells et al (1967). The near surface extent of this unit may now be clearly visualised throughout the Lake Amadeus area and its magnetic character used as an indicator of structure on a local or prospect scale.

Other features of note include a trend-linear anomaly subcropping adjacent the Bloods Range, interpreted by Close et al (2000) as basalt associated with onset of Neoproterozoic Centralian Superbasin rifting. A classic dendritic drainage pattern is

also evident in the Erldunda area of the HENBURY and KULGERA 1:250,000 map sheets. Despite its south-easterly flow direction being in broad agreement with current day drainage, the channels evident on the IVD show no direct correlation with presently active channels or any consistent relationship with post-Cretaceous geology mapped in this area. It may be assumed that these paleochannels are at least post-Alice Springs Orogeny (ASO) in age as they cross-cut ASO age structural trends and flow away from the area of major uplift to the north.

The recent coverage of airborne geophysics and advances in the manner in which this data is analysed has facilitated an assessment of structures basin wide based on their geophysical characteristics. Observation of TMI highs in the Carmichael Sub-basin is of particular interest since basement in this area has been interpreted as being in excess of 9km deep based on seismic and formation thicknesses (Lindsay and Korsch 1991). Such highly magnetically susceptible signatures are consistent with interpretations of intrusion of basic igneous material during syn-rift tectonics (after Gunn 1997).

Increased coverage of gravity data exists in the northern half of the Amadeus Basin due to exclusive oil company surveys conducted in the 1980's. Observation of a combination of gravity and magnetic data reveals many lineaments that can be traced through basement terrains and into and underneath the basin. A composite interpretation of lineaments underpinning the basin has been compared with structures mapped as within the sediment pile to reveal what influence if any reactivation of basement structures has affected basin architecture through time. Broad correlation exists between the off-set or step over of many of the basins major faults and some of the interpreted basement lineaments. This will then have implication for the distribution and development of reservoir sand facies in such places as through the step over in relay faults as well as the localised distribution of carbonaceous shales as an improved understanding of the timing and magnitude of epirogenic movements relative to stratigraphic units is appreciated.

Study of carbonaceous shales throughout the basin is continuing. This includes studies of organic richness and thermal maturity as well as trial chronometric work on Neoproterozoic stratigraphy where accurate time constraints are lacking. The sedimentary successions found within remnant Neoproterozoic basins of this type world wide also include facies that are anomalous by comparison with modern analogues. Result of an increased understanding of this unique biogeochemical environment will be more accurate stratigraphic correlation and prediction of likely hydrocarbon source facies like that generating the gas that flowed 12MCFGD from the Sturtian Glacial Areyonga Formation at Ooraminna-1 45km southeast of Alice Springs.

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TOWARDS AN ARUNTA FRAMEWORK

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The Arunta Province is a large multiply deformed, poly metamorphic Proterozoic terrain (~ 200,000 km²), in marked contrast with adjacent terrains of similar age because of the intensity and frequency of deformation, the high grade of much of its metamorphism and abundance of granite. Systematic mapping was commenced by the Bureau of Mineral Resources (BMR) in the late 1960s and proceeded through the 1970s. To assist in portraying its complex geology, the Arunta Province was divided into 3 major tectonic provinces (north, central and southern) and the stratigraphy grouped into 3 major divisions, based on facies assemblages and lithological similarities.

In the BMR terminology the inferred oldest rocks, called *Division 1* were granulite facies metamorphics that at least in part represent an original bimodal volcanic assemblage intercalated with sedimentary rocks, restricted to the central province. *Division 2* rocks variously included amphibolite facies aluminous, silica and lesser calcareous sedimentary rocks and mafic flows and sills, in the northern and central provinces. In the southern province the rocks have a significant felsic and in places mafic volcanic component. The *Division 3* rocks were platform style quartzite, shale and carbonate sediments, locally unconformably overlying the other divisions.

Are the tectonic provinces justified? As more detailed studies are made and the quality of geochronology improves, the tripartite stratigraphic and tectonic subdivision is shown to have limitations. For example: The northern province contains, in places, rocks of similar composition and metamorphic grade (mP-hT granulite facies) to those of the central province. Also, the boundary between the two provinces is irregular and complex and probably not a tectonic discontinuity. *Division 3* rocks in the southern province are significantly younger than those of the Reynolds Range Group in central Arunta. Recent recognition that regional high grade tectonism occurred in the eastern Arunta during early Ordovician rather than ~1730Ma, as previously assumed, again emphasises the fact that no stratigraphic assumptions or 'divisional' categorisation can be made on the basis of metamorphic grade and deformation alone. For example the accepted boundary between central and southern provinces, the Redbank Thrust Zone (RTZ) has stood the test of time – until now. Earlier work that included zircon dating of granitoids indicated an age difference of ~100Ma across the RTZ, with a significantly younger plutonic history to the south. Current NTGS geochronology and regional geoscientific studies have now established that younger plutons and granulite metasediments and orthogneiss are also present north of the RTZ in the Mt Liebig map sheet. The old tectonic sub-provinces are no longer clearly defined hence the stratigraphy needs to be subdivided using new parameters.

The interpretation of the geology of the Arunta province, herein presented, is based on grouping of the many disparate units into stratotectonic packages based on rock-type, observed or inferred relationships, similar tectonic and metamorphic history and **geochronology**.

This resulting simplification of the stratigraphy now allows the erection of time-space diagrams at a province scale that can then be refined to local scale where required.

Following is a brief description of each new stratotectonic package.

LANDER PACKAGE 1850-1820Ma possibly >1850Ma

The Lander package includes the Lander Rock Beds (LRB) and equivalent units, and constitutes more than 50% of the Arunta Province. Pelitic and psammitic rocks and their metamorphosed equivalent dominate, with locally occurring calc-silicate rocks, basalt lavas and metadolerite. The sedimentary rocks are mainly turbidites and in places marginal marine to fluvial deposits.

In the Mt Doreen region the metamorphic rocks vary from low grade (greenschist facies), to locally high grade (granulite facies) commonly in the vicinity of granite plutons. In the Reynolds – Anmatjira Ranges region, turbidites are locally metamorphosed to granulite facies in the vicinity of \cong 1820Ma intrusive granites. The Weldon and Aileron Metamorphics, Mt Stafford beds and many other locally named units in this region are deemed to be equivalent of the LRB.

The age of the Lander Package (LP) is poorly constrained. In the Reynolds-Anmatjira Ranges region detrital zircon populations suggest that a maximum depositional age for the LP may be 1850Ma. A minimum age is provided by ~1820-1800Ma intrusive granites. To the west in Mt Doreen region the LP deposited prior to intrusion of an 1880Ma granite. The 1880Ma zircons may, however, be inherited and a younger small population of zircons (~1840Ma and ~1820Ma) may represent the real crystallisation age of the granite. Based on this limited data, the LP is represented in the stratotectonic relationship diagram as having an 1850Ma-1820Ma component and possible earlier >1850Ma component.

NARWIETOOMA PACKAGE >1820Ma

The Narwietooma Package comprises rocks of mafic – intermediate – felsic composition intercalated with pelitic and psammitic metasediments which have been metamorphosed to granulite facies. The protolith was probably a supacrustal sequence with large and variable components of felsic and mafic volcanics, that were remelted, mobilised and mixed during a protracted IP-hT granulite facies event. In the Mt Chapple – Mt Hay region this event occurred between 1780-1760Ma, approximately 50Ma earlier than the 1730-1720Ma event in the Strangways region. These ages were established using SHRIMP analysis of zircons in granitic rocks and metamorphically derived leucosomes.

CADNEY PACKAGE 1770Ma

Named after the Cadney Metamorphics in the Alice Springs region, this package of predominantly calc-silicate rocks, marble and sillimanite and biotite gneiss, is one of shale-limestone facies which represent a change in depositional environment following a period of extensive volcanism (Narwietooma). This package was metamorphosed to granulite facies, along with Narwietooma during the same deformation events. A minimum age for this package is provided by the 1770Ma age of an intrusive granite.

WIGLEY PACKAGE >1770Ma (possibly >1870Ma)

An assemblage of compositionally layered, amphibolite facies gneisses of mainly granite to granodiorite composition, with less abundant amphibolite, sillimanite gneiss and calc-silicate

rock are interpreted to be lower grade metamorphic equivalents of the Narwietooma package. This correlation is based on compositional similarity and inferred similarity in protolith age, and the age of metamorphism and deformation. The only differentiating factor is the lower (amphibolite facies) grade of regional metamorphism.

The minimum age is constrained by intrusion 1770-1750Ma granites. Maximum age is unknown and may be older than 1870Ma or 1751Ma, the ages obtained for zircons in a tonalite trondhjemite granodiorite suite in the intrusive Atnarpa Igneous Complex. Zircons providing the 1870Ma date may be inherited. The 1751Ma date however is comparable to that obtained from other granites intruding the Wigley package in the region.

BONYA PACKAGE >1770Ma

Confined to the Jervois region the Bonya Schist (package) overlies gneissic rocks of the Wigley package with a transitional contact. Muscovite and two-mica schist are the main rock-types, with thick sequences of amphibolite, widespread calc-silicate rock and lesser metaquartzite. This package was metamorphosed to amphibolite facies during the Strangways event (1730-1720Ma) after intrusion of 1770Ma granites. The lower part of this package may be equivalent to Wigley package and the upper, containing widespread calc-silicate may be a Cadney-Reynolds packages equivalent.

REYNOLDS PACKAGE 1810-1780Ma

Named after the Reynolds Range Group in the Reynolds Range, where this package of orthoquartzite, calc-silicate rock and pelitic schist, deposited in a shallow-marine environment, is unconformable on the Lander Package.

Metamorphic grade in the type area varies from greenschist to granulite facies. Elsewhere correlatives of the Reynolds Range Group, included in this package, vary in metamorphic grade from lower amphibolite facies in the west (Mt Doreen region) to granulite facies in the east (Alcoota – Huckitta regions).

The depositional age of the Reynolds Package is younger than the 1820-1800Ma granite suite that intruded the Lander Package and older than a suite of intrusive 1780Ma granites.

LEDAN PACKAGE 1780-1760Ma

The Ledan Schist and equivalent greenschist facies rocks located in Alcoota – Huckitta region make up this package, with the Nicker beds (dated at 1772Ma) in Mt Doreen. Ledan unconformably overlies Reynold Packages and is probably intruded by 1713Ma granite. Correlation with the Nicker beds is uncertain, as is the age of this package.

YAYA PACKAGE 1680-1640Ma

Named after the Yaya Metamorphics, in Mt Liebig, which is an assemblage of granulite facies migmatite meta pelite and psammite, minor calc-silicate, orthogneiss and amphibolite. New SHRIMP geochronology accurately constrains the age of high grade metamorphism of the Yaya Metamorphics at ~1640Ma. Detrital zircon ages constrain the maximum depositional age to ~1680Ma. Included in this package is the Madderns Yard Complex, characterised by migmatised quartzofeldspathic gneiss, much of which may represent felsic

and mafic magmatic rocks with sediment intercalations. It is interpreted that Yaya is unconformable on Narwietooma.

IWUPATAKA PACKAGE 1620-1600Ma

The Iwupataka Metamorphic Complex largely comprises a lower to mid amphibolite facies sequence of dominantly pelitic and quartzitic metasediments, lesser amphibolite and minor calc-silicate rocks and marble. The package was deposited on the 1640-1600Ma Putardi Granite Suite and unconformably on migmatites of the Yaya package. North vergent deformation and metamorphism occurred during the 1600-1580 Chewings Event.

IRINDINA PACKAGE 650-500Ma

The Irindina Package represents the Irindina Supercrustal Assemblage which consists of interlayered mafic rocks that form a lithological association with meta-greywacke, shale and carbonate within an interpreted stratigraphic section having an estimated present structural thickness of 5-6km. Peak granulite facies metamorphic conditions were reached at 475 ± 14 Ma during the Larapinta Event. Recent SHRIMP zircon ages constrain the deposition of the Irindina package to the interval 650-500Ma; some zircons with an age of 520Ma suggest deposition was Cambrian age.

These stratotectonic packages need considerable refinement in terms of their regional relationships and their geochronological constraints. However it is hoped they may provide a useful tool in identifying the major tectonic zonations and sedimentary-volcanic facies associated with the formation and deformation of the southern margin of the North Australian Craton. This in turn may assist in the distinction between sterile deep crustal plutonic terrains, and form terrains with VMS, BHT, sediment hosted gold deposits in sedimentary packages, and other deposit types.

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THE SW ARUNTA - A TERRAIN AREA GETTING YOUNGER BY THE MINUTE

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After preliminary investigations in 1998, the NTGS began full scale second edition mapping of the southwestern margin of the Arunta Province in 2000. The area to be covered encompasses the northern sections of MOUNT LIEBIG and MOUNT RENNIE 1:250 000 mapsheets and all LAKE MACKAY 1:250 000. The project will combine metamorphic and structural studies with extensive geochronological and geochemical analysis to re-interpret the tectonic framework of the southwest Arunta. This will be coordinated with the geophysical interpretation of the area, undertaken by Tony Meixner as part of the National Geoscience Agreement with AGSO, to produce seamless basement interpretation maps. The prospectivity of the terrain will be fully investigated with particular reference to potential for Broken Hill style mineralisation, base metal mineralisation within McArthur Basin equivalents, Ni-Cu mineralisation associated with layered ultramafic intrusives and Mount Webb Granite style Cu-Au mineralisation.

Also within the NGA, Dean Hoatson (AGSO) has sampled mafic units in the MOUNT LIEBIG area and from Andrew Young Igneous Complex in MOUNT DOREEN as part of a wider study of mafic intrusives in the Arunta Province. Early analysis suggest mafic bodies on MOUNT LIEBIG have potential for Ni-Cu-Co sulphides. Further isotopic analysis and geochronology will provide information on age, tectonic environment and mineral prospectivity.

As the SW Arunta project lies entirely within the Aboriginal Land Trust agreement, negotiations for access are ongoing. For the 2000 field season, access to 90% of the northern MOUNT LIEBIG area was granted, with areas on MOUNT RENNIE and LAKE MACKAY to be negotiated for the 2001 field season. As a result, mapping activities in 2000 were concentrated on MOUNT LIEBIG and a preliminary map has been produced.

The project is very much in the early stages, with few analytical results as yet. However, geochronology to date suggests the terrain within the MOUNT LIEBIG area to be younger than previously recognised. The following geological framework incorporates this new geochronological data with early geochemical correlations and field relationships:

- Sedimentary packages that were assumed to predate the 1780-1730 Ma Strangways Event have yielded detrital zircon population with ages of 2500-2400 Ma and 1700-1650 Ma indicating no North Australian Craton component, and a maximum sedimentary age of about 1650 Ma
- Rapidly following deposition, these sediments underwent granulite to upper amphibolite metamorphism at 1640 Ma (informally named the Liebig Event)
- At 1640 Ma there appears to be voluminous bimodal magmatic activity with felsic volcanics and granites that can potentially be correlated with volcanics of the Pollock Hills Formation and Mount Webb Granite in Western Australia [Wyborn et al 1998]. Preliminary work suggests that mafic bodies within MOUNT LIEBIG may be related to the 1635 ± 9 Ma Andrew Young Igneous Complex
- Subsequent exhumation was followed by a second period of deposition between 1640 and 1600 Ma
- Metamorphism at amphibolite grade during the Chewings Event at about 1600Ma
- Localised migmatitisation occurred under amphibolite conditions during the poorly understood 1150 Teapot Tectonothermal event. The regional extent of this event is yet to

be defined, but it is synchronous with metamorphism and granite intrusion in the Musgrave Block to the south.

- Deformation under greenschist facies conditions during the 450-300 Ma Alice Springs Orogeny produced steep south vergent shear zones. The low metamorphic grade of these shear zones suggests that vertical stacking during the Alice Springs Orogeny was relatively limited in the southwestern Arunta.

This preliminary data suggests the SW Arunta represents a new terrain in the Arunta Province with no apparent North Australian Craton component (Figure 1). It contains sediments of age similar to mineralised sequences in the McArthur Basin and Mount Isa regions, and is intruded by extensive mafic and ultramafic rocks with prospectivity for base metals. Ongoing geoscientific studies by NTGS are expected to refine this geological framework and enhance the prospectivity of under explored region.

Products

Outcrop maps

MOUNT LIEBIG 1:250 000 map and explanatory notes

MOUNT RENNIE 1:250 000 map and explanatory notes

LAKE MACKAY 1:250 000 map and explanatory notes

Basement interpretation maps

MOUNT LIEBIG 1:250 000 map

MOUNT RENNIE 1:250 000 map

LAKE MACKAY 1:250 000 map

MOUNT DOREEN 1:250 000 map

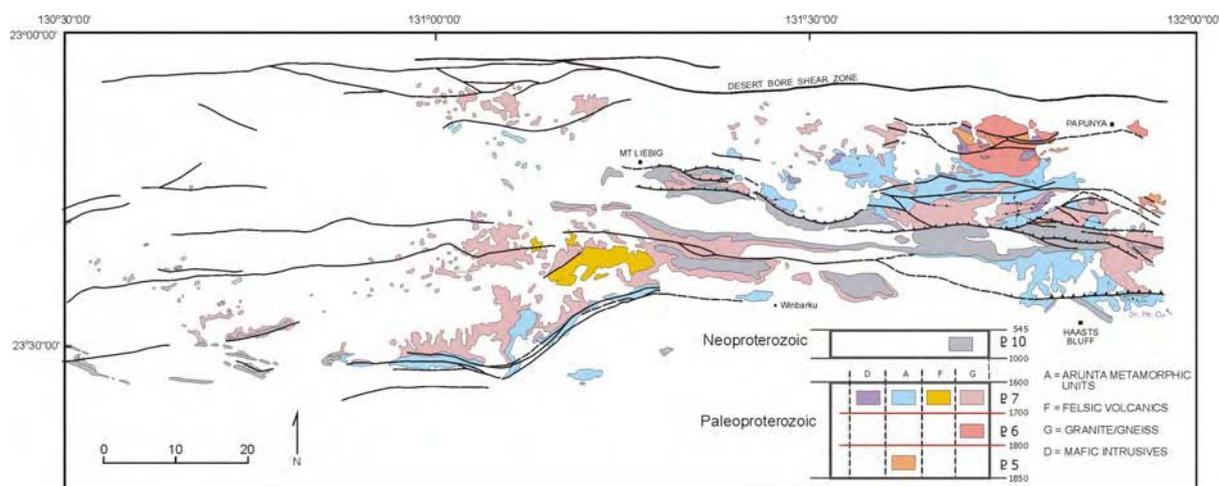


Figure 1. Tectonic units as divided on the Geological Map of the Northern Territory 1:2 500 000 for the northern section of MOUNT LIEBIG 1:250 000

Reference

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SOME TECTONOTHERMAL SURPRISES IN THE EASTERN ARUNTA PROVINCE

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The eastern Arunta Province is a Palaeoproterozoic to Palaeozoic terrain that encompasses the Harts and Strangways Ranges and Jervois region in central Australia. It has traditionally been regarded as being largely Palaeoproterozoic in age, with only low-grade reworking and exhumation during the Palaeozoic. However recent studies incorporating SHRIMP U-Pb and Sm-Nd geochronology (Mawby *et al* 1999, Hand *et al* 1999, Buick *et al* 2001) have led to a radical reinterpretation of the geology of the region. In particular, the Irindina Supracrustal Assemblage (Harts Range Group) in the Harts Range region is now believed to be a rift sequence that was deposited in the latest Neoproterozoic or Cambrian, within an extremely deep sub-basin in the Centralian Superbasin. This rift sequence was metamorphosed to granulite facies in an extensional setting during the previously unrecognised Larapinta Event in the early Ordovician (480-460 Ma), and was subsequently exhumed during compressional deformation as part of the Alice Springs Orogeny.

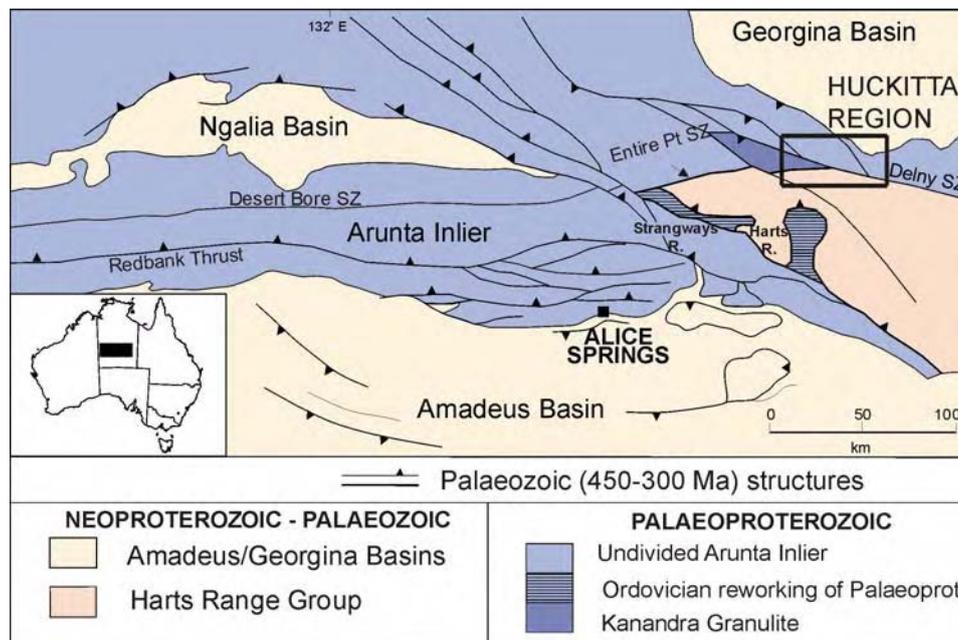


Figure 1 Map of the part of the Arunta, showing the Huckitta region and major shear zones

Recent studies by the Northern Territory Geological Survey in collaboration with the University of Leoben (Austria) have concentrated on the Huckitta region, near the northern margin of the eastern Arunta (Figure 1). In this region, two major, steeply south-dipping mylonite zones separate Ordovician granulites of the Harts Range Group from a Palaeoproterozoic terrain (the Jinka terrain) that underlies unmetamorphosed Neoproterozoic sediments of the Georgina Basin. These mylonites, the Delny and Entire Point Shear Zones, represent the northern margin of the Palaeozoic metamorphic overprint in the eastern Arunta, and extensively rework the Palaeoproterozoic Kanandra Granulite (Figure 2). Juxtaposition of Ordovician granulites adjacent to unmetamorphosed Neoproterozoic sediments in the Huckitta region implies that these north-vergent shear zones accommodated large-scale (>20 km) exhumation during the Palaeozoic.

North of the Delny Shear Zone is the Jinka terrain, a narrow (5-25 km wide) belt of low pressure amphibolite to granulite facies metasediments that includes the mineralised Bonya Schist in the Jervois region. In the Huckitta region, the Jinka terrain comprises the Deep Bore and Cackleberry Metamorphics, which were metamorphosed at low pressure (3 kbar) granulite and upper amphibolite facies, respectively. Detrital zircons in the Deep Bore Metamorphics form a homogeneous population that crystallised at 1805 ± 7 Ma, probably reflecting the timing of volcanoclastic sedimentation. Metamorphism occurred at 1730 ± 7 Ma, as part of the regionally extensive Late Strangways Event. In the Cackleberry Metamorphics, silica-undersaturated sapphirine-phlogopite schist represents a metamorphosed low-T alteration zone, having affinities with the host-rocks of Oonagalabi-style base metal mineralisation in the Strangways Range.

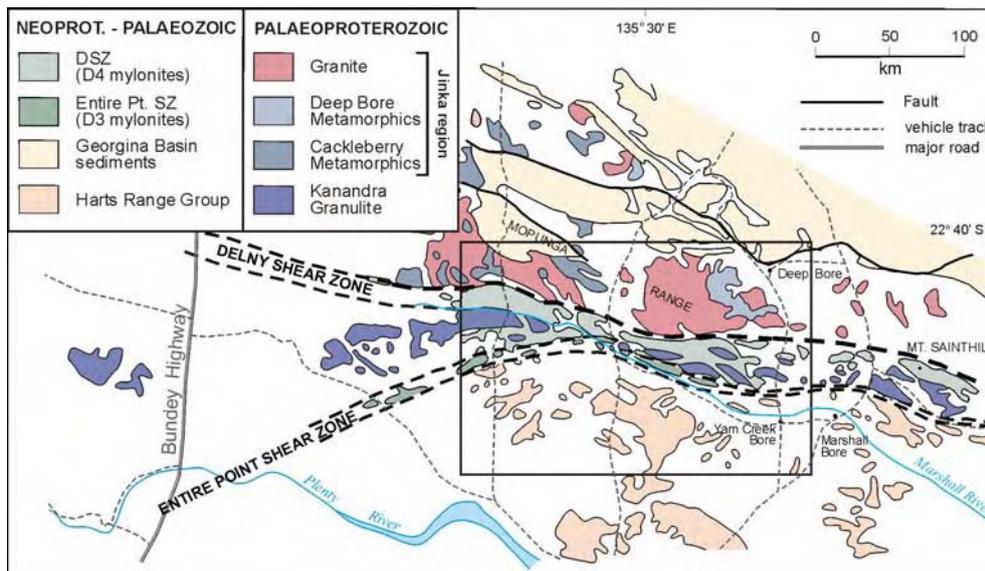


Figure 2. Map of the Huckitta region, showing the major shear zones

South of the Delny Shear Zone, the Palaeoproterozoic Kanandra Granulite comprises pelitic migmatite and mafic granulite, and has a maximum deposition age of 1817 Ma. The Kanandra Granulite was metamorphosed in the Late Strangways Event at deeper crustal levels than the Jinka terrain, and has been extensively reworked during the Palaeozoic. The first phase of Palaeozoic reworking of Kanandra Granulite was upper amphibolite facies (700°C , 7 kbar) mylonitisation, with the juxtaposition of Kanandra Granulite against Ordovician granulites of the Harts Range Group along the Entire Point Shear Zone (Figure 2). The Entire Point Shear Zone dips steeply south, with a sinistral-reverse sense of movement. Monazite in the Entire Point Shear Zone crystallised at 445 ± 5 Ma, representing the onset of Palaeozoic compressional deformation in the region. This is coincident with south-vergent thrusting in the southern Harts Range, and suggests that juxtaposition of the Ordovician granulites of the Harts Range Group against the surrounding Palaeoproterozoic terrains occurred at 450-440 Ma.

The 450-440 Ma event effectively forms the beginning of the Alice Springs Orogeny, which continued, probably episodically, for up to 150 Ma. ^{40}Ar - ^{39}Ar dating of hornblende suggests that the Kanandra Granulite and northern Harts Range Group in the Huckitta region cooled through 500°C by 420-390 Ma. Further reworking of Kanandra Granulite occurred in steeply south-dipping, north-vergent mylonites of the 2-4 km wide Delny Shear Zone that decrease in grade from mid-amphibolite facies in the south to greenschist facies in the north. Exhumation

related to movement on the DSZ juxtaposed Kanandra Granulite against the Jinka terrain. The lowest grade mylonites in the DSZ were active at 365-360 Ma, and the terrain south of the DSZ cooled through 350-420°C by 350 Ma. This cooling is interpreted to be a consequence of exhumation of the terrain along the Delny Shear Zone. Ductile deformation had largely ceased in the northeastern Arunta by the end of the Devonian, with no evidence for Carboniferous metamorphism and deformation that occurs elsewhere in the Arunta. The Delny and Entire Point Shear Zones represent fundamental structures in the eastern Arunta Province, that accommodated significant exhumation at the rear of a south-vergent orogenic wedge from the mid Ordovician to the late Devonian (Figure 3).

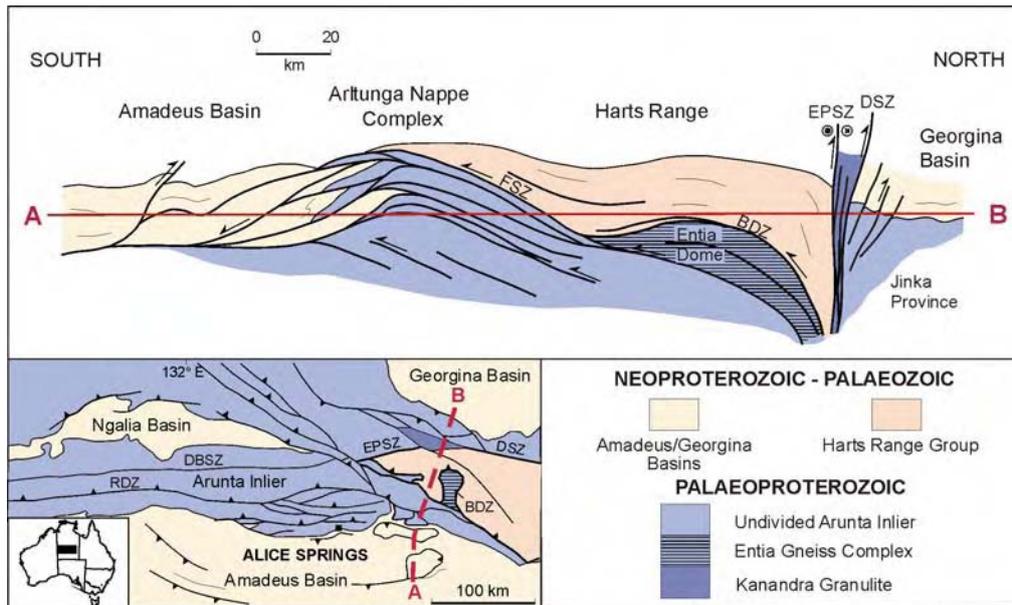


Figure 3. Schematic cross-section of the eastern Arunta, showing the Entire Point Shear Zone (EPSZ) and Delny Shear Zone (DSZ) at the rear of the south-vergent wedge

Implications

- Recognition that the Harts Range Group is a Cambrian rift sequence necessitates a complete re-evaluation of its prospectivity. The Harts Range Group can be regarded as a new province with a fundamentally different evolution to the rest of the Arunta. The abundance of mafic rock and pegmatite within the Harts Range Group makes the region prospective for PGE and REE, whilst the region also remains underexplored for other commodities such as base metals.
- The Delny Shear Zone formed a major conduit for hydrous fluids during the Alice Springs Orogeny, particularly during the late Devonian, with pervasive hydrous retrogression and veining. Coarse apatite occurs in quartz reefs in the shear zone near Mt Sainthill, suggesting potential for REE mineralisation. Barite and fluorite mineralisation also occurs within the Delny Shear Zone.
- Ordovician structures such as the Entire Point Shear Zone in the Huckitta region are relatively anhydrous, suggesting either a lack of fluid or a CO₂-rich fluid during deformation, and appear less likely to host mineralisation. However, these structures were locally reactivated during the Devonian.
- The Jinka terrain, which contains well documented base metal and tungsten mineralisation in the Bonya Schist, was affected by the 1730 Ma Late Strangways Event, and is interpreted to be an upper crustal level of the same terrain as Kanandra Granulite and Strangways Metamorphic Complex. The existence of possible volcanoclastic sedimentation and low-silica alteration zones in Cackleberry Metamorphics suggests that

base metal prospectivity continues to the west of the Bonya Schist throughout the supracrustal rocks of the Jinka terrain.

- Barite and fluorite veins in the basal sequence of the southern Georgina Basin are interpreted to reflect fluid flow during Devonian deformation on the Delny Shear Zone. High grade Ordovician to Devonian metamorphism and deformation in the northeastern Arunta is likely to have led to an enhanced geotherm and accompanying fluid flow in the southern Georgina Basin. An elevated Palaeozoic geotherm and focussing of high-T fluids along Palaeozoic structures may account for the formation of small high-T carbonate-hosted Pb-Zn deposits in the southern Georgina Basin (Ypma, 1984) as well as the high petroleum maturity in the southwest of the basin.

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GEOCHEMICAL DATASETS FROM OPEN FILE COMPANY DATA

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The Northern Territory Geological Survey has an abundance of exploration geochemical data derived from open file, annual, final, and relinquished company reports. The data has been captured in-house or by contractors, shared with AGSO, or purchased via Terra Search Pty Ltd.

The Geological Survey is creating a geochemical dataset to complement in coverage and quality the geophysical datasets available over most of the Northern Territory. Currently available geochemical datasets cover large regions of the Territory including the McArthur Basin, Victoria-Birrindudu Basin, Tanami Region, and the Arunta Province. There are also sporadic data available from outside these regions.

The Explorer 3 database holds over 146 000 geochemical data points, consisting of stream sediment, rock chip, soil, or drill collar data types. With down hole assays included, the number of total samples is in excess of 195 000 records. The data breakdown is 19 000+ collars, as well as 68 000+ down hole assays, 68 100 stream sediment samples, 42 000+ soil samples, 14 000+ whole rock samples, and 3 000+ rock chip samples.

Compilation of the Arunta Province dataset is in progress. Due to the size of the project, the data will be progressively released for the western, central, and eastern sections. The western Arunta dataset has been completed, and complements the Tanami dataset, due to be released in April 2001.

The Victoria Basin dataset, formerly part of the Northern Australia Proterozoic Basins dataset that was purchased from Terra Search, contains 31 000 stream sediment samples, 600 drill holes and 5 000 drill hole samples. It covers nearly seven 1:250 000 map sheets.

The McArthur Basin dataset contains approximately 35 000 stream sediment samples from over six 1:250 000 map sheets, and includes the NTGS Seigal dataset, which has been updated with gold and PGE suite analyses. Both the McArthur and Victoria Basin datasets are fully attributed with collection method, analytical method and company report and tenement details. The stream sediment data includes sieved stream sediment, bulk cyanide leach, orientation, coarse fraction stream sediment, bulk sample, panned concentrate, alluvial and lag. The datasets are complete to early 1997, and will be updated in the future.

The Tanami Region dataset was a collaborative project between AGSO and NTGS. This dataset covers the TANAMI, TANAMI EAST, THE GRANITES, and HIGHLAND ROCKS 1:250 000 map sheets. It contains 10 000 drill hole locations, 16 500 soil samples, 2 500 rock chips, and 560 stream sediments. Data was collected under contract by Terra Search and augmented by NTGS, with emphasis on maintaining the same standard of data quality.

The NTGS whole rock dataset, named NTWRock, has been derived from the AGSO Rockchem database. This is currently a closed file and is for in house use only. AGSO and NTGS geologists have collected the data over the last twenty years. The 14 100 samples

cover major mining and prospective areas around Pine Creek, Jabiru, Tennant Creek, Tanami Region, McArthur Basin, Alice Springs and within parts of the Arunta Province. The analyses are both whole rock and trace elements for all samples.

The remaining sporadic data are mostly digital and was submitted with company reports. Digital data are easier to load, eliminating the laborious task of manual data entry. There are 15 000 sample points, representing the majority of these data, these are soil samples around the Pine Creek area. The collection of these data is an ongoing process, precedence is given to company data in project areas.

GEOPHYSICS IN NTGS

Where are we at, and where to next?

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Introduction

Geophysical programs in NTGS are designed to assist in the early exploration protocol of regional assessment and area selection. To this end, the core business functions of NTGS Geophysics Section are to:

- Acquire, process and archive semi-regional geophysical data
- Geologically integrate these data into NTGS regional geoscience prospectivity enhancement programs
- Disseminate data and interpretations to the exploration industry.

Airborne Geophysical Program

The aim of NTGS Airborne Geophysical Program is to provide explorers with one of the most extensive, uniformly high quality airborne datasets available anywhere in the world. The process of acquiring semi-regional airborne data, and progressively replacing the AGSO continent-wide reconnaissance dataset, is being accelerated under increased funding arrangements of the NT Government 4-year Exploration Initiative. During 2000, almost 450 000-line kilometres of airborne magnetic, radiometric and DTM data were acquired by NTGS:

- 350 000-line kilometres were flown in five separate surveys at an approximate cost of \$1.7M (**AMADEUS CENTRAL, BAUHINIA, MARY RIVER, WEST ARNHEM and WISO**). Most of the data were collected using the “standard” NTGS specifications of 400 m flight line spacing, 80 m mean terrain clearance, and 33 litres spectrometer crystal volume. The exception was **WEST ARNHEM**, where specifications of 60 m altitude and 50 litres of crystal were adopted. This survey was specifically designed to map U-bearing Cahill Formation beneath younger platform cover sediments, and further focus exploration activities via the detection of broad radiometric anomalies associated with reactivated structures.
- An additional 95 000-line kilometres were acquired from the private sector and AGSO in four surveys at a total cost of \$60K (**ALLIGATOR, KAKADU, KOOLPIN and RODINGA**). These surveys were flown between 1974 and 1990, at flight line spacings ranging from 250 to 500 m. All surveys were re-processed prior to public distribution.

It has been customary for NTGS to acquire and archive raw multichannel radiometric data on all of its airborne surveys since 1996. In recent years the use of noise reduction techniques (NASVD and MNF) has seen a significant improvement in the quality of airborne radiometric images. The NASVD method has since become the

default standard in the absence of an industry-wide implementation of the MNF technique. In an attempt to redress this imbalance, all radiometric data flown under contract to NTGS in 2000 was processed using MNF. This data was collected at semi-regional specifications under wide ranging geological environments, thus providing clients with an opportunity to evaluate an alternative modern processing technique. An added benefit is that MNF noise reduction is now available to the industry through two additional airborne contractors who, in order to fulfil their contractual obligation to supply MNF processed data, opted to implement the technique into their established radiometric processing streams. A rigorous comparison of both techniques on data from the 2000 surveys is planned in the upcoming months.

Located (ASEG-GDF2 format) and gridded (ER Mapper .ers) digital data from the 2000 airborne program were released into the public domain during December 2000 – February 2001 under the current NTGS zero pricing policy. To date, over 25 requests have been filled for each survey.

The importance of airborne geophysics to the early exploration protocols of project generation and area selection cannot be overstated. This is borne out by statistics that demonstrate increased activity in land uptake for FY99/00 over areas earmarked for airborne surveys during 1999 and 2000. This encouraging trend is noted despite falling exploration expenditure in the NT over the corresponding period.

Magnetic Map of the Northern Territory

The Magnetic Map of the Northern Territory (Johnstone and Slater 2000; Clifton 2001) is the first publicly available compilation of its kind. The inaugural edition was released in October 2000. It, along with the complementary 1:2.5M Geological Map of the Northern Territory, underpins all regional geoscientific studies undertaken by NTGS. The map comprises a grid stitch of data from 47 semi-regional NTGS and AGSO airborne surveys flown between 1974 and 2000. This product, accounting for 70% of the total area of the map, was in turn merged into a resampled (100 m equivalent) grid of the AGSO Magnetic Anomaly Map of Australia (Tarlowski *et al* 1999) to produce the final map.

In addition to the 1:2.5M hard copy product, a digital grid of the NTGS component of the compilation is being freely distributed. The Magnetic Map of the NT will be updated annually to include data acquired during the previous year's airborne program.

NTGS Image Web Server

The current delivery for NTGS data and information is through hardcopy publication and, increasingly, in digital format on CD-ROM. The NTGS web site provides a conduit for delivery of a rapidly growing range of digital products. The objective is to provide Internet access to actual data through spatial interfaces. The first steps to achieving this objective have been taken with airborne geophysical data.

A major development for NTGS in 2000 was the implementation of an image web server (IWS) as a means for accessing compressed located imagery from 47 semi-regional government airborne surveys across the NT. Access to IWS is gained through the NTGS web site using standard web browsers. In essence, IWS mitigates the practical difficulties in serving raster data of extreme size over the relatively narrow bandwidth currently available to most users by combining wavelet based compression technology with image subsetting. Individual magnetic, radiometric and elevation images, numbering over 450 in total, were produced using a compression ratio of between 10 and 80:1 in order to optimise speed of delivery over the Internet with a relatively minor compromise in data quality. The average compressed image file size is around 330 KB.

Web plugins allow images to be imported directly into a suite of industry standard software packages by specifying image URLs. Consequently, IWS particularly caters to geologists who require an enhanced geophysical image as a raster layer within GIS datasets. This utility encourages clients to browse images over the Internet, and to actively work with them using the enhanced functionality of specialised software.

In December 2000, NTGS posted compressed images on IWS from the nine airborne surveys acquired during 2000. In two instances, access to located imagery preceded official data release by more than two months. The logical extension of this concept is that IWS can enable NTGS to serve preliminary imagery during the conduct of an airborne survey, thereby facilitating earlier area selection decisions and complimentary airborne surveys by explorers. This service will be made available by NTGS for the first time during the 2001 airborne program.

Web serving of NTGS geophysical data, identified as an action item at AGES 2000, is now a reality using IWS. A more holistic approach to integrating additional raster and vector information awaits the development of a DME web-based spatial information system.

Interpreted Geology Map Series

NTGS Regional Geoscience programs involve multidisciplinary geoscientific studies of major geological regions in order to enhance the perceived mineral and petroleum prospectivity. An important part of these prospectivity enhancement studies involves synthesizing all public domain and private sector geophysical data (in most cases potential field data) to produce “bedrock geology” maps. This is particularly critical for many areas of the NT where outcrop is scarce. The interpretation process demands that all geophysical responses be assigned a meaningful geological source. When integrated with lithostratigraphic, structural and metallogenic studies for the region, a powerful new product is produced – the Interpreted Geology map series – which augments the traditional surface geology standard-series map product.

The first batch of the Interpreted Geology map series, focusing on the Tanami Region, was released in February 2001. The release comprises both traditional hard copy (1:100K and 250K) and GIS products.

Program for 2001

The following items are on the agenda for 2001:

- Acquisition of 480 000-line kilometres of airborne magnetics, radiometrics and DTM in three surveys. Approximately 45% of the total amount will be acquired from the private sector. These surveys will complete coverage of all Barramundi (pre 1850 Ma) basement inliers of the North Australian Craton (NAC), as well as the eastern extents of the Arunta Province and Amadeus Basin. A subsequent edition of the Magnetic Map of the Northern Territory, scheduled for release in March 2002, will incorporate data from the 2001 airborne acquisition program, and for the first time preserve the resolution of individual component data sets.
- Gravity surveying in the Tennant Creek region will be undertaken during May-June 2001, following satisfactory conclusion to land access negotiations. AGSO and NTGS are each contributing 50% of the funding for this work (\$110K total). The new data will be acquired at nominal station spacings of 1 and 4 km, augmented by substantial private sector data over the TENNANT CREEK and northern BONNEY WELL 1:250K sheets.
- A similar level of funding has been apportioned for additional gravity work during FY01-02. Area selection has not yet been finalised.
- By mid 2001, selection of several seismic reflection transects for the ANSIR program will be finalised. The focus of this work will be to elucidate upper crustal signatures that have demonstrable economic implications.
- Ongoing “basement” geophysical interpretations, undertaken prior to and coincident with field mapping activities, are tabled for 2001. These include the western Arunta Province, Victoria-Birrindudu Basin and Rum Jungle area.
- The scope and quality of the airborne geophysical coverage of the NT is now at a stage where NTGS can begin to consider various “value adding” options. Initial thoughts include:
 - 3D analysis of airborne magnetic data to better define the edges and internal framework of the NAC. One approach is to “worm” the data using wavelet analysis.
 - Production of a Territory-wide DTM.

Longer Term Geophysical Plans – Beyond the Current Initiative

The end of the 2002 flying season effectively signals the conclusion of funding for airborne surveys under the current Exploration Initiative. It is estimated that by this time approximately 85-90% of the Northern Territory will be covered by airborne surveys with semi-regional specifications (< 500 m line spacing). The task of providing explorers with a high quality data set of international significance will essentially be complete. Consequently, beyond the current Initiative the focus for airborne survey work will be somewhat less holistic, with area and technique selection likely governed by exploration trends, geological environment, target styles and, of course, cost. Two airborne techniques that may figure prominently in NTGS programs beyond 2003 are TEM and gravity gradiometry:

- TEM. Regional traverses will help characterise regolith, transported cover and basement responses over broad regions. District-scale surveys, using appropriate flying specifications, may help upgrade the mineral prospectivity of several parts of the NT.
- Gravity gradiometry. Historically, NTGS has devoted relatively few resources to the collection of semi-regional gravity data. Consequently, of all Australian jurisdictions, the Northern Territory stands most to gain from flying semi-regional (400-500 m line spacing) airborne gravity gradiometry. This may represent, in most areas, several orders of magnitude improvement in spatial resolution on the current AGSO coverage. However, commercial availability and cost considerations will impede access to this technology in the medium term (2-3 years).

NTGS may be in a position to contribute funding to the ANSIR program by as early as FY02-03 with the bulk of the airborne acquisition program completed.

Concluding Remarks

The focus of NTGS geophysical programs is the provision of high quality data and interpretations to explorers that assist in regional target definition and area selection. The semi-regional airborne acquisition program remains the flagship activity of NTGS under the current Exploration Initiative. Through Image Web Server, explorers now have the capacity to rapidly access airborne data over the Internet from within the GIS environment.

Adding value to our highly regarded airborne data set is gathering momentum. The Interpreted Geology map series encapsulates current geoscientific thinking on NTGS Regional Geoscience programs. Other “value adding” activities under consideration over the next year include 3D potential field analysis.

Geophysical strategies going forward into the second half of the current Initiative and beyond may involve regional airborne TEM and district-scale gravity gradiometry. Planning is underway for future NTGS involvement in the ANSIR program.

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INFORMATION SERVICES AND DELIVERY

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Introduction

The Northern Territory Geological Survey (NTGS) has gained significant additional funding for the 1999 – 2003 period through the Northern Territory Exploration Initiative. A portion of this funding is allocated for the development of information management systems that support and complement the geoscience programs.

Over the last two years an image web server (IWS) for the delivery of geophysical images has been developed, and, together with the Industry Reports Management System (IRMS) and the Core library database has been made available to the public on the redesigned NTGS web site. The focus for provision of information and data has changed from hardcopy maps and reports to delivery via CD-ROM and increasingly, the Internet. During the first two years of the Initiative an increasing number of NTGS products has been released and many of these new products are being placed on the web site for downloading. Such products include digital geological maps, presentations, open file geochemical data sets, the Northern Territory Mineral Deposits database (MODAT), spatial indices to both industry and NTGS open file airborne geophysical surveys and NTGS Records. The NTGS web site (www.dme.nt.gov.au/ntgs) has become a dynamic resource for clients and this is a highly desirable and important outcome considering over 90% of NTGS clients are not based in the NT. In future more databases and datasets, many with an interactive spatial interface, will be made available on the web site.

Recent Achievements

The IRMS project has involved scanning all open file mineral exploration reports back to 1983 and providing a web interface to the improved and updated index database. Clients can identify and obtain reports by searching the IRMS index on the web and then emailing a request to the Geoscience Information Branch of NTGS. Requests for digital reports are increasing and are usually satisfied with the provision of one or two CDs. Feedback on this service is very positive and NTGS prides itself on its timely response to client requests as most requests are actioned within one or two days. Although not a priority at present, new compression technology and delivery mechanisms are being monitored with a view to providing future access to the entire collection of scanned reports over the Internet.

Although the DME Titles Information System (TIS) is available for querying over the web, it does not contain historical tenement information. This poses a problem for identifying relevant open file exploration reports within an area of interest as the only spatial references within the IRMS index are the tenement number and the 1:100 000 and 1:250 000 map sheet codes. To overcome this problem all relevant historical exploration licence boundaries (those with associated reports) have been digitised and are now available in MapInfo and ArcView formats. Only the original EL boundary has been captured and each EL polygon will be associated with multiple reports. At this stage, digital boundaries for historical mineral claims (MCs) are not being captured although this is likely in the future. The historical EL dataset will be included on future quarterly IRMS CDs and will be available for downloading on the NTGS web site.

In 2000 all of the onshore petroleum well completion reports, a total of 186, were retrieved, checked and reindexed. All relevant records in IRMS Index were amended and upgraded and a number of new records created. This project was undertaken in preparation for the commencement of scanning in 2001.

The redeveloped core library database, COREDAT, is available within the NTGS in Access format and is used to administer and maintain the core library. In February 2001 a searchable subset of COREDAT was made available on the NTGS web site. The subset is created in DB/TextWorks software and will be updated on a bimonthly basis.

Current Projects

Current projects involving the Geoscience Information Branch include:

- ◆ scanning of open file onshore petroleum well completion reports;
- ◆ upgrading IRMS (petroleum) by barcoding, indexing and reorganising the seismic section sepias and updating IRMS Index accordingly;
- ◆ checking closed file industry reports and open filing wherever possible;
- ◆ collecting open file geochemistry data in the Arunta Province;
- ◆ developing a GIS package over the Tanami Region;
- ◆ checking and upgrading the content of the core library database (COREDAT); and
- ◆ web-enabling the library catalogue.

IRMS

The bulk scanning of open file mineral exploration reports has been completed, although scanning of newly open filed reports is continuing. Following the success of this project, the focus of the bulk NTGS scanning project has now moved to petroleum reports. After completely reindexing the onshore well completion reports (186 in total), scanning has commenced and is due to be completed by July 2001. Although the number of reports is very low compared to the mineral exploration project, the reports are larger and more complex, and have a number of different document types and sizes.

As part of the overall IRMS project, the petroleum data are being reorganised, reindexed and barcoded and the database upgraded accordingly. The current subproject is the reorganisation and indexing of the onshore seismic section sepias and the addition of these details to the IRMS index. Until recently, the number or details of seismic sections have never been regularly recorded in NTGS databases and therefore until this project is completed, NTGS has no idea of the amount of data it is responsible for managing except in bulk volume terms such as number of tubes or racks.

The seismic section subproject involves retrieving, barcoding and indexing the onshore seismic sections, labelling and reorganising the storage tubes and entering all the information on to spreadsheets that are then linked to the IRMS index. Significant byproducts of this process are the identification of missing and duplicate documents as well as the highlighting of problems with current database records. At present the project is progressing slowly within existing staffing levels, but a new two-year contract position has been created to accelerate and extend the project to include offshore seismic sections. This position will commence in April 2001.

Over the years, and as a result of inadequate and varying workflow practices, a number of industry reports have remained in closed file although due for open file release. In 2000 a project commenced to systematically check the status of all post-1982 closed file reports, and open file those overdue for release. This time consuming and at times, complicated process, is due for completion in 2001, after which, NTGS will be seeking support from industry to embark on a new project to open file as many closed file reports as possible.

Territory-wide Geochemistry Database

During 2000, the Tanami geochemistry database was compiled and released to the public. Subsequently, work commenced on compiling data in the Arunta Province and this data capture is still in progress. Data compiled by Terrasearch for both the McArthur and Victoria Basins was released to the public by NTGS in January 2001. Together with the ongoing collection from statutory reporting by industry, these datasets form the basis of a Territory-wide geochemistry database.

Tanami GIS

Data collected for and during the Tanami regional geoscience project is being compiled into a GIS package for release later in 2001. The package will contain geology, structure, mineral occurrences, geophysical interpretations, geophysical images and geochemistry layers. This will be only the second GIS package produced by NTGS and encompasses a much larger area than the first package which covers the Seigal 1:100 000 map sheet.

COREDAT

COREDAT, the core library database has been redeveloped in Access format and is used within NTGS to administer and maintain the core library. There are currently around 3320 records in COREDAT but only 2000 have map references, and only 1201 of these have map coordinates. Work is continuing to upgrade the database content, including determining coordinates for those records that do not have any geographical information or that have only map references.

Library Catalogue, LEDA

The NT DME library catalogue, LEDA, is targeted for uploading to the web site by the end of 2001. LEDA is the main reference source for bibliographic details on all NTGS publications. As the catalogue has had minimal data validation in the last few years, a major data cleansing and validating project is under way. Validation files are being cleaned, validation rules tightened and records upgraded and added as necessary. When the data cleansing is completed the database will be made available for searching on the web site.

Other databases and projects which have an internal focus and/or less priority at present, but which may be relevant to industry in the future include:

- ◆ upgrading the index of aerial photographs held by NTGS
- ◆ refining and populating the extractives database EXDAT
- ◆ developing a virtual library
- ◆ identifying and reorganising spatial datasets for internal use
- ◆ preparing to move to the corporate database system based on Oracle.

Future projects

Future plans are focussed in three main areas: web delivery of scanned reports; a web-enabled open file geochemistry database covering the entire Territory; and the development of a spatial interface for NTGS datasets on the web site.

Web delivery of open file company reports will include further scanning, in particular pre-1983 mineral exploration and all offshore well completion reports, and investigations into image compression technology. The compilation phase of the open file geochemistry database project is well under way and complete coverage of the NT is projected for mid-2002. In addition, a Territory-wide open file diamond indicator database will be compiled, and as far as NTGS is aware, will be the only public database of its kind in Australia. The development of a spatial interface for NTGS datasets may proceed in several phases, possibly using the DME Titles Information System (TIS) as a development platform (www.dme.nt.gov.au/tis/olz.asp) and eventually integrating this with the image web server.

The Department has adopted Oracle as the corporate database system and as such, NTGS is preparing to move relevant databases into Oracle and is proposing to use Oracle 8i Spatial to store and retrieve spatial data in the future. COREDAT is likely to be the first NTGS database migrated to Oracle and this is expected in the second half of 2001. However, prior to this migration, a corporate database model has to be developed and inventories of datasets, databases and software undertaken. Development of the corporate data model and database system will in turn guide the development of the departmental spatial interface to the titles and geoscientific datasets.

NTGS policy for product marketing and distribution is for continuous disclosure via the web site. Therefore regular checking and browsing of the NTGS web site is highly recommended. Increasingly, NTGS publications will be available in digital format and many will be available on the web site for downloading. Old NTGS unpublished reports, the "GS" series, are scheduled for scanning in the 2001-2002 financial year and other publications will be considered for scanning if the need arises.

Finally, the DME web site, including the NTGS pages, is scheduled for a further upgrade and redesign in 2001 and this will be a good opportunity for clients to provide feedback on the ease of navigation and usefulness of the site and any suggestions for enhancements. In particular, NTGS is interested in industry's view on the desirability of web delivery of scanned reports and the advantages it may have over the current search and delivery system, bearing in mind the large cost of online delivery systems in some other states.

MANGANESE, BAUXITE AND IRON ORE DEPOSITS OF THE NORTHERN TERRITORY

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World class deposits of bauxite and manganese have played an important role in the Northern Territory economy over the last 30 years. Iron ore has been mined in the past and significant sub-economic deposits exist. Information on location, geological setting, orebody character, ore controls, resource and ore genesis of iron ore, manganese and bauxite deposits is widely disseminated in unpublished reports and in some published articles. Construction of the Alice Springs to Darwin railway is essential for the development of any inland bulk resource commodities.

There are currently 120 manganese, 26 bauxite and 105 iron ore occurrences known in the Northern Territory. These have been digitally recorded in MODAT (Mineral Occurrence Database) that can be downloaded as an EXCEL file via the NTGS website. An NTGS report series publication will be available in June 2001 covering the geological setting, ore characteristics, resource status, resource potential and genesis of manganese, bauxite and iron deposits in the Northern Territory. Results from this largely office-based project has improved understanding of geological setting and ore genesis of a variety of deposit styles and identified new areas with significant resource potential.

Manganese

Sediment-hosted Mn deposits represent the most prospective exploration target. The well documented giant *Groote Eylandt* deposit (300 Mt @ 48% Mn, 8% SiO₂ and 4.5% Fe) consists of stratiform, massive to disseminated ore in a sheet-like body that averages 3 m in thickness. Manganese minerals were originally precipitated during an early Cenomanian (~95 Ma) marine regression on coastal terraces and troughs. Exploration by BHP Minerals Ltd in places along the southern and western margins of the Carpentaria Basin has identified several mineralised areas, the largest being at *South Rosie Creek* (Berents 1994). The source of the Cretaceous-hosted manganese remains uncertain.

In the Renner Springs district, north of Tennant Creek, manganese mineralisation that was previously interpreted as surficial is now considered to be of sedimentary or low temperature hydrothermal origin. A manganese horizon (6 to 12 m thick) at the base of the Palaeoproterozoic Bootu Formation (Hussey et al in press) can be traced for 24 km around a faulted syncline. Small scale mining on the western side of the syncline at *Mucketty* produced 13 300 t @ 42% Mn between 1955 and 1969 for use as an oxidant in uranium processing at Rum Jungle. Drilling on the eastern side by BHP Minerals Ltd (Nunn 1997) within a conductive GEOTEM zone, intersected massive Mn mineralisation to 75 m depth. There is no surface expression of the mineralisation in the vicinity of the drill holes. The lower 2 m of the Mn horizon hosts low silica (<10%), high grade (>40% Mn) ore.

The *Renner Springs* deposits are hosted in siltstone and dololomite near the base of the Palaeoproterozoic Shillinglaw Formation (Hussey et al in press). A percussion drill hole

(W38RDH) by Key Resources NL (Ward 1987) located 12 km south-southwest of Renner Springs intersected 9 m grading 36.7% Mn including 3 m @ 42.4% Mn from 63 m depth.

Wangatinya is located in a remote area 170 km west of Alice Springs. This Mn prospect is hosted in shallow marine quartz sandstone near the base of the Late Cambrian Pacoota Sandstone (Amadeus Basin). Mn-Fe mineralisation is present in a series of massive, bedding concordant lenses, up to 7.6 m in width and 53 m in length. Random grab samples (n=9) from the lenses averaged 44.3% Mn (Morlock 1972).

Bauxite

Lateritic bauxite deposits are highly constrained in time and spatial distribution but represent the most prospective exploration target. These deposits developed during the Tertiary on stable plateaux along the northern coastline. World class low silica bauxites are found on the Gove Peninsula (330 Mt @ 48% available Al_2O_3 , 3.2% reactive SiO_2). The *Gove* deposit averages 3.7 m in thickness and has developed over arkosic Cretaceous rocks (Yirrkala Formation), derived from Proterozoic granites. Profiles through the deposit at Gove indicate some bauxite layers are residual (tubular) while others (loose and cemented pisolites) are transported in origin.

The *Dhupuma* Plateau is located south of the Gove Plateau, about 21 km south of Nhulunbuy. A geological section by Grubb (1970), water bores and engineering test holes suggest 3 to 4 m of bauxite material is present. Limited analyses of water bore cuttings indicate some ore grade (2 m @ 50% total Al_2O_3 , 5% total SiO_2) material exists. Potential for >35 Mt of untested lateritic bauxite is indicated. Several pockets of low silica (4% reactive SiO_2) bauxite totalling 9.9 Mt @ 46% available Al_2O_3 exist on *Marchinbar Island*. These deposits average about 2 m in thickness and rest unconformably on laterite-resistant Marchinbar Sandstone. The bauxite is very similar in composition and character to Gove ore and was probably derived from Cretaceous remnants. Further potential exists in untested bauxite occurrences on *Elcho Island*.

A north sloping lateritic bauxite sheet up to 4 m in thickness has developed along the northern coastline of the *Cobourg Peninsula* and *Croker Island*, over the Cretaceous Bathurst Island Formation. These bauxite deposits are small and relatively low grade (<35% available Al_2O_3) with high (>13%) reactive silica. The largest deposit is at *Vashon Head* with 9.7 Mt @ 46.2% total Al_2O_3 and 16.1% total SiO_2 . Further potential exists in Arnhem Land across untested lateritic areas west of *Woolen River* and in the *King River* area where Cretaceous sediments overlie Proterozoic granites.

Iron ore

Oolitic sedimentary and distal hydrothermal iron ore deposits represent the most prospective exploration targets. Mesoproterozoic iron ore deposits in the *Roper River district* are examples of the former style of Fe mineralisation. Oolitic ironstones form beds 0.5 to 4 m thick that are laterally continuous over tens of kilometres. Several hundred million tonnes of ironstone material is present in the Roper River district. Ore

quality is generally low, typically about 40% Fe, 30% SiO₂ and 0.1% P, although better quality ore (>50% Fe, <30% SiO₂ and 0.1% P) exists in some areas (*Hodgson Downs*). Shallow drilling is required over the Hodgson Downs deposits to determine subsurface phosphorus levels. Oolitic ironstones are also present in the South Nicholson, Amadeus and Georgina basins.

Distal hydrothermal iron ore deposits are massive stratabound ironstone lenses hosted in Palaeoproterozoic, ferruginous, marine siliciclastic lutites. Hydrothermal fluids derived from magmatic, metamorphic and orogenic activity have remobilised sedimentary iron in the host sequence into adjacent stratigraphic and structural trap sites. In the *Frances Creek* Iron field ironstones are hosted in Wildman Siltstone and consist of tabular lenses composed of specular hematite with minor quartz. The ironstone lenses in the *Tennant Creek* mineral field, *Rum Jungle* and *Haverson Pass* areas are also examples of this style of mineralisation.

A series of discontinuous, stratabound, massive hematite lenses can be traced over a 40 km strike length in the *Frances Creek Iron field*. Complex folding of the host rock influences the distribution and thickness of ore lenses. Thick ore intersections (up to 110 m @ 63% Fe) are present in synclinal structures. Detailed gravity over selected areas in the southern part of the Frances Creek iron ore field could be used to detect 1 to 5 Mt lenses in gently plunging synclinal structures under shallow cover. Many of the 700 ironstones at *Tennant Creek* are aboriginal sacred sites. However, mine tailings containing 70% magnetite at Warrego (10 Mt), Peko (4 Mt) and Nobles Nob (2 Mt) represent potential sources of low cost iron ore.

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NORTHERN TERRITORY GEOLOGICAL SURVEY

AGES SEMINAR - 20 March 2001

Alice Springs

Native Title and the Grant of Mining & Petroleum Tenure

by

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Northern Territory Department of Mines & Energy

Substantial portions of this paper were also presented to the Northern Territory Minerals Council 'What's it all About' Seminar (23/2/01) and also a meeting between the ANZMEC Land Access (Native Title) Task Force and the Minerals Council of Australia's Land Access Committee (6/2/01).

Introduction

The Northern Territory is subject to two Commonwealth Acts which provide land access right and benefits to Aboriginal people and constrain access to and impose conditional use of land for mining and petroleum exploration and development.

The *Aboriginal Land Rights (Northern Territory) Act 1976* (ALRA) and the *Native Title Act 1993* (NTA).

There are fundamental differences between the two Acts.

The ALRA provides the capacity for Aboriginals who are able to prove traditional attachment to vacant crown land (and leasehold land owned by Aboriginals) to claim grant of the land as inalienable Aboriginal freehold.

The NTA recognises prior Aboriginal ownership of all land, provides for certain extinguishment and sets up a process for Aboriginals who claim title to the land to confirm that claim.

While the grant of land to Aboriginals under ALRA does not extinguish native title the NTA provides that the ALRA regimes operate on land granted as Aboriginal freehold subject to ALRA.

Currently	43.0%	of Territory land is granted as Aboriginal freehold
a further	<u>10.7%</u>	is subject to Aboriginal land claim
making a total	<u>53.7%</u>	of the area of the Territory

Of the remaining 46.3%, less than 2% would be ordinary freehold land on which native title was extinguished leaving approximately 45% of the area of the Northern Territory as subject to native title.

Native Title

Native title arose out of two High Court hearings Mabo (No. 1) and (No. 2).

Mabo (No. 1) was an appeal to the High Court against a Queensland Act, the *Queensland Coast Islands Declaratory Act 1985*, which sought to extinguish any native title claim to ownership of land on the Murray Islands in the Torres Strait with effect from 1879 when the islands were annexed to Queensland, and to deny payment of compensation for such extinguishment.

The *Racial Discrimination Act 1975* of 31 October 1975 makes it unlawful to do an act:

- to impair a right or freedom of a person based on race, or
- to have discriminating laws.

The Commonwealth Constitution says that acquisition of property can only be made upon payment of just terms of compensation.

The *Racial Discrimination Act* rendered the annexation of the Murray Islands null and the Queensland Act invalid.

In Mabo (No. 2) the High Court determined that Eddy Mabo held and had always held title to land on the Island of Mer in the Murray Islands. It rendered the previously held principle that Australia was a land owned by nobody (*terra nullius*) invalid.

The High Court decision left many questions unanswered and the Commonwealth “resolved” the issues by creating the *Native Title Act 1993* which was passed on, 23 December 1993 and came into effect as of 1 January 1994.

The Native Title Act

The *Native Title Act* was passed on 23 December 1993 and came into operation from 1 January 1994. It recognised that native title may exist in Australia where the necessary traditional connection to the land has been maintained and where it has not been extinguished by the action of Government or by the grant of certain types of exclusive tenure.

On 23 December 1996 the High Court in the Wik decision determined that native title could exist over pastoral leases.

Amendments to the *Native Title Act* were passed by the Federal Parliament on 8 July 1998 and commenced on 1 October 1998. These amendments provided powers for the States and Territories to pass (or amend preexisting) legislation validating all interests granted between 1 January 1994 and 23 December 1996 and to pass other legislation setting up alternative State/Territory procedures for the grant of mining tenure.

The Northern Territory passed appropriate validating legislation in August 1998 and amended its *Mining Act* and *Petroleum Act* to provide alternative procedures (to the right to negotiate) in accordance with the *Native Title Act* to grant mining interests on land subject to native title in the Territory.

The Northern Territory Government’s amended procedures were endorsed by determination of the Commonwealth Attorney General on 27 April 1999. The Attorney General’s determination was disallowed in the Senate on 31 August 1999 despite extensive consultation with minority Senators and with the Land Councils.

The three reasons given for disallowance were:

- security of legislation
- the problem of dealing with the accumulated backlog of title applications
- further desired legislative amendments

Decision to use the *Native Title Act* right to negotiate procedures

Approaches by the Territory to the Federal Government to seek repeal of the disallowance appeared to have no imminent chance of success and on 21 March 2000 the Territory Government determined to commence processing mining and petroleum title applications using the right to negotiate procedures of the *Native Title Act*. There were then about 1000 outstanding applications under the *Mining Act* and 12 outstanding Petroleum Permit Applications under the *Petroleum Act*.

In preparation for commencing use of the *Native Title Act* procedures for the grant of title, the Territory has introduced a number of minor amendments to its Mining and Petroleum Acts to simplify the transitional provisions in the Acts and provide a clearer pathway for dealing with the backlog of titles.

In preparation for processing title applications the Department wrote to applicants to seek their agreement to proceed with the right to negotiate grant procedure and to determine their priority and whether they wished the Government to seek to use the expedited process for the grant of ELs. Applicants who did not respond to the initial and follow up letters have had their applications refused.

It was intended that advertising of the backlog of title applications would be completed within 12 months, however the high number of applicants who wished to proceed using the *Native Title Act* means that the process will take longer than anticipated.

The first right to negotiate (Section 29) advertisements were placed on 6 September 2000 for the grant of exploration licences using the expedited process. It is planned that advertisements will be placed each fortnight to coincide with publication of the Koori Mail which is the only national “Aboriginal” newspaper, and that about 20 titles will be included in each advertisement.

In addition, over the months since the decision to proceed to grant using the right to negotiate process 200 titles have been advertised and 150 new title applications have been lodged. The consequence of this is that at the current rate of tenure release, the outstanding tenure numbers are in fact reducing very slowly.

Reaction of the Representative Bodies

The two major Territory Land Councils (who have been appointed Representative Bodies for the *Native Title Act*) have stated that they believed that they had a requirement (or duty of care) to seek the advice of the “native title holders” for every title. This effectively meant that we could expect a native title claim over, or to get an objection to the grant, of every title. This

would drive the grant procedure down the time consuming negotiation route and into the hands of the National Native Title Tribunal.

The Northern Land Council has discussed the matter with the Department of Mines and Energy and the Minister's office advising that they did not have the resources to deal with these procedures. They were advised that any potential arrangements discussed during talks leading up to the rejection in the Senate of the alternative procedure were not now available (including funding offers) and that they should seek resource assistance from the Commonwealth as the *Native Title Act* was a Commonwealth Act.

Options available to Representative Bodies (Land Councils) include:

- not making application for native title or objecting to the grant of exploration licences;
- entering into agreements with the title applicants so that subject to the agreement no native title claim or objection would be lodged;
- entering into an Indigenous Land Use Agreement (ILUA) with applicants; and
- submitting a native title claim over the title applications and then objecting to the use of the expedited process to grant exploration licences or negotiating about mining tenements and potentially driving the title to the National Native Title Tribunal for mediation and determination.

Land Councils reaction to S29 notices

Following the commencement of the Section 29 advertising, and as the first 3 month period for the lodgement of native title claims was about to expire, the NLC and CLC:

- wrote, complaining about the format of the advertisements;
- sought reasons, pursuant to the *Administrative Decisions (Judicial Review) Act*, as to why the Northern Territory Government was advertising title applications, and why the assertion of expedited processing of exploration licences was made;
- submitted a complaint to the Human Rights and Equal Opportunities Commission that the Northern Territory Government was in breach of the *Racial Discrimination Act*, because the Government was proceeding at an unprecedented rate and the Land Councils were unable to handle the workload; and
- brought an injunction against the NT Minister for Resource Development and the NT Government on 28 November 2000 seeking:
 - to restrain the Territory from granting any exploration or mining interests;
 - to restrain the Territory from continuing to process outstanding applications until a complaint lodged with the Human Rights and Equal Opportunities Commission was determined;
 - an order suspending the notice decisions and expedited procedure decisions until their injunction was determined; and
 - an order seeking reasons for the Territory proceeding along the expedited procedure route.

A Directions Hearing was held in Sydney on Wednesday 5 December 2000 and the matter was transferred to the Northern Territory Registry of the Federal Court.

The interlocutory (interim) injunction hearing was held on Thursday 6 and Friday 7 December before Justice Olney who determined on Friday 15 December 2000 that the interlocutory injunctions be dismissed.

He did note however, that there was a serious question to be tried in relation to the form and content of the section 29 notices. This referred to the issue of including diagrammatic maps in the advertisement lodged in the Koori Mail newspaper pursuant to the Section 29 of the *Native Title Act*.

As recently as 22 February 2001 the NLC sought to amend their Federal Court Applications by seeking an order that:

- the Koori Mail is not a special interest publication; and
- the NT government did not advertise the applications on TV and radio.

The matter is listed for trial on 24, 26 and 27 April 2001.

In the meantime the NNTT has held its first Directions Hearing in the Territory.

At this hearing procedures for the Tribunal to hear objections to expedited procedure claims for EL's were determined.

In addition the NLC with the support of the CLC sought to delay proceedings by claiming that the Tribunal could not hear such claims until a "jurisdictional" matter before the Federal Court was resolved. Tribunal Vice President Chris Sumner agreed to have the jurisdictional matter determined and set a timetable for submissions and a hearing was held in the week commencing 26 February 2001.

Despite this the Tribunal has continued to hold direction hearings on objections to the expedited process.

Press Release announcing the commencement to use the RTN to grant mining tenure

**EXPLORATION APPLICATIONS TO BE PROCESSED
UNDER NATIVE TITLE ACT**

The Minister for Resource Development Daryl Manzie today advised that more than 1000 exploration and mining title applications would be processed using the Right to Negotiate provisions of the Commonwealth *Native Title Act*.

"This comes as a result of the intransigence of Labor and Democrat Senators, who have refused to endorse the Northern Territory's alternative procedures for granting mining and petroleum titles", Mr Manzie said.

"This Senate rejection came despite the rigorous review and endorsement of our alternative procedures by the Commonwealth's Wik Task Force and the Federal Attorney General's agreement that our procedures met all the requirements of the *Native Title Act*."

Mr Manzie said that this action by the Commonwealth Parliament meant that the Territory's mining industry was now forced to deal with the Aboriginal Land Councils in respect of about 98% of the Northern Territory's total land area.

"There are already about 715 exploration licence applications outstanding on Aboriginal Freehold Land under the Aboriginal Land Rights (Northern Territory) Act, which affects about 50% of the Territory", Mr Manzie said.

"The addition of a further 1000 exploration and mining applications which are on pastoral leases (and therefore subject to the Commonwealth *Native Title Act*) will further stretch the resources of the Land Councils.

"The Territory Government believes that its proposed alternative provisions were fair and equitable to all parties and would have provided a far better administrative process.

"However, the Government is prepared to work closely and in good faith with the Land Councils to facilitate the grant of these titles under the Commonwealth scheme."

21 March 2001

Funding for Native Title			
Financial Year	Annual Total ATSIC \$000	NLC \$000	CLC \$000
1999/2000	48,366	2,283	1,702
1998/99	48,477	1,757	1,765
1997/98	44,277	2,311	1,701
1996/97	42,185	1,492	1,521
1995/96	26,690	450	1,103
1994/95	14,100	915	20
Total	224,095	9,208	7,812
Total for NT Land Councils \$17,020 Million			

Indigenous Land Use Agreements

Definition of an ILUA

" An agreement in writing under which persons agree that one or more future acts in a particular area may be done subject to conditions to be complied with by one or more of the persons. Such agreements may cover any other matter which the parties choose to include but registration of the agreement will provide validity under the Act for future acts authorised under the agreement."

Mining companies in the Territory have to date entered into two ILUA's.

They include Otter over Supplejack Pastoral Lease (registered) and Giants Reef at Tennant Creek (subject to registration).

The first two EL's granted on non Aboriginal land in the Territory since December 1996 were granted in the Supplejack area on 23 January 2001.

Relevant tables

Northern Territory Exploration Mining Tenure			
Period End	Number of granted ELs	Period	Expenditure \$ million
December 1995	769	1994/95	75.8
December 1996	719	1995/96	93.8
December 1997	536	1996/97	88.9
December 1998	351	1997/98	75.9
December 1999	298	1998/99	64.5
December 2000	286	1999/00	57.5

Priority Nominated by applicants for proceeding through the Right to Negotiate process	
No of Title Applications	Priority Requested
205	High
111	Medium
277	Low
593	Sub Total
140	New Applications (priority not nominated)
733	Total

No of Applications Nominated for Expedited/Normal Procedure	
No of Title Applications	Nomination
311	ELs nominated the expedited procedure
282	Right to Negotiate procedure [this includes 47 EL's]
593	Total

REE AND CARBONATITES IN THE EASTERN ARUNTA INLIER.

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Despite their name, the rare earth elements (REE) are relatively abundant in the Earth's crust. Gold for example is less abundant. REE often substitute as impurities in many common rock forming minerals and whilst there are a large number of REE minerals only a limited number of them contain significant quantities of REE. In addition, the number of economically mineable concentrations of REE minerals is indeed relatively rare. The high cost of isolating and purifying REE also precludes the exploitation of high volumes of these materials. While REE substitutes are available for some applications, they are in general less effective and hence REE are incorporated in many manufacturing and production processes, being essential components in the catalytic, ceramic, glass, metallurgical, and electronic industries. Recent developments in permanent magnets, autocatalysts, high temperature superconductors, rechargeable batteries and (most recently) alloys are expected to provide continued growth in the demand for REE.

World production of REE has remained relatively stable at about 80 000 t of rare earth oxide (REO) per annum over the last few years, 70 000 t of which on average comes from the giant Bayan Obo deposit in Inner Mongolia, and is only a fraction of the known 110 Mt REO world reserve base (Hedrick 2001). Undiscovered REE resources are still thought to be present but finding markets for these may be difficult given the current status of the industry and its reserves. It appears that environmental concerns in relation to the impact of monazite sand mining may lead to the opening up of new markets.

REE are principally derived from by-products of beach sand mining (monazite) and from primary and secondary deposits associated with carbonatites and associated alkaline-ultramafic igneous rocks and hydrothermal deposits. World REE resources are primarily won from bastnaesite and monazite.

Apart from monazite sands, Australia has significant carbonatite related REE resources such as the Mount Weld (~15.4 Mt @ 11.2wt% REO; Duncan and Willett 1990) and Cummins Range (3 to 4 Mt @ grades of ~2-4 wt% REO; Andrew 1990) prospects in Western Australia. REE are also present in alkaline volcanics in the Brockman rare metal deposit (measured resource of 4.29 Mt @ 0.09 wt% REO; Chalmers 1990) again in Western Australia, and were also associated with the now mostly exhausted Mary Kathleen U-REE remobilised skarn deposit (~200 000 t REO with a grade of 0.02 wt% REO; Solomon and Groves 1994) in Queensland. REE also form a significant component of the Proterozoic iron oxide (Cu-Au-U-REE) deposits (Hitzman *et al* 1992) with grades commonly up to 1 wt% REO. Smith and Chengyu (2000) suggest that there are genetic similarities between these iron oxide Cu-Au-U-REE deposits and the giant Bayan Obo Fe-REE-Nb hydrothermal deposit which contains 100 Mt @ 6% REO (Drew *et al* 1990).

The discovery of significant REE mineralisation at Nolans Bore in the central Arunta Province, Northern Territory by PNC (Thevissen 1995), has renewed interest in Arunta Inlier as a possible

REE field. REE in the Nolans Bore prospect is mainly contained in poorly outcropping fluorapatite veins or dikes with surface samples averaging about 7 wt% total REE (J Goulevitch, pers comm). Arafura Resources, the current holders of the Nolans Bore prospect, have suggested a potential resource of ~3.5 Mt @ >4% REE within 50 m of the surface. The occurrence is located within variably deformed and altered granitic gneiss and pegmatite, and minor calcsilicate rocks (?alteration). Nolans Bore REE may have a close spatial relationship to major structures in this region and appears to be either a hydrothermal or carbonatite related deposit.

Other styles of REE mineralisation occur in the Arunta Province. For example, a 2 by 2 km area of predominantly pegmatite containing ~4% allanite known as Blueys Folly prospect occurs near Arltunga (Edser 1991). These allanite concentrations indicate grades of 1% REO and although the actual size is unknown, about 1 Mt has been estimated (O'Driscoll 1988). Although uneconomic, this prospect is intriguing and the presence of nearby calcsilicate rock units suggests there may be some potential for skarn or hydrothermal deposits in this vicinity. The age of these pegmatites are unknown but they are probably related to allanite bearing pegmatites further north in the Harts Range region (Drake-Brockman 1996). Pegmatites in Harts Range have ages which suggest they are related to the Alice Springs Orogeny (Drake-Brockman *et al* 1996; Hand *et al* 1999). Relationships such as monazite growth in shear zones (Scrimgeour and Raith in press) and numerous REE enriched pegmatites in this region suggest there could be a major REE rich fluid-flushing event in the Arunta at this time. If this is the case then the calcsilicate rocks of Harts Range Group and the adjacent units may host significant REE mineralisation. The presence of bastnaesite in Harts Range stream sediment further supports the potential of this region. It is possible that the pegmatites at Blueys Folly may be older than those in the Harts Range. If this is the case then there may be two different REE mineralising events in this region. The older event could be related to the 1150 Ma Teapot thermal event, or more likely, the allanite bearing Gum Tree Granite which appears to be much older.

Allanite bearing granite and pegmatite also occur elsewhere in the Arunta. The Quartz Hill apatite occurrence in northwestern NAPPERBY appears to be related to the igneous fluids derived from the REE rich Wangala Granite, although relationships have not been fully investigated. According to Davies (1979) and Stewart *et al* (1980), uraniferous REE rich apatite-mica schist occurs in an east-northeast trending belt over an area of about 2 km² within the Wangala Granite. Because of their unusual composition and whole rock chemistry Davies (1979) and Stewart *et al* (1980) interpreted these as metasomatised sedimentary rocks. These schists comprise up to 55% biotite, up to 25% apatite (probably fluorapatite), up to 25% muscovite and up to 55% quartz. The enclosing Wangala Granite is a composite pluton with numerous phases of variably fractionated, crustally contaminated LREE enriched granodiorite-granite. Some of these phases contain allanite suggesting the Wangala Granite is metaluminous rather than peraluminous as report by Stewart *et al* (1980). Young *et al* (1995) suspected that the Wangala Granite (mapped as the Yaloolgarrie Granite by them in MOUNT DOREEN) was older than the 1565 Ma Southwark Granitic suite on structural grounds. As suggested by Stewart *et al* (1980), the Wangala Granite appears analogous to the 1622 Ma (Smith 2000) allanite bearing Ennugan Mountain Granite with also seems to have similar REE mineralisation potential.

REE mineralisation has not been found in the vicinity of Mud Tank carbonatite complex. This is surprising given that carbonatites and alkaline igneous rocks typically have high LREE contents

and that secondary enrichment is commonly associated with weathered carbonatites. Carbonatite and alkaline igneous complexes typically tend to occur in clusters along or near major structures implying there may be additional complexes in the Arunta Province. Some magnetic features located near major structures in the northern Arunta Province may be carbonatites or mafic alkaline igneous rocks. If this is indeed the case, then they are considered to be likely candidates for lateritic REE enrichment.

In summary the Arunta appears to have further untested REE potential.

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SOME ASPECTS OF REGIONAL CORRELATION AND MINERALISATION

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Northern Territory has been divided into two principal tectonic domains, the North Australian Craton (NAC) and the Central Australian Mobile Belts (CAMB). The tectonic and metamorphic history of the NAC was dominated by one major episode, the Barramundi Orogeny at 1865-1850 Ma.

The CAMB represents polydeformed linear belts of medium - to high-grade metamorphic terranes that underwent repeated deformation from ~1880 Ma to Carboniferous. Seven distinct tectonic events are identified in the Arunta Province: Yuendumu (1880 Ma), Strangways (1780-1760 Ma), Aileron (1670 Ma), Chewings (1600 Ma), Anmatjira (1450 Ma), Ormiston (1140 Ma) and Alice Springs (400-300 Ma). Two major tectonic events have been recognised in the Musgrave Block to the south: Musgravian Event (1200 Ma) and Petermann Orogeny (580-520 Ma).

Within the NAC, Palaeoproterozoic orogenic strata older than about 1800 Ma crop out as inliers surrounded by younger basins. These deformed and metamorphosed rocks comprise the Pine Creek Orogen, Tennant Inlier, Tanami Region, Murphy and Arnhem inliers. They overlie late Archaean granites and older metasediments. These are present in the Pine Creek Orogen and Tanami Region. Mildly deformed and unmetamorphosed Palaeo- to Neoproterozoic (1800-570 Ma) sedimentary basins unconformably overlie the orogenic strata and include the McArthur, Victoria, South Nicholson, and Birrindudu basins as well as the Davenport and Ashburton provinces. These together constitute the North Australian Platform Cover (NAPC).

In the Amadeus, Ngalia, Georgina, Wiso, Daly and Ord basins sedimentation ceased by the Early Carboniferous. In the Pedirka, Arafura and Bonaparte basins sedimentation continued well into the Triassic. During the Jurassic to Cainozoic period, sediments of the Eromanga, Browse, Bonaparte, Money Shoal and Carpentaria basins were deposited.

It is possible to recognise, correlate and divide the Proterozoic into 10 well recognised unconformity-bound regional packages (*E1* to *E10*).

ARCHAEAN (Ar)

Archaean granite, gneiss and metasediments outcrop as small inliers at Rum Jungle (Rum Jungle and Waterhouse Complexes ~2500 Ma), Jabiru (Nanambu Complex ~2500 Ma), The Granites (Billabong Complex and Browns Range Dome ~2500 Ma) and are also intersected in drill holes at Woolner (Woolner Granite ~2700 Ma). They form the basement to the Palaeoproterozoic strata. Granites and gneisses are enriched in uranium and are a possible source for uranium deposits in the Pine Creek Orogen.

PROTEROZOIC

E1 (2500? -1885 Ma)

This represents the earliest known Proterozoic strata unconformably overlying the Archaean basement and includes the Namoon and Kakadu Groups in the Pine Creek Orogen. Arenite and carbonate sequences (Beeston Formation and Celia Dolomite) in the vicinity of the Archaean shoreline grade basinward into argillaceous lithologies (Mason Formation). This sequence hosts the giant uranium deposits in the Alligator Rivers Region, minor Pb-Zn deposits in the center of the Pine Creek Orogen and the Celia magnesite deposit in the Rum Jungle area.

E2 (2500?-1885 Ma)

P2 includes the Mount Partridge Group in the Pine Creek Orogen and possibly the Macfarlane Peak Group in the Tanami Region. Predominant lithologies are arenite, shale, dolostone, magnesite, and mafic volcanics in the Mount Partridge Group and amphibolite schist and calc-silicate rocks in the Macfarlane Peak Group. This sequence hosts a variety of uranium and base metal deposits in the Rum Jungle Region as well as iron ore deposits in the Central Region of the Pine Creek Orogen. In the Tanami Region the Ground Rush gold deposit is within this sequence.

E3 (~1885 Ma)

This sequence outcrops in the Pine Creek Orogen (South Alligator Group) and Tanami Region (Dead Bullock Soak Formation). Carbonaceous shale, BIF, mudstone and chert are the main lithologies and felsic tuff beds are present in the Pine Creek Orogen. This sequence hosts major gold deposits including Cosmo Howley and Callie. The uranium and gold-platinum-palladium deposits in the South Alligator Valley (Coronation Hill) are also within the E3 sequence.

E4 (1885-1850 Ma)

This is the most widespread pre-Barramundi sequence and is represented by greywacke-siltstone-shale sequences marking the flysch cycle towards the end of geosynclinal deposition. In the Pine Creek Orogen it hosts vein-type Au, Sn and base metal deposits as well as Sn-Ta bearing pegmatites. The ironstone hosted Au±Cu±Bi deposits in Tennant Inlier and many gold deposits of the Tanami Region are also within this sequence. The Lander Rock beds in the Arunta Province are correlatives and are the oldest known rocks in the CAMB. Small Cu and gold veins in the Arunta Province occur within this sequence.

E5 (1850-1800 Ma)

This interval is represented by late to post orogenic granites, and felsic volcanics and arenites in the NAC. The Strangways Metamorphics in the CAMB are correlated with this sequence and include felsic and mafic granulites, felsic metavolcanics, orthoquartzite and calc-silicates. The granites which are mostly I-type in composition were mainly emplaced at 1845, 1825 and 1800 Ma. The 1825 Ma event (Cullen Event and

equivalents) is considered to be responsible for the genesis of most of the mineral deposits in the Pine Creek Orogen, Tennant Inlier and Tanami Region.

P6 (1800-1700 Ma)

This sequence is the basal unit of the NAPC and comprises fluvial to shallow marine arenite, mafic and felsic volcanics as well as carbonate lithologies. It hosts the Westmoreland uranium deposits, Redbank copper deposits and Mn occurrences in the Bootu Creek area. The Alligator River Region uranium deposits as well as the South Alligator Valley U±Au±Pt-Pd deposits are spatially associated with Kombolgie Formation. In the CAMB this sequence is correlated with Reynolds Range and Harts Range groups. The latter is now considered to be Paleozoic age and contains a number of mica pegmatites. These groups comprise gneiss, amphibolite, calc-silicate and quartzite. Felsic igneous activity related to the Strangways Orogeny is widespread in the CAMB.

P7 (1700-1600 Ma)

In the NAC, the P7 is represented by the McArthur, Limbunya, Namerini and Fickling groups comprising mostly carbonate lithologies. The McArthur Group hosts the giant HYC deposit and a number of other smaller base metal occurrences in the McArthur Basin. It is a time equivalent of the Mount Isa Group which also hosts a number of world class base metal deposits. In the CAMB, the Maddern Yard and Iwupataka metamorphic complexes comprising felsic and pelitic gneiss, schist, orthoquartzite, amphibolite, migmatite and calc-silicate represent the P7 sequence. Minor Zn and Cu mineralisation is recorded from this area.

P8 (1600-1400 Ma)

The P8 sequence is dominated by shallow marine carbonates and is present in the McArthur and Victoria basins. It hosts the Bulman Pb-Zn prospect and minor Pb occurrences in the Victoria Basin.

P9 (1400-1000 Ma)

The P9 sequence is represented by marine arenites in the NAPC which hosts sedimentary oolitic iron ore deposits. In the CAMB it constitutes felsic and mafic gneiss, schist and quartzite. Granite, basalt and mafic intrusives are also present. No major mineral occurrences are recorded from this sequence but the mafic intrusives may hold potential for nickel.

P10 (1000-545 Ma)

This sequence represents the Centralian Superbasin and comprises arenite, carbonates and glaciogenic sediments. The White Range gold deposit is hosted by the basal arenite (Heavitree Quartzite) and was partly detached from the basement during the Alice Springs Orogeny. The Bukalara Sandstone covering a large part of McArthur Basin and the Duerdin Group in the Victoria Basin are included in P10.

PALAEOZOIC

The Amadeus, Ngalia, Wisio and Georgina basins all have very similar stratigraphic and structural features and were formed during P10. Outpouring of flood basalt occurred

during the early Cambrian and these flows cover a large part of the NAC. Marine carbonate and clastic deposition continued into Cambrian and Ordovician. Significant phosphate accumulations occurred during the Middle Cambrian in the Georgina Basin. Younger Silurian to Early Carboniferous sequences are restricted in aerial extent. Economically important accumulations of oil and gas occur in Ordovician and Late Proterozoic reservoirs in the Amadeus Basin, including the commercial Mereenie oil and gas field and the Palm Valley gas field. The Ord and Daly Basins are shallow early Palaeozoic basins containing marine carbonate and clastic sequences. In the Pedirka Basin a Permian to Triassic sequence consisting of terrestrial and in part glaciogenic sandstone and shale with minor coal overlies the early Palaeozoic Amadeus Basin sequence. Oil shows have been recorded in the basin.

The Arafura and Bonaparte Basins are located mostly offshore and have similar structural and stratigraphic features. In the Bonaparte Basin economically important accumulations of oil and gas occur in Permo-Carboniferous reservoirs and oil shows have been found in the Arafura Basin.

The Bonaparte Basin hosts the Sandy Creek (Legune) Zn-Pb deposit which is a Mississippi Valley style deposit. Pb-Zn occurrences are also noted in the southern Georgina Basin highlighting the untested base metal potential of the Palaeozoic basins.

MESOZOIC

The onshore Eromanga Basin consists of thin fluvial sandstone and associated flood plain and lacustrine sandstone, shale and siltstone overlain in the southeastern corner of the Northern Territory by marginal marine and thick open marine siltstone. Oil shows have been recorded in the basin. The mostly offshore Browse, Bonaparte, Money Shoal and Carpentaria Basins contain dominantly marine shales and carbonates with minor sandstone sequences. Economically important accumulations of oil and gas occur in Jurassic reservoirs in the Browse and Bonaparte Basins, including the commercial Jabiru and Challis oil fields. Petroleum indications have been found in the Money Shoal Basin and outside the Northern Territory in the Carpentaria Basin.

Mesozoic strata of the Carpentaria Basin host the Groote Eylandt manganese deposit and weathering of the Cretaceous strata along the northern coastline has resulted in the formation of the Gove bauxite deposit. Several, relatively untested manganese and bauxite occurrences are known from the Mesozoic strata.

CAINOZOIC

The Cainozoic is largely represented by unconsolidated sand, silt, clay and laterite covering most of the NT. Except for the minor heavy mineral sand accumulation on Cobourg Peninsula and alluvial gold deposits no major mineral occurrences are known from the Cainozoic.

RUM JUNGLE REGION AND THE PINE CREEK OROGEN: SYNTHESIS AND EVALUATION OF EXISTING DATA

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The Rum Jungle Mineral Field is located 100 km south of Darwin in an area of greenschist facies Palaeoproterozoic sediments unconformably overlying late Archaean (~2500 Ma) granite and gneiss. It contains a wide spectrum of mineral commodities including U, Cu, Co, Ni, Pb, Zn, Au, magnesite and phosphate. These mineral occurrences have not been the subject of modern comprehensive geoscientific investigations. The existing geological map was compiled in 1981 and since then considerable amount of new mapping, drilling, geochemical and exploration data have been collected. With the above consideration the NTGS, in conjunction with the University of Leoben, Austria initiated the Rum Jungle Project aiming to synthesise available information, evaluate stratigraphic and structural settings and carry out detail metallogenic studies.

Work on the Rum Jungle project commenced in mid 2000 and during the first phase diamond drill collars, water bores, prospect scale exploration maps and 1:100k government maps were captured in MapInfo. New airborne magnetic and radiometric surveys were completed in the previous year and airborne multispectral data for a large part of the Rum Jungle area was acquired in late 2000. Preliminary sampling has been carried out at Browns, Woodcutters and Rum Jungle deposits and mineralogical and geochemical studies on these samples are in progress.

Previous workers have divided the Pine Creek Orogen into seven structural/palaeogeographic entities viz: Chilling Platform, Western Fault Zone, Batchelor Shelf, South Alligator Trough, South Alligator Hinge Zone, Nanambu High and Kakadu Shelf. These have no expression either in the regional scale gravity or the airborne magnetics data. The gravity data shows two depocentres, a northwest trending depression between South Alligator and Darwin and a narrow belt west of Jabiru. The basement (granite and gneiss) in these centers is up to 4 km deep. Elsewhere it is less than 2 km and is exposed at Rum Jungle, Nanambu and is about 60 m deep at Woolner. In this paper the Pine Creek Orogen is divided into four depositional domains, Batchelor Shelf, Central Trough, Nanambu Shelf and the Eastern Trough. The Pb-Zn-Cu-Ni-Co±U rich Rum Jungle Region represents island highs on the Batchelor Shelf and a similar situation is apparent at the Alligator River uranium province bordering the Nanambu Shelf.

This study proposes to subdivide the strata at Rum Jungle and adjoining area into three supergroups:

1. *Manton Supergroup* representing Archaean metasediments including BIF, schist and gneiss which in the Rum Jungle area are intruded by predominantly S-type granite

dated at ~2500 Ma. This sequence is poorly exposed and little is known about its characteristics. It is correlated with the Dirtywater Metamorphics intersected in drill holes in the Woolner area where it unconformably overlies the Woolner Granite dated at 2675 Ma. The age of the supergroup is therefore constrained at 2675-2500 Ma. Although restricted in outcrop, this group may be present over a larger area and constitutes the basement to the Pine Creek Orogen.

2. *Woodcutters Supergroup* representing the Namoonna and Mount Partridge Groups on the Batchelor Shelf, Masson Formation in the Central Trough and possibly the Kakadu Group and Cahill Formation on the Nanambu Shelf. This supergroup unconformably overlies the Manton Supergroup and comprises current bedded and ripple marked fluvial arenite, intertidal stromatolitic carbonate and argillite including carbonaceous and pyritic shale. This sequence is apparently confined to the Central and Eastern troughs and their margins. There are no definitive age constraints on this supergroup which is younger than 2500 Ma and older than 1885 Ma.
3. *Cosmo Supergroup* represented by the South Alligator and Finniss River groups on the Batchelor Shelf and Central Trough and possibly the Nourlangie Schist and Myra Falls Metamorphics on the Kakadu Shelf. This sequence is more widespread than the underlying Woodcutters Supergroup. It unconformably overlies Woodcutters Supergroup and comprises BIF, mudstone, tuff followed upward by monotonous flysh sequence. Tuffs in Mount Bonnie Formation provide a precise depositional age of 1885 Ma.

The Woodcutters and Cosmo Supergroups have distinct REE patterns. Whereas the former shows smooth curves indicating provenance from calc-alkaline andesite source, the latter shows prominent negative europium anomaly indicating a source region which has undergone plagioclase fractionation. This indicates that the nature of the source region changed markedly with time and may reflect either uplift in the source region or deeper erosion levels. Alternatively these two groups may have entirely different source regions.

Sulphur isotope values of sedimentary pyrite in the lower half of the Woodcutters Supergroup are set at 0 ± 5 per mil and indicate sulphate poor environments. Major shift towards heavier sulphur isotope values occur from Whites Formation upward indicating an increase in the sulphate levels in the hydrosphere which could be attributed to onset of global oxygenation of hydrosphere considered to have occurred at about 2000 Ma onward.

These two supergroups have contrasting mineralisation styles. The Woodcutters Supergroup contains predominantly stratabound deposits of U, Zn-Pb-Ag, Cu-Ni-Co-Pb, Fe and magnesite. The Howley Supergroup contains vein type mesothermal deposits of Au, Sn, Cu, Pb, Zn as well as small vein-type U deposits and Sn-Ta bearing pegmatites.

At least two major tectonic events can be identified: an event between 2700-2500 Ma resulted in deformation and metamorphism of the Manton Supergroup, and the Barramundi Orogeny at 1880-1850 Ma.

Major felsic intrusive activity was at ~2700 Ma (Woolner Granite) ~2500 Ma (Rum Jungle Granite, Waterhouse and Nanambu granites), ~1865 Ma (Nimbuwah Granite), ~1845 Ma (Litchfield granites) and ~1825 Ma (Cullen Batholith).

SHRIMP data on the Pine Creek sediments (Mundogie Sandstone, Masson Formation and sandstone unit within the Gimbat Ignimbrite Member) shows provenance ages between 2700 and 2100 Ma with peaks at 2500, 2300 and 2100Ma. The peak at 2500 Ma obviously indicates derivation from the Rum Jungle type late Archaean terrane. The younger provenance (2300-2100 Ma) suggests the existence of a younger basement that is hitherto not identified in the nearby terranes or alternatively this is the age of the Woodcutters Supergroup. The Hermit Creek/Well Tree/Fog Bay Metamorphics in the Litchfield Province may be possible candidates. The age of the Cosmo Supergroup is constrained at 1885 Ma through SHRIMP and conventional zircon dating of tuffaceous units. Rb/Sr ages are about 50 Ma years younger than the corresponding conventional zircon or SHRIMP ages and are suggestive of a younger thermal event (Shoobridge Event) resulting in resetting. This event coincides with the early Strangways Orogeny in the Arunta Province.

Regional metamorphism and deformation are attributed to the craton-scale Barramundi Orogeny. Metamorphic grade ranges from lower greenschist facies in the center to amphibolite/granulite facies to the west and east. There has been some discussion if these metamorphic differences actually represent age differences and if the high-grade metamorphic terranes represent older basement. Four deformation events have been recognised by previous workers. D1 is represented by a local north trending cleavage in the South Alligator Valley. D2 is represented by bedding parallel thrusts which are generally west verging. D3 is represented by simple open to tight, doubly plunging northeast to north-northeast trending upright folds with a well defined axial plane cleavage. D3 folds are refolded by east trending D4 folds.

The geology of Rum Jungle area is dominated by two interconnected Archaean granite domes intruding the Manton Supergroup metamorphic rocks. Doming of Archaean granites is attributed to (1) intrusion of younger granite, (2) diapir (3) fold interference and (4) buckling around original paleohighs. The latter mechanism seems more appropriate.

Sediments of the Woodcutters Supergroup unconformably overlie the Archaean and host almost all major deposits of the Rum Jungle Mineral Field. These deposits have strong stratigraphic control and are hosted within Whites Formation just above its contact with underlying Coomalie Dolomite. The deposits include the following metal associations:

- a) Uranium,
- b) Uranium-copper,
- c) Copper-nickel-cobalt-lead-zinc
- d) Lead-zinc-silver
- e) Magnesite

The interrelationship of these deposits is being investigated. Preliminary microscopic work has revealed a wide spectrum of minerals including pitchblende, base metal sulphides and a number of unusual Co and Ni minerals which distinguish "Rum Jungle" style mineralization from other Pb-Zn-Ag deposits and the uranium deposits of the Alligator Rivers Region. These unusual minerals include bournonite (CuPbSbS_3), cobaltite (CoAsS), gersdorffite (NiAsS), linneite (Co_3S_4), siegenite (NiCo_3S_4), polydymite (Ni_3S_4), niccolite (NiAs), tennantite (Cu_3AsS_4), and wittichenite (Cu_3BiS_3).

In summary in the Rum Jungle Region late Archaean granites intrude metamorphosed metasediments which are unconformably overlain by Paleoproterozoic sediments. These are divided into a lower sequence of arenite, carbonate and argillite (Woodcutters Supergroup) which are unconformably overlain by argillite, BIF and flysch sediments (Howley Supergroup). This was followed by widespread metamorphism and deformation during the Barramundi Orogeny and intrusion of syn to post orogenic granites. The Woodcutters Supergroup hosts all the major uranium and base metal deposits whereas the Howley Supergroup contains significant deposits of Au, Sn-Ta as well as small U (\pm Pt, Pd).

EXPLORATION IN A MIDDLE CAMBRIAN CARBONATE SUCCESSION, GEORGINA BASIN, AUSTRALIA

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Introduction

This paper addresses salient aspects of the geology and hydrocarbon potential of the southern Georgina Basin, an area exceeding 100 000 sq km. This basin includes a Middle Cambrian petroleum system which to date has attracted little exploration largely due to a dearth of modern seismic. The area includes only 750 km of modern seismic. In addition only 18 exploration wells have been drilled, none of which tested a valid structural closure. The electric log data together with seismic, core, and newly acquired aeromagnetic data facilitated simplification of the existing stratigraphy and allowed the construction of regional isopachs based on lithostratigraphic units, correlateable over hundreds of kilometres, which in turn enabled an improved reconstruction of basin history and tectonic controls.

Structure and Tectonic Elements

The Georgina Basin is the largest of the Neoproterozoic- Palaeozoic basins on the North Australian Craton. The main depocentre is the Toko Syncline where up to 4 km of Palaeozoic sediments are preserved and up to 1500 m of section occurs in the Dulcie Syncline. Over the central and northern shelf areas the succession progressively thins to less than 100 m. Much thicker Neoproterozoic sequences occur in underlying deep half grabens recognised on seismic. The basin has been deformed by moderate folding and faulting with overthrusting along the southern basin margin. This deformation, together with some normal faulting within the basin, took place during the Alice Springs Orogeny (Middle Devonian – Early Carboniferous). Additional earlier structural episodes are noted in Figure 3.

Two asymmetric synclines, the Dulcie and Toko Synclines, are controlled by northwest trending convergent fault systems. Major thickening of the Middle Cambrian section occurred in the Toko Syncline via growth on the Toomba Fault. The bounding Toomba Fault system (Figure 2) is a northwest trending, right lateral, transcurrent basement controlled fault system. Secondary conjugate faults and joints trend northeast and many faults are associated with wide 'joint zones', several kilometres across, which could provide fairways of improved permeability in the Middle Cambrian target reservoirs.

Stratigraphy and Basin History

The southern Georgina Basin comprises a succession of carbonate and clastic sedimentary rocks of Neoproterozoic to Devonian age. New studies using electric log, seismic and aeromagnetic data have helped elucidate basin architecture and depositional history. An interval of Neoproterozoic and Early Cambrian clastics and carbonates is unconformably overlain by platformal, dolomitic beds of the Middle

Cambrian Thornton Limestone. The latter has sheet like extent and is the main target petroleum reservoir reaching thicknesses of up to 100 m.

Rapid basin deepening generated anoxic, pyritic and carbonaceous shale of the basal Arthur Creek Formation over an area of some 80 000 sq km on a gently undulating unconformity surface. This unit grades upwards into more oxic carbonates of the upper Arthur Creek Formation which includes thin, permeable grainstone shoals. Deposition occurred on a gently dipping ramp. The Arthur Creek Formation as a whole reflects an initial rapid basinal transgression (the basal 'hot shale') succeeded by a gradual regression with superimposed upward shoaling and upward deepening cycles formed in response to higher order sea level oscillations on a low relief depositional surface. Sedimentation was influenced by structural growth in the Toko Syncline.

As accommodation space filled, the Arthur Creek Formation was succeeded by a thick Late Cambrian interval of mixed carbonate and siliciclastic sediments (Arrinhrunga Formation) deposited in an extensive and intermittently emergent epeiric sea. The basal unit of the Arrinhrunga Formation, the Hagen Member, has sheet like extent and in the southwestern portion of the basin comprises reservoir quality dolostone with subordinate grainstone at the base, overlain by massive to bedded anhydrite seal. The unconformably overlying latest Cambrian - Ordovician and Devonian succession which in part provides the loading event necessary for hydrocarbon generation, are thickest in the Dulcie and Toko Synclines but have been largely eroded over much of the southern Georgina Basin.

Hydrocarbon Prospectivity

The Middle Cambrian succession in the Georgina Basin contains potentially prolific marine source rocks with expulsion signified, in part, by the abundance of oil and gas shows. The most important potential source rocks occur in the lower Arthur Creek Formation, particularly the basal 'hot shale' facies. This facies ranges in thickness up to 60 m (Elkedra 3) and often grades upward into thinly bedded source rocks extending up to 100 m above the basal 'hot shale'. Total organic carbon (TOC) contents are commonly between 0.5% and 10% and rarely up to 16%. The organic material is microbial with high initial hydrogen content (Hydrogen Indices 600-800) and total yield (S1+S2) ranging up to 57 kg/tonne. The shale extends over about 80 000 sq km and a Russian research group estimates 40 billion tonnes of hydrocarbons have migrated from these rocks in the southern Georgina Basin.

Although data are extremely sparse good potential reservoir rocks are recorded at a number of stratigraphic levels including alluvial and fan delta sandstones of the Early Cambrian Mount Baldwin Formation and also the overlying Red Heart Dolostone. However the Middle Cambrian Thornton Limestone is the main target reservoir in the basin. Intergranular porosity is evident in dolomitised bioclast and ooid/intraclast grainstones but interconnected vugs and fracture networks are also important. Several drill stem tests are available, the best flow rate being 500 BWPD in Ross 1, but the reservoir was badly damaged in this case. The upper unit of the Arthur Creek Formation contains shoaling cycles capped by recrystallised grainstones. In MacIntyre 1 this interval shows a gross thickness of 15 m with permeability up to 1.2 darcies at the top. The Hagen Member of the Arrinhrunga Formation is also an important target

reservoir which has flowed 300 BWPd in Randall 1. This unit in Elkedra 6 and 7 includes very coarse, cross-bedded intraclast dolograins, locally with good visual porosity. Overlying anhydrite seals these reservoirs in the southwestern portion of the basin where a promising new play has developed.

In the southern Georgina Basin shales at the base of the Arthur Creek Formation grade from immature in the north to overmature near the southern margin of the basin. The maturation history of the basin is complicated by complex geothermal history and uncertainties related to the amount of erosion at major unconformities. However elevated maturities in the southern portion of the area are probably related to high temperature granites in the basement (M Hand pers comm.). Maturation modelling in the Dulcie Syncline indicates peak oil generation post-dated structuring associated with the Alice Springs Orogeny (Middle Devonian - Early Carboniferous). However there is a northward gradation from the gas window (MacIntyre 1 area) to the oil window (Elkedra 7, Ross 1 and Owen 2) to marginally mature- immature source rocks in the Elkedra 2, Mulga 1 and Bradley 1 wells. In the Toko Syncline oil generation was initiated by Ordovician sediment loading (2,500 m+) and the Middle Cambrian source rocks are today in the dry gas window. There is a northward gradation, over a large area of oil mature sediments, to immaturity in the Bradley 1 and Mulga 1 area.

Play Types

Exploration within the southern Georgina Basin has suffered from a dearth of modern seismic data. As a result there have been no valid structural tests which normally precede exploration for stratigraphic plays. Only 750 km of seismic exists in this basin but numerous structural leads have been identified in the form of 20-40 ms rollovers often related to normal/ transtensional faults accompanied by adjacent zones of fracturing and jointing. To the southeast, structural traps associated with the Toomba Fault are well located to trap hydrocarbons migrating from the Toko Syncline. This play was tested in part by Ethabuka 1 which recorded a minor gas flow from the Ordovician but was not deepened to the Middle Cambrian.

In the south-southwestern portion of the basin important stratigraphic plays have been recognised at Middle-Late Cambrian levels. The Hagen Member shoal onlaps the southern margin of the Tennant Inlier and overlying bedded anhydrite provides vertical seal. Source and bottom seal are provided by Arthur Creek organic rich shales which are in the peak oil generation window. Excellent oil shows were recorded in the Hagen Member shoal and the Thornton Limestone (Elkedra 7), both of which display updip onlap onto basement. Neither of these zones have been electric logged or tested. Analysis of oil extracts derived from core indicates a Middle Cambrian source without evidence of water washing or biodegradation. Drill stem test results from a downflank well, Randall 1, indicate viable reservoir in the basal Hagen Member which flowed 300 BWPd. The reservoir in this well and in Phillip 2 recorded abnormally high salinities (14 000ppm NaCl compared with 2-3000 ppm normally) suggesting the presence of an isolated aquifer that may not have been subjected to recent flushing by fresh meteoric waters as occurs elsewhere in the basin. The presence of an extensive anhydrite seal is important as this lithology is capable of preserving hydrocarbon deposits for hundreds of millions of years and shallow target depths of 300 m are also encouraging.

Conclusions

The southern Georgina Basin is a vast 'greenfield' exploration province which has only been subject to cursory seismic and drilling activity. Only 18 petroleum exploration wells have penetrated the prime Middle Cambrian target reservoir- source couplet of the Thornton Limestone and Arthur Creek Formations. This equates to one well per 6000 sq km and of these over half lacked any seismic control while seismic grids were very sparse for the remainder. None of the wells tested a confirmed structural closure but hydrocarbon shows were widespread and locally abundant.

Comparison with adjacent Palaeozoic basins reveals that this Middle Cambrian reservoir-source couplet is unique in onshore Australia in terms of its lateral extent and in particular, richness of source rock. Maturation modelling indicates that the relative timing of hydrocarbon generation and structuring are favourable over a vast area. Traps adjacent to the Dulcie Syncline are most likely to be oil charged with target depths of less than 1000 m. Within the Toko Syncline traps are likely to be gas charged with target depths of 2000-4000 m. On the distal flanks of this depocentre oil charge is predicted with target depths of less than 1500 m. In addition, early formed stratigraphic traps are attractive targets, particularly on the margins of the Tennant Inlier at the levels of the Hagen Member and Thornton Limestone where excellent oil shows have been recorded below thick anhydrite seals in an area of major stratigraphic onlap.

In the current oil price environment the Georgina Basin offers attractive, cheap entry acreage for explorers targetting 'greenfields basins' with shallow oil potential. Deeper gas prospects in the Toko Syncline have a lower risk than the oil plays, given the gas flow from Ethabuka 1, and are of strategic interest given the burgeoning of gas markets and pipeline grids.

GEOLOGY AND MINERALISATION OF THE TANAMI GOLD REGION

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Stratigraphy

The stratigraphy of the Tanami region is summarised in Figure 1.

Archean rocks of the “Billabong complex” lie to the east of The Granites mine area and consist of banded granitic gneiss with an interpreted igneous age of 2514 ± 3 Ma (SHRIMP U-Pb zircon, Page 1995).

Browns Range Metamorphics outcrop on the southern flank of Browns Range Dome (northwest corner of TANAMI) and define a thin east-west striking, steep south dipping shear zone (Vandenberg et al 2001). Granitic orthogneiss (quartz-feldspar-muscovite \pm biotite), muscovite paragneiss and muscovite schist are intruded by fine grained Coomarie suite granitic sills and dykes, aplite and pegmatite (Hendrickx et al 2000, Dean 2001). The Browns Range Metamorphics underwent a high-grade metamorphic event at approximately 1880 Ma. This represents the maximum age for the deposition of the overlying MacFarlane Peak Group.

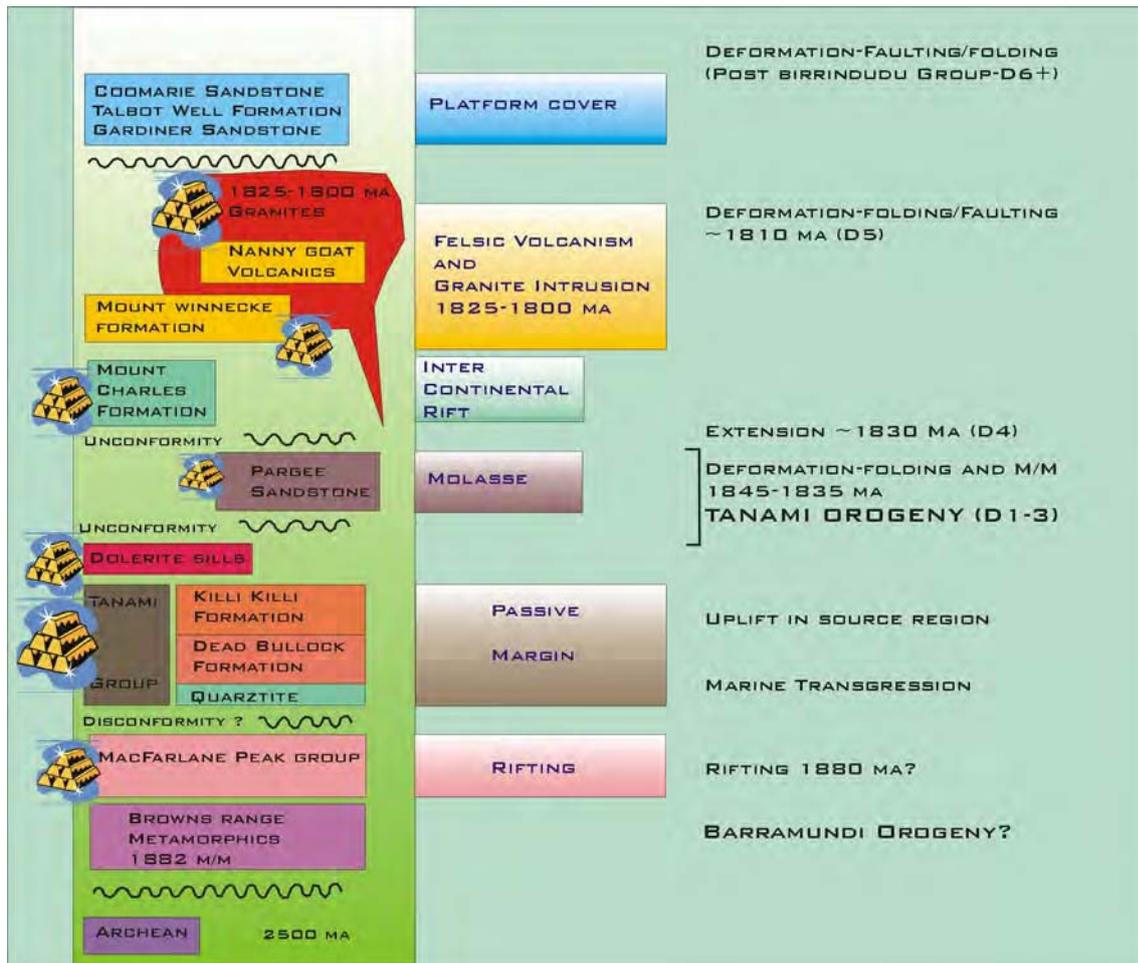


Figure 1. *Please note: 'Tanami Event' referred to in the text is labeled 'Tanami Orogeny' in this diagram.

MacFarlane Peak Group is inferred to have been deposited on a thinned and rifted crust. This group is poorly outcropping and consists of mafic volcanics, turbiditic sandstone, siltstone, and minor calc-silicate, intruded by mafic sills (now amphibolite). Small economic gold occurrences are hosted in this unit. MacFarlane Peak Group has a distinct high magnetic response facilitating its subsurface interpretation over a wide area.

Tanami Group overlies MacFarlane Peak Group with an inferred disconformity. Sedimentation of this group involved rapid transgression and deep marine sediment-starved deposition, followed by rapid sedimentation of a prograding wedge at the onset of deformation. This is typical passive margin sedimentation. The basal unit of the Tanami Group has a thin (100-400m) meta-quartzite consisting of deformed laminated quartz-arenite and vein quartz conglomerate. It is interpreted to represent a rapid transgression preceding deep marine deposition of Dead Bullock Formation.

Dead Bullock Formation consists of siltstone, graphitic shale, iron rich beds (BIF), and silicified and nodular chert. Metamorphic grade varies from greenschist to amphibolite facies, with the highest grade in the southeast involving syn-tectonic partial melting of biotite-sillimanite-garnet pelitic gneiss. This formation is a chemically reactive package and has a demonstrated ability to reduce oxidised fluids and host gold mineralisation (Wygralak 2001). Magnetically responsive mafic sills intrude Dead Bullock Formation.

Killi Killi Formation conformably overlies Dead Bullock Formation. This unit is a thick (2-4km), monotonous package of interbedded sandstone and siltstone, deposited in a turbiditic marine environment. Mafic and felsic sills intrude the unit. Detritus was derived from a granitic source, although some felsic volcanoclastics indicate nearby tectonic activity. Metamorphic grade, as with Dead Bullock Formation, varies from greenschist to amphibolite facies.

Conclusion of sedimentation of Killi Killi Formation is marked by the onset of tectonism, with metamorphism and multiple deformation comprising a significant orogenic event, here called the Tanami Event. In the Tanami Region, this event has been previously ascribed to the Barramundi Orogeny, but a significant time break between this orogeny and the deformation seen in the Tanami warrants separation of the Tanami Event from this widespread northern Australian orogeny. The Tanami Event overlaps temporally with the Halls Creek Orogeny (Hendrickx et al 2000).

Pargee Sandstone unconformably overlies Killi Killi Formation. It only has some of the deformations attributed to the Tanami Event. It consists of conglomerate and arenite, is restricted to a small area and is considered to be syn-orogenic molasse, occupying a sub-basin formed during the Tanami Event.

The period immediately after the Tanami Event is characterised by crustal extension. Mount Charles Formation consists of basalt and turbiditic volcanoclastics deposited in an inferred failed rift. This interval is also punctuated by felsic volcanism and high-level granite intrusion of Winnecke Group to the north. Subsequent, widespread granite intrusion contact metamorphosed existing lithologies. Granites are mostly I-type and have a similar character to Halls Creek Orogen granites (Table 1, Dean 2001). Structural and alteration features indicate that the granites play an important role either 'priming' host rocks, acting as structural buttresses, or providing heat. The latest granites were intruded by about 1790 Ma. The following period represents a time significant peneplanation before deposition of widespread siliciclastic platform sediments of Birrindudu Group.

Suite	Rock type	Texture	Magnetic signature	ASI	Oxidation state	Members and Age
The Granites Suite	predominantly biotite monzogranite to granodiorite (\pm magnetite)	Porphyritic to equigranular, foliated to massive	Variable low to moderate	metaluminous to weakly peraluminous (fractionation)	reduced and oxidised	<ul style="list-style-type: none"> Granites granite (1795 ± 5 Ma) Ptilotus monzogranite (1805 ± 5 Ma) Twin Bonanza porphyry (1802 ± 8 Ma)
Inningarra Suite	predominantly biotite monzogranite to tonalite (\pm muscovite \pm magnetite)	Weakly seriate, coarse to fine grained, porphyritic to equigranular, foliated to massive	Variable high to low	metaluminous to peraluminous (fractionation and alteration)	oxidised	<ul style="list-style-type: none"> Bunkers tonalite (1815 ± 4 Ma) Watertower tonalite (1821 ± 4 Ma) Quorn monzogranite Muriel Range intrusives Grimwade Ridge intrusives Murdoch Cliffs intrusives Officer Hill intrusives Ptilotus intrusives
Coomarie Suite	biotite syeno/ monzogranite, biotite granodiorite, biotite-quartz monzodiorite (\pm hornblende \pm magnetite)	Foliated to massive, coarse to medium grained, porphyritic to equigranular	Low	metaluminous to peraluminous (K and Na alteration)	reduced and oxidised	<ul style="list-style-type: none"> Coomarie granodiorite (1815 ± 4 Ma) Browns Range intrusives (variable Na-metasomatism) Frankenia monzogranite (1805 ± 6 Ma) Talbot South monzogranite and other intrusives (variable K-metasomatism) MacFarlanes granodiorite (1809 ± 8 Ma)
Winnecke Suite	biotite syeno/ monzogranite to granodiorite (\pm magnetite)	Coarse to medium grained, porphyritic to equigranular	Variable high to low	metaluminous to peralkaline (Na alteration)	reduced and strongly oxidised (weathered)	<ul style="list-style-type: none"> Mount Winnecke volcanics (1824 ± 5 Ma) Winnecke granodiorite (1825 ± 5 Ma) Undefined intrusives Nanny Goat volcanics (1816 ± 7 Ma)
Frederick Suite	biotite monzogranite, hornblende-biotite granodiorite to biotite trondjemite (\pm magnetite)	Medium to fine grained, weakly porphyritic to equigranular, foliated to massive	Variable high to low	metaluminous	oxidised	<ul style="list-style-type: none"> Mavericks granodiorite (1801 ± 4 Ma) Pipeline monzogranite Apertawonga monzogranite Inspiration Peak monzogranite MacFarlane intrusives Orion, Slaty Creek and Lewis granites (WA) Walnut Granodiorite Undefined intrusives

Table 1. Characteristics of Granite suites in the Tanami Region (from Dean 2001).

Structure

Structural analysis indicates the Tanami Region has been subjected to at least seven regional deformation events (D^*_1 , D_1 - D_{6+}). Archaean Browns Range Metamorphics possesses bedding-parallel gneissosity, the earliest recognisable fabric S^*_1 . A SHRIMP zircon date of 1882 ± 14 Ma (AGSO-OZCHRON) is the interpreted age of formation of S^*_1 and M^*_1 amphibolite facies metamorphism (Barramundi Orogeny).

SHRIMP based analysis of detrital zircon from Killi Killi Formation indicates a maximum depositional age of 1848 ± 22 Ma (AGSO-OZCHRON). Post-Barramundi deposition of MacFarlane Peak Group and Tanami Group on Archaean basement during an initial basin forming event is inferred. Subsequent deformation and metamorphism of MacFarlane Peak and Tanami Groups is due to the Tanami Event (\sim 1845-1830 Ma).

The Tanami Event is characterised by three phases of deformation (D_1 - D_3) together with early M_1 regional greenschist to amphibolite metamorphism. D_1 structures are variably orientated due to later deformation and are characterised by asymmetric, disharmonic F_1 fold couples. Within siliceous beds, the S_1 axial planar fabric is a discontinuous, anastomosing dissolution-style cleavage. Within siltstone beds the S_1 fabric is a slaty cleavage. Fabric-porphyroblast overprinting relationships indicate peak M_1 was syn-to post- D_1 . Peak M_1 metamorphic assemblages are biotite-andalusite-amphibole (garnet, cordierite) in pelitic units, and quartz-garnet-biotite-epidote-amphibole-cordierite in semipelitic units. These assemblages indicate $T \sim 600^{\circ}\text{C}$ and $P \sim 3.5$ kbar (10-14 km depth; Scrimgeour and Sandiford 1993) and this suggests shallow to mid crustal burial during D_1 .

Structural and stratigraphic relationships indicate Pargee Sandstone molasse deposited syn to post D_1 , prior to D_2 . D_1 and M_1 fabrics and Pargee Sandstone are deformed by open north-south striking D_2 folds. Within pelites and lower grade equivalents, the S_2 fabric is a spaced crenulation cleavage (spaced 0.1 – 1 cm). Rare oblique F_1 - F_2 mushroom style fold interference structures are also observed.

D_3 structures are characterised by east to northeast striking chevron folds and kinkbands. S_3 fabrics are generally fracture style cleavages within siliceous units. Mineralogically differentiated S_3 cleavages within less silicious lithologies are rare. These observations indicate basement rocks formerly at mid crustal depths during D_1 and D_2 were at higher crustal levels by D_3 .

Aeromagnetism indicates intercalated basalt and turbidite of Mount Charles Formation lie unconformably above deformed MacFarlane Peak Group (Slater 2000a,b). Basalt geochemistry indicates a continental rift setting for Mount Charles Formation (Tunks 1996). Deposition of Mount Charles Formation, widespread intrusion of granite (for example Coomarie Suite granite 1815 ± 4 Ma, **Table 1**, Smith 2000) and extrusion of felsic volcanics (Winnecke Group, Nanny Goat Volcanics) are consistent with extension, rifting and basin formation (D_4). D_1 - D_3 structures are not observed at this stratigraphic level.

D_5 shear zones, thrust faults and oblique slip thrusts dissect the region and constitute major bounding structures. D_5 structures formed after emplacement of Winnecke, Inningarra, Coomarie and Frederick granite suites and are spatially coincident with several gold deposits. Late thrusts, oblique slip and normal faults cut all earlier structures. As no clear timing criteria have been identified, these late faults are collectively designated D_{6+} . These D_{6+} structures have affected fault-propagated folding within overlying Birrindudu Group (post 1770-1660 Ma) and deformed Antrim Plateau Volcanics (513 ± 12 Ma, Hanley and Wingate 2000). D_{6+} probably reflects the effects of Late Strangways Orogeny (1745-1730 Ma), Chewings Orogeny (~1600 Ma), King Leopold Orogeny (560-540 Ma) and Alice Springs Orogeny (400-300 Ma).

Displacement along regional D_{6+} structures (40+km strike length) range from several hundred meters of oblique slip (Frankenia Fault), to several kilometers of horizontal displacement (Tanami Fault). Northeast to southeast striking D_{6+} normal faults (post-mineralisation) within the Tanami and Dead Bullock Soak goldfields have displacements of up to several metres. For The Granites and Dead Bullock Soak goldfields, post-mineralisation D_{6+} thrusts trend north to northeast and dip east with vertical displacements of tens to hundreds of metres.

Extension into Mount Solitaire, Highland Rocks and Mount Theo

Reconnaissance of MOUNT SOLITAIRE, MOUNT THEO and HIGHLAND ROCKS confirms much of the lithological mapping conducted by the BMR during the 1970s. Integration of geological and geophysical data indicates several major domains at the southern margin of Tanami Region. These include Archaean Billabong Complex, newly proposed Surprise Igneous Province, Highland Rocks Metamorphic Complex, Lander Rock Beds of North Arunta complex, and the Neoproterozoic(?) Nungurmanu Basin (**Figure 2**).

Billabong Complex granitic gneiss displays a penetrative, steep northwest dipping gneissosity and overprinting north-northeast dipping shear bands (AMG 694690 7712190). The preservation of quartz dynamic recrystallisation microtextures indicates shearing outlasted

the thermal peak. Similar shear sense and textures in structurally overlying quartzite (Tanami Group) indicates the contact between Archaean Billabong Complex and Tanami Group may be a north dipping shear zone with normal sense displacement.

Highland Rocks Metamorphic Complex (HRMC) coincides with the Willowra Gravity Ridge. Outcrop through central-eastern HIGHLAND ROCKS includes small pavements and rounded elongate tors of granular garnet-sillimanite gneiss, layered garnet-sillimanite pelite, migmatite and deformed granite (AMG 616160 7632717 and AMG 628766 7636554). Drilling in northern MOUNT THEO suggests extensive granite and granitic gneiss under shallow surficial cover. Bedding is locally preserved and a pervasive gneissosity is defined by alternating biotite-sillimanite and quartzofeldspathic rich zones. Metamorphic grade is upper amphibolite-granulite facies.

Geophysics indicate numerous faults through the HRMC. In the east, faults are marked by large quartz reefs and topographic lineaments. These structures continue into MOUNT PEAKE, where they cut Cambrian Central Mount Stewart Formation and indicate Palaeozoic tectonism and fluid movement. Many of these faults may be reactivated Proterozoic structures.

Surprise Igneous Province is defined by a northwest trending zone of deformed granite and minor metasediment across central and eastern MOUNT SOLITAIRE. Granitic textures range from fine grained equigranular to megacrystic, and most are tectonically foliated. Porphyritic and megacrystic granites show syntectonic flow alignment of phenocrysts. Granites are lithologically similar to those in HRMC and megacrystic granites are similar to Mount Stafford Granite (~1820 Ma). Interbedded psammite and pelite is indistinguishable from Lander Rock beds on MOUNT PEAKE to the east and MOUNT THEO to the south (AMG 759744 7740891). Bedding in upper-greenschist facies andalusite-biotite schist and psammite is well preserved. Structure is dominated by large east plunging F_1 folds with axial planar S_1 schistosity. S_2 crenulation cleavage overprints F_1 structure and is axial planar to northeast striking open F_2 folds. Late pegmatite dykes strike northwest.

North Arunta Lander Rock beds in MOUNT THEO are interbedded quartz-muscovite (\pm biotite, amphibole) psammite and muscovite-biotite-tourmaline \pm amphibole pelite (AMG 771694-7594701). Bedding trends east, dips steeply north and metamorphic grade is mid to upper greenschist facies. Macroscopic F_1 folds plunge steeply west and contain axial planar S_1 schistosity defined by muscovite-biotite alignment. Angular F_2 folds plunge moderately west-northwest and contain axial planar S_2 crenulation cleavage. Pegmatite dykes cut F_1 folds and are deformed by F_2 structure. D_3/S_3 structure consists of low angle asymmetric kinks.

The newly identified Nungurmanu Basin includes outcrops of low grade sedimentary rock (example Mount Patricia, MOUNT THEO). Purple, thick bedded, poorly sorted, gritty lithic sandstone and purple siltstone are cut by thick, east striking quartz reefs. Bedding trends southeast. East trending reticulate cleavage is best developed in siltstone. Geophysics (gravity low and relatively bland magnetic signature) and limited outcrop indicate the basin is fault bounded and extends west into HIGHLAND ROCKS and east into MOUNT PEAKE. A Neoproterozoic-Palaeozoic age is based on correlation with outliers of Vaughan Springs Quartzite and Central Mount Stewart Formation to the east in MOUNT PEAKE. Nungurmanu Basin may be of similar age to the Ngalia Basin to the south.

Tanami region mineralisation

Three main styles of structurally controlled mineralisation have been identified: *Tanami style*, *The Granites style* and *Dead Bullock Soak style*.

Tanami style mineralisation is spatially associated with post-Coomarie suite D₅ thrusts, backthrusts, layer-parallel decollement and breccia horizons. D₅ structures formed at upper crustal levels where large granitic bodies have acted as buttresses, around which lower greenschist iron and graphite rich rocks have deformed (basalt and carbonaceous siltstone of Mount Charles Formation). Mineralised Tanami structures define three preferred orientations: 035° strike and subvertical dip, 035° strike with 45-60° southeast dip, and 360° strike with 45-60° east dip (Nicholson 1990, Tunks 1996, Tunks and Marsh 1998). In Hurricane-Repulse pit (Tanami mine corridor) lensoidal ore zones plunge shallowly to the north and formed at intersections between D₅ structures, bedding contacts and chemically favourable lithostratigraphy.

The Granites style mineralisation is spatially associated with regional D₅ shear zones and faults localised around the margin of the Inningarra granite (1815 ± 4 Ma). Mineralisation is concentrated within biotite-free cummingtonite-gedrite schist of the informally named footwall *Host unit* (Ireland and Mayer 1984). Tabular ore bodies contain lenticular high grade shoots and mineralised quartz and quartz-carbonate veins (Scrimgeour and Sandiford 1993). *Host unit* is discordant to bedding and is probably related to D₅ shearing (oblique left lateral thrust, Bunkers Hill pit) localised in amphibolite grade, iron rich rocks. *Host unit* is truncated by The Granites granite (1795 ± 6 Ma) and this indicates D₅ shearing and mineralisation occurred between 1815-1795 Ma.

Dead Bullock Soak mineralisation includes D₅ *Callie-style* and *Villa-style* deposits. *Callie style* deposits are defined by general east striking, moderately east plunging ore shoots. Ore shoots follow the intersection between east-northeast striking sheeted D₅ dilational quartz veins ('070 veins') and east plunging, tightly F₁ folded, iron or graphite rich lithologies. Mineralised veins form an east trending mineralised D₅ corridor with highest grade found in F₁ hinge regions. Lithologies more susceptible to brittle deformation (hence increased permeability) have also favoured mineralisation. *Villa-style* mineralisation is characterised by east-northeast trending, bedding-parallel D₅ faults and shears localised within and around axial zones of isoclinally F₁ folded, iron rich graphitic siltstone and BIF).

Regional models

The nature of the contacts between Tanami Region, Arunta Province to the south and Tennant Inlier to the east remain enigmatic. Geophysics indicates fault bounded terranes. Stratigraphic and structural information indicates Tanami Region is more likely to be contiguous with the eastern Halls Creek area (Hendrickx et al 2000). Tanami Region underlies the Victoria River Basin and may merge with the Litchfield Province to the north.

The Tanami Event (D₁-D₃, 1845-1830 Ma) possibly correlates with the Halls Creek Orogeny recorded in the Eastern Lamboo Complex. The event reflects closure of an ocean basin west of the eastern Lamboo complex, and collision of North Australian Craton with Kimberley Craton (including western and central Lamboo Complex at about 1835 Ma, Tyler et al 1995, Sheppard et al 1999). Collision involved east directed shortening, and subsequent deformation (D₄-D₆₊) involved north-south directed shortening. This change probably reflects the influence of transpression focussed to the south of Tanami Region. Within this overall transpressional regime the late stage structural evolution of Tanami Region (D₅/D₆₊) involved the interaction of several granite-cored structural domains.

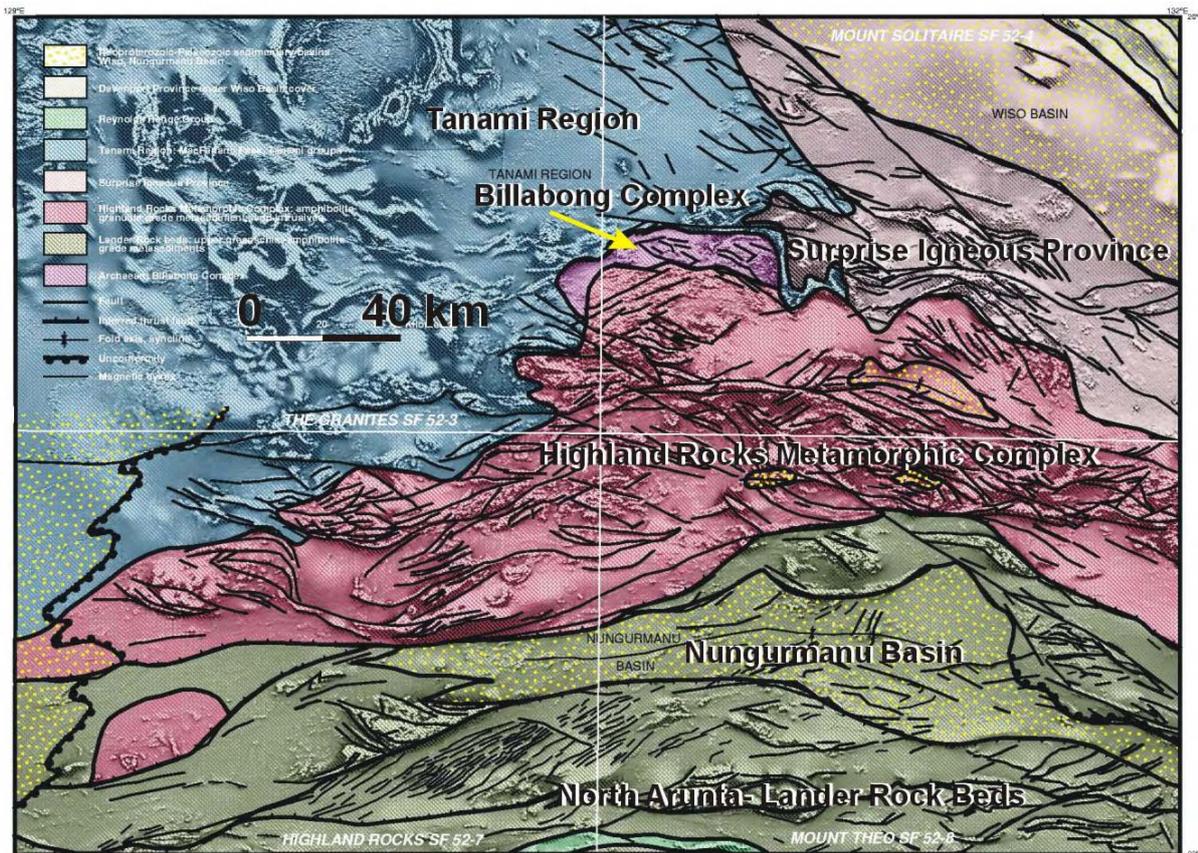


Figure 2. Regional tectono-metamorphic domains across MOUNT SOLITAIRE, HIGHLAND ROCKS AND MOUNT THEO 1:250 000 map sheets (identified during 2000 reconnaissance).

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GOLD MINERALISATION OF THE TANAMI REGION

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The Tanami Region contains over 50 gold occurrences including three established goldfields (Dead Bullock Soak, The Granites and Tanami). Significant new prospects include Ground Rush, Titania, Crusade, Coyote and Kookuburra. The entire Tanami Region has produced 4.1 Moz Au and the remaining resource is 8.4 Moz (260 t) Au.

Late Archaean (2500 Ma) metamorphics and granite are exposed at the Billabong Complex east of The Granites goldfield and along the southern margin of the Browns Range Dome.

MacFarlane Peak Group forms the base of the Palaeoproterozoic sequence and is dominated by volcanic and volcanoclastic rocks. It is overlain by the Tanami Group consisting of Dead Bullock Formation siltstone, carbonaceous shale, calc-silicate and banded iron formation, and by Killi Killi Formation turbidite. These rocks were deformed and metamorphosed prior to the felsic igneous activity and sedimentation of the overlying Tanami Group.

The overlying sequences are extension-related basalt, turbidites and felsic volcanics of the Mount Charles Formation, Mount Winnecke Group and Nanny Goat Volcanics. Unconformably overlaying these units are siliciclastic sediments of Birrindudu Group.

The Tanami orogenic event (1845-1830 Ma) affected MacFarlane and Tanami Groups. It involved three deformational events (D1-D3) and regional greenschist to amphibolite facies metamorphism. Early dolerite intruded prior to D1. Late to post orogenic granites are associated with D4 rifting and deposition of Mount Charles Formation, Mount Winnecke Group and Nanny Goat Volcanics (1830-1795 Ma). Mount Charles Formation was metamorphosed to a sub-greenschist facies and deformed by D5 thrusting.

Gold mineralisation is late in the Tanami Event and associated with D5 structures. It is spatially related to felsic, and to a lesser extent mafic intrusives. The geology of the three goldfields and the significant prospects are summarised below.

The Dead Bullock Soak (DBS) goldfield (remaining reserves 4.3 Moz Au) contains stratabound mineralisation in folded greenstone facies siltstone, BIF and chert of the Dead Bullock Formation. These rocks have been metamorphosed to greenschist facies. Most (90%) mineralisation is concentrated in metasiltstone hosted quartz veins of the Callie deposit (open at depth). Callie mineralisation consists largely (70%) of free gold and minor arsenopyrite, is localised in fold closures and controlled by intersecting lithology and D5 veining. The remaining DBS resource consists of BIF and chert hosted disseminated gold mineralisation associated with sulphides (apy, po, py).

The Granites goldfield (remaining reserves 0.6 Moz Au) comprises stratabound mineralisation within intensely folded and metamorphosed (amphibolite facies) BIF of the Dead Bullock Formation. Gold occurs in disseminated sulphides (apy, po, py), and

is also associated with quartz and quartz-carbonate veining. Inningarra and The Granites granite suites (1815 ± 4 and 1795 ± 5 Ma respectively) lie in close proximity to mineralisation. The geometry of the host sequence is related to D5 deformation which occurred post Inningarra but pre The Granites granite intrusion.

Tanami goldfield (remaining reserves 0.9 Moz Au) consists of quartz vein mineralisation hosted by weakly deformed basalt and medium to coarse grained sediments of Mount Charles Formation. These units exhibit little metamorphism (sub-greenschist facies). Mineralisation is strongly controlled by three sets of D5 faults striking 350-010, 020-040 and 060-080, and dipping. There is also a southeast spatial relationship to the Coomarie and Frankenia granites (1815 ± 4 Ma and 1805 ± 6 Ma respectively). Gold occurs in sulphides (py, apy, po) and vein textures indicate high level mineralisation. Alteration includes bleaching of basalt and sediments and introduction of sericite + quartz \pm pyrite \pm carbonate assemblages.

Ground Rush prospect (reserves 0.7 Moz Au) is characterised by dolerite hosted quartz vein mineralisation. The majority of the ore is free gold but some auriferous arsenopyrite is present. The orebody is open at depth. Mineralisation and deformation relationships remain to be determined.

Titania (Oberon) prospect (reserves 0.48 Moz Au) includes turbidite hosted mineralisation in extensively folded, lower greenschist Killi Killi Formation. Ore bodies are structurally controlled by D5 cleavage and are localised in anticlinal closures. Mineralisation appears to be related to carbon in the host rock. Ore minerals include arsenopyrite, pyrite and free gold.

Crusade prospect (reserves 0.1 Moz Au) contains quartz vein mineralisation associated with a faulted rhyolite-basalt contact within Nanny Goat Volcanics. The location of auriferous quartz veins is controlled by reverse thrusting related to D5 deformation. A significant part of the ore is free gold.

Microthermometric and laser Raman microprobe studies of fluid inclusions show that ore stage fluids in each goldfield vary in their physico-chemical character. At Callie the ore stage fluid exhibits a temperature range of 310-330°C and salinity of 7-9 wt % NaCl eq. The gas phase was dominated by CO₂. It also contained minor N₂ but no CH₄. Depth of formation, calculated using the MacFlinCor computer program (calculates isochores for fluid inclusions considering their salinity, CO₂ and CH₄ content), is estimated at 4.6 km.

The ore stage fluid from The Granites goldfield shows a temperature range of 260-280°C and a salinity of 4-8 wt % NaCl eq. Like Callie the gas phase is dominated by CO₂ but also contains minor N₂ and CH₄. The depth of formation ranged between 1.8-3.8 km.

The majority of inclusions in the ore stage quartz from the Tanami goldfield contains aqueous inclusions (indicating the largely degassed character of fluid) and a minor population of CO₂-bearing inclusions. Aqueous inclusions homogenised between 140-210°C and salinity ranged from 0 to 9 wt % NaCl eq. Depth estimations for this dominant class of inclusions ranged between 0.4 to 0.8 km. These shallow depth

estimates are consistent with a number of high level features (comb and “ghost sphere” textures in quartz, presence of chalcedony).

Ore stage fluid inclusions from Ground Rush have a distinctly different character. The inclusion population was dominated by high temperature, gas rich inclusions. These inclusions homogenised over a temperature range of 390-430°C to either the liquid or vapour phase, or by fading of the meniscus. This behavior indicates critical homogenisation conditions, and thus a temperature correction for pressure is not required. The salinity ranged between 4-10 wt % NaCl eq. Raman spectrometry indicated that the gas phase is dominated by methane with minor CO₂. The estimated depth of formation of these inclusions range between 5.7 and 8.3 km.

Initially the study of Tanami Region gold mineralisation concentrated on determining the physico-chemical character of fluids. But a more holistic, mineral systems approach, is necessary to derive meaningful genetic models. The problems to be addressed involve the three basic components of any mineral system the *source* of energy, fluids and chemical species; physico-chemical aspects of *transport* and *precipitation mechanisms*.

One of the important questions is the role of granites in the Tanami mineral system. There is a clear spatial association between some granitic intrusions and gold mineralisation. Comparison of Pb/Pb isotopic ratios of hydrothermal K-spar and auriferous pyrite from the Tanami goldfield with the relevant Pb/Pb ratios of the Coomarie and Frankenia granites, reveal that these intrusives were not the source of the ore stage fluids.

Oxygen and hydrogen isotope data indicate a predominantly magmatic source for ore fluids in Callie, a magmatic source in The Granites goldfield, and an exchanged meteoric source for the Tanami goldfield. Sulphur isotopes, compiled largely from the previously existing data, indicate a gradual evolution from sedimentary to magmatic source or changing oxidation conditions. Carbon isotope data from CO₂ in fluid inclusions suggest a magmatic provenance of carbon in both The Granites and Callie deposits. The magmatic signature of carbon from fluid inclusions at Callie is in apparent conflict with the organic values of carbon isotopes in carbonaceous sediments and with the decarbonisation process which is believed to play an important role in mineralisation in this deposit. The most likely explanation for this discordance is total flushing of the system by a large flux of ore-stage magmatic fluid at the time of mineralisation.

Hydrothermal alteration is best developed in the Tanami goldfield. The main changes involve depletion of Na and Fe⁺³, and addition of K, Fe⁺², SiO₂ CO₂, Au, As, Sb and in some cases minor addition of Hg. PIMA studies revealed that in the Tanami goldfield the main alteration minerals are Fe-chlorite, illite, phengite and ankerite. Mineralised zones are also characterised by a decreased wavelength of the FeOH band and by a decrease in FeOH/MgOH wavelength ratios. In the Dead Bullock Soak goldfield the main hydrothermal alteration minerals are Fe-chlorite, muscovite and dolomite. A decrease in the wavelength and/or depth of the FeOH band correlates well with ore zones. In The Granites goldfield the main hydrothermal alteration minerals are Fe-chlorite, illite and phlogopite. Mineralised zones correlate with

decreasing wavelength of the FeOH band or by an increase in the FeOH:AlOH wavelength ratio.

In spite of growing data on the ages of felsic and mafic intrusives in the Tanami Region, limited information is available on the direct age of mineralisation. Initial attempts to date auriferous arsenopyrite from Callie mine by Re-Os indicate these elements re-equilibrated after sulphide crystallisation and the obtained ages were not reliable. Ar-Ar dating of D5 related hydrothermal sericite from the Carbine Pit at the Tanami Gold Mine returned an approximate age of 1800 Ma. Dating of sericite associated with the post-mineralisation D6 faulting in Callie returned an age of ~1350 Ma. Some recoil or redistribution of ³⁹Ar occurred during the irradiation of both samples and these ages should be treated as provisional only. K-Ar dating of hydrothermal sericite from the ore zone in the Twin Bonanza prospect returned an age of 1746±2 Ma. The Ar-Ar dating of hydrothermal mineralisation is in the initial stage and more ore zone dates from Callie, Carbine and Dogbolter deposits are expected in the near future. The recent discovery of hydrothermal zircon in ore-stage, quartz veining from Callie offers further scope for the direct dating of mineralisation.

At this stage of research, a proposed model for Callie involves gradual reduction of magmatic fluid by reaction with carbonaceous sediments. The formation of orebodies is restricted to closures of D5 folds, where auriferous fluid rising along fractures, intersects bedding at a high angle. Fractures parallel to bedding allowed fluids to flow without greatly interacting with host rocks, and hence, no mineralisation occurred on these structures.

A model for BIF hosted mineralisation in the Dead Bullock Soak and The Granites goldfields assumes that mineralisation results from destabilisation of gold bisulphide complexes when fluids are reduced during interaction with magnetite or graphite in host rocks. This leads to formation of Fe-sulphides and coprecipitation of gold.

The model for Tanami goldfield proposes gold precipitation by mixing of CO₂-bearing, magmatic or metamorphic fluid with a pre-existing saline brine. This fluid mixing is thought to have occurred at relatively shallow depths and has been localised along brittle fractures and zones of dilation. Gold deposition was probably also induced by cooling, pressure loss and – at least locally – boiling.

The integrated model proposes one(?) gold mineralising system ranging in depth from 8 km (Ground Rush) to epizonal mineralisation in the Tanami goldfield. It is possible that the shallowest part of this system is represented by auriferous and copper enriched quartz vein hosted by the Winnecke granophyre in the Birrindudu area. Further work is needed to prove this concept.

Future gold exploration should concentrate on second order D5 fault structures localised near margins of 1830-1800 Ma granites. Evidence for decarbonisation of sediments, high angle intersections between D5 faults and bedding, and regional scale folding of iron and graphite rich rocks are factors favouring gold mineralisation. On the microscopic scale, presence of carbon dioxide and methane in fluid inclusions is an indication of auriferous fluids.

TENNANT CREEK BEDROCK INTERPRETATION

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Overview

The new basement interpretation of the Tennant Creek region, incorporating modern semi-regional airborne magnetic data and recent geological mapping, is unlocking some of the secrets of the Tennant Creek Au-Cu-Bi mineral field. A GIS based environment facilitated the effective integration of several geological and geophysical data sets.

Five different magnetic signatures are associated with mineralised Warramunga Formation. The major deposits of the Tennant Creek mineral field are hosted by the magnetic siltstone lithofacies. Several of these deposits are adjacent to areas with a 'washed out' magnetic response, possibly caused by destruction of magnetite by hydrothermal alteration.

In addition to classic Tennant Creek style iron hosted Au-Cu-Bi mineralisation, the Tennant Creek region has potential to host Iron Oxide Cu-Au deposits, such as Ernest Henry and Olympic Dam, as well as structural or lithological controlled, vein hosted Au similar to that found in the Tanami or Pine Creek regions of the Northern Territory.

Introduction

AGSO collected high quality magnetic and radiometric data covering the Tennant Creek 1:250 000 sheet in 1998. The survey was flown at a height of 60m, with 200m line separation, in a north-south direction. The survey was released to the public on 31 May 1999.

Integration of the Tennant Creek airborne magnetic data with mapped geology enabled construction of a basement interpretation. The process was streamlined using a GIS interpretation environment. There is only about 20% basement outcrop on the Tennant Creek 1:250 000 map sheet. The interpretation is largely based on extrapolation of magnetic signatures and trends under younger cover. Other raster data sets, including radiometrics and regional gravity, plus vector data sets such as drill hole and deposit locations, were also examined.

The interpreted basement geology includes Warramunga Formation, Flynn Group and Tomkinson Creek beds, plus all granites and other intrusive and extrusive units. Younger magnetic units such as Helen Springs Volcanics are also included in the interpretation. All magnetically transparent stratigraphy younger than Proterozoic has been ignored. Coherent magnetic trends in the Cambrian units have been noted as they may relate to structures not clear in the magnetic response of underlying basement.

The Tennant Creek region can be divided into magnetic domains that broadly define the above mentioned basement elements. Definition of individual units within these groups

is problematic as the signatures become more subtle and the geological relationships are complex.

Results

Warramunga Formation:

The Warramunga Formation is a greenschist-facies, turbiditic flysch sequence of lithic and tuffaceous arenite, wacke, siltstone, mudstone and argillaceous banded ironstone. The depositional age is ~1860 Ma (Donnellan et al., 1995; Compston, 1995). The new airborne magnetic data shows the Warramunga has five associated magnetic signatures four of which could be considered magneto stratigraphic units:

1. The magnetic Warramunga Formation ($P_{W_{m(hm)}}$) occupies much of the central part of the Tennant Creek region. It correlates with siltstone dominated lithofacies. This unit is structurally complex and hosts many high amplitude (averaging 1100-1200 nT) discrete magnetic anomalies attributed to ironstone bodies. The most intense anomaly (2950 nT) is associated with the White Devil deposit. The ironstones display an east-west structural control (Wedekind *et al* 1989). Faults and joints are defined in this unit by low amplitude magnetic lineaments. Faults trending 030-060° seem to intersect mineralisation. The larger deposits are hosted by $P_{W_{m(hm)}}$. They include Warrego, White Devil, Orlando, Gecko, TC8, Chariot, Juno, Argo, Eldorado, Nobles Nob, Peko, Rising Sun, and Golden Forty.
2. The southern portion of $P_{W_{m(hm)}}$ hosts an east-west elongate zone of subdued magnetic intensity corresponding to an area of Warramunga dominated by porphyry P_{W_p} . This zone is relatively unmineralised. The southern margin of P_{W_p} is defined by a major mineralised east-west structure, the TC8 line, hosting both TC8 and Chariot deposits.
3. There are several areas of low magnetic intensity siltstone facies Warramunga $P_{W_{m(lm)}}$. This unit has a very subtle linear texture and occasional high amplitude discrete magnetic anomalies related to ironstones. Joints and faults are difficult to identify in this package. $P_{W_{m(lm)}}$ hosts Edna Beryl, North Star and Whippet.
4. The magnetic signature of the sandstone facies Warramunga $P_{W_{s(lm)}}$ is very similar to $P_{W_{m(lm)}}$. Blue Moon is the only deposit of note in this unit that is otherwise relatively unmineralised.
5. The Juno, Argo, Eldorado, Nobles Nob, Peko, Rising Sun and Golden Forty deposits cluster around a zone of subdued and washed out magnetic response in the 1VD enhancement. This is possibly related to hydrothermal alteration. An area displaying similar magnetic character is apparent immediately east of Warrego.

Junalki Formation is exposed in the south central Tennant Creek region. A recent date 1862 Ma (Smith 2000) (Warramunga ~1860 Ma) indicates equivalence with Warramunga Formation to the north. The Junalki comprises subaqueous volcanic and deep water sedimentary rocks, in contrast to deeper water Warramunga Formation. Junalki

Formation extends south onto BONNEY WELL and southeast onto FREW RIVER 1:250 000 map sheets. This unit has high exploration potential.

Flynn Subgroup:

The Flynn Group, aged between 1855 and 1820 Ma (Compston 1995), unconformably overlies Warramunga Formation and comprises predominantly subaerial volcanic rocks and associated shallow water volcanoclastic and clastic sedimentary rocks. Tennant Creek Au-Cu-Bi mineralisation has an age range of 1830-1825 Ma (Compston & McDougall 1994). The “magnetic layering” in some Flynn stratigraphy is probably due to subaerial interbedded lava and ignimbrite flows, volcanoclastics and sediments.

Economic Potential

Tennant Creek iron hosted Au-Cu-Bi

The Tennant Creek mineral province has produced in excess of 150t Au and 318,000t of Cu, plus significant amounts of Bi, Se, and Ag from over 130 mines (Donnellan *et al* 1995). Most mineralisation is hosted by ironstone in the magnetic siltstone Warramunga lithofacies.

Exploration in the Tennant Creek region has traditionally focused on this mineralisation style. The recent discovery of Chariot (Normandy/PacMin) and Billy Boy (Giants Reef) has created renewed interest in the field. Basement interpretation highlights small pockets of previously unrecognised prospective Warramunga and Flynn stratigraphy and some additional ironstones.

Some oxidised examples of classic Tennant Creek mineralisation are not magnetic due to presence of hematite at the expense of magnetite, for example Eldorado, Argo and Nobles Nob. Semi-regional gravity, scheduled for May-June 2001, may identify additional weakly-magnetic ironstones.

Iron Oxide Cu-Au (IOCG)

There are similarities between the Tennant Creek province and the Eastern Succession in northwest Queensland, which hosts IOCG deposits such as Ernest Henry, Eloise, Mt Elliott, Osborne and Starra. IOCG mineralisation on the Stuart Shelf, including Olympic Dam, is also considered related to Tennant Creek mineralisation.

There are two broad magnetic highs (magnetic flare ups) on the Tennant Creek map sheet which show similar magnetic characteristics to other IOCG regions in Australia. There are also a number of gravity anomalies in the regional AGSO data that could represent potential IOCG targets.

Structural, lithological or vein hosted Au

Gold in quartz veins, lodes, sheeted veins, stockworks, saddle reefs and iron rich sediments are known in the Pine Creek, Tanami, Arunta and Davenport provinces. There are also a number of Au occurrences of these types recorded in the Tennant Creek region.

They represent the dominant style of Au mineralisation found in the Northern Territory and are predominately hosted by greenschist facies flysch sequences, occasional basic intrusive and volcanic rocks, and are all associated with late to post orogenic granites. BIF is present in both the Pine Creek and Tanami regions. Potential is high for this style of deposit in the Tennant Creek region.

Skirrow (2000) discusses Tennant Creek examples of structurally controlled vein Au, including Geko K44 (Main *et al* 1990), Orlando East (Skirrow 1993), Bishop Creek (Edwards 1993) and Au zones peripheral to the West Peko ironstones (Skirrow 1993). Ferenczi (*pers comm* 2001) cites additional examples: Last Hope (north of Warrego), Bull Pup and the Dolomite mine (Pinnacles extended; east of Tennant Creek), and Kovax (south of Tennant Creek).

Gold may be focused into ironstone in the siltstone lithofacies of the Warramunga Formation. However the relatively unmineralised sandstone Warramunga lithofacies and the Junalki Formation may prove to be suitable hosts for vein or structure hosted Au mineralisation.

The large tongue of weakly magnetic siltstone lithofacies Warramunga may also have potential for structurally controlled vein hosted Au mineralisation.

Future

There are clear differences between the magnetic signatures of the Tennant Creek stratigraphic units. These differences are recognised as variations in magnetic intensity or texture. Junalki Formation has a similar magnetic signature to Warramunga Formation. New age dates confirm a relationship, which upgrades the economic potential of the Junalki.

Five different magnetic signatures are associated with the Warramunga Formation. Four of these reflect variations in lithology and the fifth possibly due to hydrothermal alteration. Major deposits are largely confined to the siltstone lithofacies. There are only a few small deposits in the magnetically subdued sandstone lithofacies. This could be due to a lack of structural preparation, or the mineralisation is of an unrecognized nature.

Subtle structures trending 030-060° intersect a number of mineralized ironstones, and may play a part in the location of alteration near the Juno and Warrego deposits.

The main output from this project is the Tennant Creek Interpreted Geology map. Map release is in both hard copy (1:250 000 scale) and digital (MapInfo GIS) form. There may be scope to extend the interpretation south and southeast onto BONNEY WELL and FREW RIVER 1:250 000 map sheets, where recent NTGS airborne geophysical work highlights extensions of Tennant Creek basement stratigraphy, including Junalki Formation.

The upcoming Tennant Creek semi regional gravity program will help elucidate relationships between Warramunga stratigraphy (and age equivalents), Flynn Subgroup and the various intrusive suites. Gravity has potential to define IOCG targets and may also identify new non-magnetic ironstone bodies.

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STREAM SEDIMENT SURVEY OF WESTERN MACDONNELL RANGES

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Northern Territory Geological Survey has undertaken a stream sediment survey of western MacDonnell Ranges covering an area of 6 700 km². Many samples come from the P7 sequence within the Palaeo and Mesoproterozoic metamorphic Arunta Province. This includes rocks of the same age as host sequences to Broken Hill, Mount Isa, McArthur River and Century ore bodies. Some samples are sourced from northern Amadeus Basin (Neoproterozoic to Devonian) and Tertiary rocks.

Samples comprise:

- 1193 samples with an average spacing of one sample per 5.6 km². These were sieved to <6.5 mm and analysed for 35 elements using four-acid digest and combined ICPMS/OES. Au was also analysed to 0.01 ppb detection level by cyanide leach and ICPMS. This size fraction and analytical techniques were established following an orientation study at Oonagalabi base metal and Winnecke gold prospects to the east of the study area
- 75 wet pan concentrates were analysed for Ag, Au, Cr, Cu, Ni, Pb, Sn and Zn by four-acid digest and ICPMS/OES. Zn was also analysed using peroxide fusion and ICPOES
- 29 magnetic fractions analysed by four-acid digest and ICPOES for Cu, Fe, Ni, Pb, Sn, Ti and Zn.

Statistical distributions of elements include normal (Ba, Pb, Rb), log-normal (Co, Cu, Fe, Mn, Ni, U, Y, Zn) and mixed populations (K, Na, Sr). Robust measures of central tendency are used in preference to traditional arithmetic means. Data have been censored, log-transformed and reduced to the standard normal distribution (LNSND) to enable meaningful comparisons between different units of concentration and analytical methods. Box Cox power transformation is presented as an alternative where the LNSND conversion is inappropriate.

Statistical principal component analyses indicate four factors that account for over 75% of total variance. The principal factor of Ca, Co, Cr, Cu, Fe, Mg, Mn, Ni, P, Ti, V and Zn is highest in Narwietooma Metamorphic Complex, particularly Mount Chapple Metamorphics and Mount Hay Granulite. This factor is probably a combination of mafic rock geochemistry and the affects of metal scavenging in the weathering profile. Spatial principal component analysis generated different factors, of which, an association of Ca, Mg and Y in Amadeus Basin sedimentary rocks is the most robust.

Anomalism has been determined by three alternative criteria (inflection on n-score plots, >95th percentile and >2 LNSND). The last two are portrayed by stars on dot and colour proportional single point-source images. Other images are gridded and contoured to show regional trends. This format includes Pb-Cu-Zn, Cu-Ni-Co and K-Th-U portrayed as red-green-blue ternary images. Exploration indices based on numerous ore body models are also provided as colour image maps.

A rigorous statistical and spatial approach to geochemistry enables mapping of both regional trends related to lithological units and individual anomalies that would be prospective for follow-up.

The high U Teapot Granite and overlying younger rocks have regionally elevated (?radiogenic) Pb but relatively little Cu or Zn. Mount Chapple Metamorphics and Mount Hay Granulite have relatively high levels of Cu and Zn and some individual streams contain long dispersion trails. The highest Zn recorded in sieved samples comes from Mount Chapple Metamorphics. Several samples sourced from Mount Hay Granulite are also anomalous in Co, Ti and V. Mount Hay Granulite and Mount Chapple Metamorphics are gradational to one another. They contain 1850 Ma mafic and felsic rocks and locally significant amounts of varied metasediments. These are regarded as potential hosts for epigenetic base metal mineralisation associated with their long history of tectonism.

The highest sieved sample Pb comes from near Round Hill in HAAST BLUFF and is probably sourced from 1620-1600 Ma Ikuntji Metamorphics. It is constrained to a catchment of less than 1 km² and although in the same area as base metal occurrences at Nickel Hill and Haast Bluff II, it is probably not directly related to them.

Other geological units with base metal prospectivity defined by various additive indices include Speares Metamorphics and near the contact of the newly named 1640-1600 Ma Putardi Granite Suite and Peculiar Volcanics in MOUNT LIEBIG.

One sample from Talyi Talyi Hills in LIEBIG, with a catchment of just over 1 km², is anomalous in Nb, Sn, Ti and W based on n-scores. It is also anomalous in Zn using other criteria. This sample has high additive indices for Jervis and Oonagalabi type base metals, U, VHMS and kimberlite and is sourced from charnockite or overlying younger rocks.

Unconformity uranium-gold indices are highest in Narwietooma Metamorphics and Neoproterozoic Amadeus Basin sedimentary rocks.

Au anomalies are point source with no discernible dispersion trails and probably reflect placer concentrations. Of various sampling and analytical techniques tried for Au, wet pan concentrates are probably the most reliable, but significant anomalies in the sieved samples also warrant further investigation (cyanide leach of 5251-031 is 174 times the geometric mean). The Gold Index is generally higher in the Amadeus Basin than the Arunta Province but the highest index is sourced from the Arunta Putardi Granite Suite and the rocks overlying it.

Anomalies identified during this study need to be ground-truthed, particularly where Tertiary sediments or duricrust can be implicated.

The first release of raw data and univariate statistics was made two weeks ago on the NTGS website. More rigorous statistical analysis and a comprehensive GIS presentation will be available shortly.