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MINISTER: Hon Daryl Manzie, MLA
SECRETARY: Peter Blake

NORTHERN TERRITORY GEOLOGICAL SURVEY
DIRECTOR: Dr R Dennis Gee

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For further information contact:

Reference Geologist
Northern Territory Geological Survey
GPO Box 3000 Darwin NT 0801
Phone: +61 8 8999 5281
Web site: http://www.dbird.nt.gov.au/ntgs

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ANALYSIS OF THE AMADEUS BASIN

Project leader: Jamie Burgess
Phone: 08 8999-5307
Facsimile: 08 8999-6824
E-mail: jamie.burgess@nt.gov.au

The Amadeus Basin covers approximately 170,000 square kilometres in the southern Northern Territory. It sits at the heart of a series of intracratonic remnant basins on the Australian continent that share their origins in the breakup of the supercontinent Rodinia at ~1 Ga. The genetic relation of these basins has facilitated strong correlation of their individual sedimentary fills, which in later years has led to the Amadeus, Officer, Ngalia and Georgina Basins being referred to collectively as the Centralian Superbasin (Walter *et al* 1995). Since the discovery of hydrocarbons in the 1960s, the Amadeus Basin has been the focus of intermittent oil industry activity culminating in development of Mereenie and Palm Valley Fields in the mid 1980s. It has more recently drawn the attention of mineral explorers seeking to find comparison with gold deposits of the Witswatersrand Basin of South Africa. The present NT Geological Survey program focuses on advancing knowledge of Amadeus Basin evolution and producing a coherent synthesis of basin-wide geology for explorers.

Mapping by NTGS geologists in Petermann Ranges on the southwestern margin of the Amadeus Basin, has found bimodal volcanics and sediments that represent the onset of rifting and basin formation. The Amadeus Basin succession began thereafter with sheet-like, tidally influenced deposition of the Heavitree and Dean Quartzites. An increase in accommodation space led to the deposition of thick shallow-marine anoxic rocks (Bitter Springs Formation). This unit contains basal evaporites and salt that form the foundation for diapiric structures observed throughout the Amadeus Basin. A basin-wide hiatus at the top of Bitter Springs Formation coincided with structural evolution in the basin in which several sub-basins and a prominent central ridge were established. This hiatus was succeeded by deposition of a sequence of glacial and interglacial deposits including representatives of the Sturtian (Areyonga Formation) and Marinoan (Olympic Formation) glaciations. Intervening environments included periods of anoxia suitable for the preservation of organic matter (both Areyonga and interglacial Aralka Formations).

Deposition through the latest Neoproterozoic was dominated by marine-influenced clastics and carbonates of the Pertatataka, Winnall and Julie Formations, among others. Movement associated with the Petermann Ranges Orogeny (~580-520 Ma) rearranged basin geography and further localised sedimentation, introducing foreland sedimentation to the southwest of the basin and extensive fluvial tongues of Arumbera Sandstone to the north and east. Cambrian clastics continued to be deposited in the south and west (Mt Currie Conglomerate and Cleland Sandstone), while the Cambrian succession in the north and east was dominated by marine and marginal marine dolomite and evaporitic mudstone, incorporating organic-rich facies in the Chandler and Giles Creek Formations.

Clastic Ordovician sequences in the northern Amadeus Basin include fluvial Pacoota Sandstone, shallow marine Horn Valley Siltstone (predominantly siltstone with lesser black shale and carbonate) and tidally-influenced Stairway Sandstone.

The Alice Springs Orogeny (~400-300 Ma) is represented in the east and across the northern margin of the basin by foreland sedimentation including fluvial and lacustrine lithofacies of the Pertnjara Group.

Exploration began in the Amadeus Basin in the 1950s with reconnaissance work by BMR. Since the discovery of Mereenie Oil and Gas Field in early 1964 and Palm Valley Gas Field in 1965, both in the Pacoota-HornValley-Stairway sequence, exploration and scientific study in the basin has largely focused on the Ordovican petroleum system in the north and east of the basin (Korsch and Kennard 1991). However, with only 5 wells located away from the central ridge (to the south and west) and most recent data in some areas dating back to the 1960s, the greater Amadeus Basin must be considered a “greenfields” area for exploration.

Good results indicate a number of active but poorly defined older petroleum systems in the Amadeus Basin. The Dingo gas field located 80 km south of Alice Springs, is relatively little tested and has proven and probable reserves of 25 BCF. Dingo 1 was drilled in 1981 and tested 1.5 MMCFGD from the Neoproterozoic Arumbera Sandstone. The first petroleum exploration well drilled in the Amadeus Basin (Ooraminna 1 by Exoil in 1963) encountered a small gas flow of 0.12 MMCFGD from the Cryogenian Areyonga Formation. Drilled in 1992, Magee 1 became the first (and still only) hole drilled into Heavitree Quartzite and it showed gas from this unit which flowed 63.1 MSCFGD in an open hole test.

These results combined with those from correlative successions in the Centralian Superbasin indicate yet more likely Amadeus Basin petroleum systems. Potential exists for development of Cambrian source rocks in eastern Amadeus Basin like those of Arthur Creek Formation in southern Georgina Basin. Significant potential also exists for an oil and gas occurrence similar to that in the Neoproterozoic (Adelaidean) of the Officer Basin (South and Western Australia).

Because of the limited volume of thermal maturity data and restricted aerial extent of other data, the history of thermal regimes acting throughout the basin is not well understood. Similarly, in better studied areas, existing thermal and burial history models (Schroder and Gorter 1984) are significantly out of date. Recently acquired maturity data at Wallara 1 in the centre of the basin, indicating that potential source rocks are overmature for hydrocarbons generation, confirm that models of thermal maturity simply increasing towards the northern margin of the basin (Schroder and Gorter 1984) are inaccurate.

Aeromagnetic geophysical surveys over the western and southern Amadeus Basin by the NTGS are underway. It is expected that interpretation of these datasets will supplement the outdated data available to explorers in these areas.

There are numerous untested structures and play types throughout the basin. Gas from Heavitree Quartzite at Magee 1 a glaring example. The existence of salt diapirs in the south and west of the basin is known only from 1960s vintage mapping. Furthermore, oil shows in both Horn Valley Siltstone and Bitter Springs Formation at Mt Winter 1 highlight the existence of good source rocks at generating maturities in an area once thought to be devoid of source rocks.

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GEOSCIENCE INFORMATION BRANCH

Acting manager: Craig Bentley
Phone: 08 8999-5279
Facsimile: 08 8999-6824
E-mail: craig.bentley@nt.gov.au

The Geoscience Information Branch (GIB) of NTGS plays a key role in supporting and promoting mineral and onshore petroleum exploration in the Northern Territory. Our Darwin and Alice Springs offices provide traditional library and specialist geoscience information services to explorers and the general public.

Geoscience Information staff are trained to receive, store and retrieve information, conduct on-line literature searches and deliver products in hard copy or digital form. Explorers can access on-line databases such as the summaries of statutory exploration reports (IRMS - Industry Report Management System), the library reference collection (LEDA), and a series of other databases containing drill core data, environmental reports, and digital data associated with exploration reports. Off-line reference databases (on CD-ROM) include Georef, AESIS, and Minmet. Free photocopying is available in both offices, and explorers may borrow material if they register with us.

Core stores at Darwin and Alice Springs allow industry geologists to review, sample and log our holding of drill cores and cuttings. NTGS endeavours to retain a representative collection of cores through mineral deposits, rock types and stratigraphic sections, but does not attempt to retain all diamond core drilled in the NT. Our Darwin store is also an off-site storage facility for onshore and offshore petroleum documents such as well completion reports, seismic sepias, and shot point base maps. Large plans associated with statutory mineral exploration company reports are also stored at this facility.

Our Geoscience Information Branch manages an extensive collection of reference material pertinent to mineral and petroleum exploration: 12 000 monographs, over 16 000 exploration reports (mineral & petroleum), 2 000 geological maps, over 450 journals, around 1 300 pamphlets, and over 900 NTGS geological records. This entire collection has recently been made open file. These include “unpublished” technical studies and the formally published Report Series. Recent reports include *Gold deposits of the Northern Territory* (Report 11) and *Atlas of the mineral occurrences and petroleum fields of the Northern Territory* (Report 10). Bibliographical details of other reports can be found in our product catalogue under:
http://www.dme.nt.gov.au/ntgs/NTGSCatalogue.pdf.

This catalogue also includes a full listing of 1:100 000 and 1:250 000 geological maps and explanatory notes with the most recent additions being 1:250 000 Petermann Ranges, Tennant Creek, Blue Mud Bay, Milingimbi and Mt Marumba - the latter three produced under the national Geoscience Mapping Accord with AGSO. An additional range of thematic products includes Commodity, Metallogenic and Petroleum Basin Studies, the latter covering the intracratonic Georgina, Ngalia, Wiso and Amadeus basins among others. NTGS publications are prepared in-house, have limited print runs, and maps are printed on demand. Digital versions (PDF) will soon be available over the Internet.

Because of problems with different pricing policies, NTGS has temporarily ceased to act as selling agent for AGSO products relating to the Northern Territory. AGSO products will continue to be catalogued by GRS, however, all purchase requests will be referred to AGSO.

In addition to hardcopy products are an increasing range of quality digital products. The core resource is the high-resolution airborne geophysical surveys now covering 55% of the Northern Territory. The geophysical datasets are distributed as gridded data (Ermapper format) or located line data (ASCII). They are pictorially and spatially portrayed (jpeg images) on our Internet site with full specifications:
http://www.dme.nt.gov.au/ntgs/ntgs/geophysics/air_map/air_geo_map.html.

A new range of geochemical datasets is being produced, eg Tanami Region, which are available in Explorer3 or MapInfo format. Datasets, based on company open-file exploration geochemistry for the McArthur Victoria and Ord Basins will become available to explorers once a moratorium period with Terra Search has expired on 1 January 2001.

New digital products include MODAT (mineral occurrence data), Seigal 1:100 000 map stream sediment geochemistry (our first GIS package), and the IRMS database which will soon be made interactive on our Internet site. All these products are distributed on CD-ROM as run-time applications in the case of databases, or with freeware viewers for GIS datasets.

NTGS supports the Australia-wide program to encourage the submission of statutory exploration data in digital format, according to nationally developed guidelines and standards. These standards, which have been circulated to NT explorers, are on trial until 1 January 2001. They have received a broad level of acceptance in principle if not in universal practice. These digital reporting standards are currently available in portable document format (PDF) from our Internet site:
http://www.dme.nt.gov.au/ntgs/ntgs/geoscience_info/exploration_rep.html

The largely static nature of our Internet site will be addressed in coming weeks with web publishing of our IRMS database. This will enable explorers to perform textual searches on open file exploration reports – both mineral and petroleum. An explorer will able to view up to fifteen fields of bibliographical data including an abstract for each report. Viewing the actual reports over the Internet, the next challenging task, is currently being addressed at grass roots level. NTGS is committed to scanning historical exploration reports in black and white tiff compressed format (Group IV), uncompressed grayscale and 256 colour tiffs. Methods to serve these images over the Internet as either low resolution gifs or PDFs are currently being investigated. By the end of April our entire open file collection will be scanned back to 1981. These scanned reports are being primed for eventual web delivery, but in the foreseeable future, delivery methods will rely on CD-ROM, or possibly e-mail depending on the quantity of reports requested. All scanned reports delivered on CD-ROM or by email will be as scanned.

All our products are freely available, including limited quantities of scanned exploration reports. Our products can be requested by e-mailing our Reference Geologist (reference.geologist@dme.nt.gov.au) or our information staff (geoscience.products@dme.nt.gov.au). Your request must include a mailing address for courier bag delivery. All requests will be acknowledged and processed in-house by the Geoscience Information Branch. In the case of digital products CD-ROMs are burnt on demand from on-line storage and/or master copies. The turnaround for requests depends on the data type and the amount requested, but we expect the turnaround time for CD-ROM to be less than one week. To expedite the acquisition of urgent data please prioritise your request. All data requests will be honoured in full, whether instantly or by instalments based on your priorities.

Note: A product catalogue is included on this CD-ROM in portable document format (PDF).

DIRECTIONS OF THE NORTHERN TERRITORY GEOLOGICAL SURVEY UNDER THE EXPLORATION INITIATIVE.

Project Leader: R Dennis Gee
Phone: 08 8999-5377
Facsimile: 08 8999-6824
E-Mail: dennis.gee@nt.gov.au

Introduction

In November 1998 the NT Government announced an Exploration Initiative program with the intention of stimulating mineral and on-shore petroleum exploration. The initiative was to take the form of additional fundings of $16 million over a period of 4.5 years, to produce an expanded range of modern geoscientific data packages designed to attract explorers. This funding was additional to the existing recurrent level of normal government funding for industry services, and would be administered by the Geological Survey Division of the Department of Mines and Energy.

This initiative recognised that the level of exploration expenditure, both in absolute terms, and as a percentage of the national expenditure, had been falling over a five year period. Thus we had a situation where NT with 17% of the land area of Australia, was attracting only 7% of the national exploration budget.

Apart from notable exceptions in the Tanami goldfield, the rate of mineral discovery was slowing alarmingly, such that resource inventories were not being replenished by discovery, as they were in the other mining states. Moreover, most of the major mineral resource projects in the Territory were in fact nearly a quarter of a century in age. Consequently the contribution that mining makes to the GSP of NT was declining.

There are three basic reasons why NT became marginalised:

- Difficulties with land access for explorers – a constraint that remains the greatest impediment to exploration resurgence in NT and in Australia.
- A phase of globalisation by explorers – an adventure that has been less than successful for many, and is possibly being reversed.
- Active promotion by other states of their resource prospectivity by special funding packages.

It is this third point that the Exploration Initiative addresses. In essence, the programs of NTGS will specifically focus on production of geoscientific data packages and prospectivity enhancement studies of direct relevance to mineral and on-shore petroleum exploration. These programs are specifically designed to redress the current discounting of the NT share of the national exploration cake, which is not warranted by our undoubted geological prospectivity, or even our current land access problems. There will be less emphasis on traditional *geological survey research*, and more emphasis on information packages that will assist in the initial exploration protocols of *area selection* and *project generation*.

In gathering together these packages, NTGS will merge data derived from our own pro-active programs with industry-sourced data. Under this refocusing there will be five major programs, under which specific projects will hang. These projects will be precisely defined in terms of their objectives, time frames, work programs, and outputs. These five major programs are:

- Geophysics
- Regional Geoscience
- Mineral Resources
- Petroleum Geology
- Geoscience Information

The remainder of this paper summarises the programs and current projects that are relevant to mineral exploration in the NT.

Geophysics Program

Airborne Geophysics

Airborne geophysical surveys are the cornerstone of the Initiative. Since 1981, NTGS has been acquiring semi-detailed airborne magnetic and radiometric data on a prospectivity priority basis over mineral fields and basement terrains. Up until 1998, approximately 45% of the NT had been flown in 33 separate high-resolution surveys at line spacings of between 150 and 500 m. During the 1999 field season this coverage was increased to 55%, at a cost of around $2.2 million, through the completion of five additional surveys. These new surveys covered parts of:

- Western Amadeus Basin (400 m line spacing)
- Southern Georgina Basin (400 m)
- Concealed portions of the Tennant Creek and Davenport Provinces (200 and 400 m)
- Rum Jungle Complex and adjacent part of Pine Creek Orogen (200, 250 and 400 m).

A notable feature of the recent surveys is that we have extended into the sedimentary terrains of the Centralian Superbasin. These regions will require new interpretation techniques. The magnetics are able to see lithological and structural features in both the sedimentary piles, as well as the basement. This will be of great value as we anticipate that future exploration will focus on buried extensions of basement terrains, as well as the basins themselves.

Over the life of the Initiative, the remaining continental-scale BMR magnetic coverage will be progressively replaced with modern surveys. Choice of areas will be driven both by internal priorities and industry requests. We will also be acquiring on a discounted cost-recovery basis, selected high quality regional surveys done by industry as multiclient or open-range surveys.

NTGS has taken the unprecedented step of providing all data free of charge in order to provide greater accessibility to all explorers. Individual surveys in the form of located line data and grids of TMI are available on CD-ROM.

Regional Gravity

NTGS has also commenced a program of semi-regional gravity surveys in selected areas to assist in the resolution of critical geological relationships in mineral fields. The first of these projects, in a joint effort with AGSO, covers the entire Tanami Goldfield on a 4-km grid. These data will address the distribution of felsic intrusives and mafic rocks within this poorly exposed terrain, and elucidate the enigmatic boundary between the Tanami and the northern Arunta Province.

Regional Geoscience Programs

These involve integrated multidisciplinary studies of major geological regions (such as basement orogenic belts, platform covers, sedimentary basins), in order to gain a better understanding of geological processes, so as to elucidate mineral and petroleum prospectivity. This is done by synthesising geological, geophysical, geochemical, structural, geochronological and metallogenic data, on the basis of discrete geological regions rather than individual map sheets.

Tanami Project

This project illustrates the new style of endeavor. It is one of our core projects, as it commences a major assault on the Arunta Province – one of the exploration frontiers for exploration in the NT. This project will develop models for the regional stratigraphic, structural, lithological and tectonothermal controls on gold mineralisation of the Tanami region, and establish whether this model can be extended throughout the northern part of the Arunta Province.

More specifically, the gold model to be tested may well have the essential ingredients of:

- Proximity to specific types of granite domes
- Located in late generation structures in anticlinal highs
- Hosted by iron-rich rocks (basalt, dolerite, BIF)

This may then serve as a predictive model through similar terrains in the Northern Arunta. Bearing in mind that this area is covered by geochemically inert regolith, the range of work here involves:

- Preparation of 1:50K base map derived from rectified Spot imagery
- Compilation of company basement data from drilling
- Field mapping of selected 1:100K sheets with emphasis on mesoscopic structural analysis
- Scout rotary drilling with diamond tails of selected targets, especially on characterising granite domes
- Bedrock interpretation of geophysical magnetic data
- 4x4 km gravity mapping
- SHRIMP geochronology of host rock and mineralisation phases
- Basement lithostratigraphy and petrogenetic characterisation
- Mine-scale documentation of relationship between mineralisation, structures, alteration and rock types
- Detailed studies of mineral paragenesis

This will result in a range of products including "traditional" standard series 1:100K bedrock map sheets, digital datasets in GIS format, and a synthesis bulletin.

Tennant Inlier Project

This project aims to integrate all geological mapping done in recent years, with new geophysical and geochemical data, in order to provide a new geological base for future gold and basemetal exploration, especially involving the application of new ore deposit models.
The challenges here are to:

- Determine precisely the chronometric correlation of the cover sequences of the Warramunga "nucleus"
- The possible repetition of the highly fertile Warramunga "rocks" to the south and under the shallow cover of Cambrian sedimentary basins to the west
- The presence of granite aureole Cu-Au-Fe systems
- Subtle geophysical or geochemical responses of non-classical Tennant Creek orebodies

This work will result in the production of a variety of standard series maps, as well as a GIS package of data and interpretation, with emphasis on the newly released 200m line spaced AGSO-derived aeromagnetic data.

Barramundi "Foundation"

Other basement projects are being commenced as projects of the recent past years are wound up. Future work in the Palaeoproterozoic will involve the pursuit of the Tennant-Tanami Link, through the planned Arunta North Project.

A long range vision is to piece together the various components of the foundations of the Barramundi Orogeny, throughout the entire North Australian Craton. Wherever we see these terrains exposed (Tanami, Tennant Creek, Pine Creek Orogen) they are well mineralised. This work will place a heavy reliance on sub-surface mapping of the upper 500 metres of the basement, north of the seemingly infertile central Australian collision zones. Old continental margins, intra-cratonic rifts and infolded cover sequences all have their own metallogenic significance, and specific ore-deposit models.

Victoria Basin Project

This is an example of a platform-cover regional geoscience project. It aims to establish the chronostratigraphic correlation between the well-know McArthur Basin and the lesser known Victoria Basin. This will lead to understanding the sequence stratigraphic framework of the greater platform covers, with a view to modeling basin history in terms of the sedimentation, syn-sedimentary faulting, thermal events, fluid flow, and potential mineral systems.
This project has involved some selected re-mapping, lots of lithological and gamma-ray section measurements, sampling for SHRIMP dating, and so far two deep stratigraphic diamond holes. Further work will involve geophysical modeling of the geological framework with a view to identifying buried syn-sedimentary fault troughs or basinal margin features.

Georgina Basin Project

This is a regional geoscience project that addresses one of the younger sedimentary basins. The objective is to develop a three-dimensional understanding of the structure, sequence stratigraphy, and thermal evolution of the deeper part of the Georgina Basin. This part of the Basin contains extensive gently folded organic-rich intervals. Basemetals (mainly lead) are known from carbonate units, and phosphorite mudstones occur in what seems to be marginal facies of depocentres.

Current work includes:

- Re-mapping of Tobermorey 1:250K sheet
- Drilling of one deep stratigraphic hole through the previously undrilled Marqua Formation in 1999
- Detailed re-logging of previous petroleum cored holes, together with re-interpretation of electric logs
- Biostratigraphic zonation studies in conjunction with AGSO
- Organic geochemistry and thermal maturation studies
- Analysis of regional petroleum systems in regard to source rocks, fluid migration pathways and seals/traps
- Depth to basement modeling from recently acquired airborne geophysics

Mineral Resource Program

This program consists of a range of mineral exploration and resource-focussed projects that involve metalliferous deposits, commodity studies (including extractives), exploration monitoring, resource inventories, and as a new initiative, the production of exploration geochemical data sets. Some projects of relevance to exploration are described below:

Tanami Gold Deposits

The morphology, structural controls, alteration, mineral paragenesis, fluid systems and isotopic signatures, of the mesothermal gold deposits of the Tanami Goldfield are being studied as part of the regional Tanami Project. This will enable, for the first time, an integrated model to be constructed that may be applied to the under-explored terrains of the Northern Arunta. We are receiving excellent co-operation and data input from the three producing companies in the area – Normandy North Flinders, Otter Gold and Acacia Resources.

Rum Jungle Project

A new project is about to commence on the polymetallic mineralisation of the Rum Jungle Complex, which includes Woodcutters, Browns and Rum Jungle itself. This study will test the hypothesis that these polymetallic deposits result from remobilisation of sediment-hosted basemetal deposits by tectono-thermal actively of granite domes, and are then overprinted by gold and uranium hydrothermal fluids. This work will be done in cooperation with the Mining University of Leoben, Austria.

Gold Deposits of the Northern Territory

An important new bulletin on the Gold Deposits of the Northern Territory was released in 1999.

Geochemical Datasets

This is a new program which has the potential to match the importance of airborne geophysical surveys for future mineral exploration.
The objective is compile exploration geochemistry datasets in the Explorer3 database, using the wealth of material from company exploration activity, and then to develop interpretation products to stimulate geochemical exploration.

Data will be drawn from open and closed file statutory exploration reports, as well as specific NTGS geochemical surveys. Geochemical datasets will be acquired for the McArthur and Victoria Basin, and a major new future project will address the Arunta Province. Already an orientation geochemical survey has been undertaken in the southern Arunta, in preparation for a major project next year, using CRC LEME as consultants.

Ultimately such datasets will be released as GIS datapackages. To this end a trial GIS datapackages was recently released on CD-ROM for 1534 stream sediment samples from the Seigal 1:100k Sheet in the Murphy Inlier.

Geoscience Information

This program manages the collection, curation, and open-file release of statutory reports, the development of GIS and other geoscientific relational databases, and the publication of geoscientific products.

Access to data, and dissemination of information is a most important part of Geological Survey activities, as is the delivery mechanism for achieving the objective of the Exploration Initiative.

Access to data and information is mainly through the release of products – either hardcopy publications or CD-ROM. We will be working toward providing on-line access to actual data via the internet, but this is not yet possible due to required developments in regard to storage capacity (NTGS data is now approaching one terabyte), band width, server technology and security matters.

The various geoscience information projects of direct relevance to the mining and exploration industry are summarised below.

Industry Reports Management System (IRMS)

Technical reports detailing exploration activity on mining activity are required to be submitted under the Mining Act. These reports are reviewed, indexed, keyworded and abstracted, and the summary information is entered into a Db Text-based relational database called IRMS.

There is currently a holding of 13,000 mineral company reports, of which about 1,400 are on open file. This database of summary information can be interrogated in the NTGS library, or by acquiring a CD-ROM package. We expect the summary data for IRMS will be on line through our Website in early 2000.

At present access to the full information in the report is by the actual hard copy report. NTGS is currently embarking on a major scanning project to digitally capture all company reports so they can be read and reprinted (in colour) in the Department of Mines and Energy Library, or acquired in batches on CD-ROM. We expect to complete scanning of legacy data back to 1981 by December 2000. Direct on-line access to company reports is not planned for the foreseeable future.

In recent years NTGS, along with other states, has encouraged the submission of statutory reports in digital form. In consultation with industry, national standardised guidelines for the submission of digital data have been developed and have been adopted for a two-year trial period by all state agencies. The value of these national standards is that they will facilitate the digital storage and future retrieval of documents. The nature of the delivery systems remains a challenge.

Mineral Occurrence Database (MODAT)

Recently NTGS released MODAT - the new mineral occurrence database. It is an Access-based relational database containing over 2,600 records of documented mineral occurrences. The attributes of each occurrence includes location, tectonic unit, deposit shape, ore minerals, commodity, host rock, age of mineralisation, metamorphism, lithology, structure, genesis, production and resource details. All of these attributes are individually searchable. Prime features include a GIS export facility and a run-time version with a free software driver on the CD.

The Mineral Occurrence Atlas is a complementary hard-copy product which pictorially shows all the MODAT occurrences on a simplified geological background.

Publication and Products

NTGS now substantially follows the practices of print-on-demand, and in-house desk top publishing. These practices, together with the appointment of a geoscientific editor, have greatly accelerated the release of published products. In 1999 this includes:

- Blue Mud Bay map and report
- Millingimbi map and report
- Mt Marumba map and notes
- Tennant Creek map and report
- Mineral Atlas of NT
- Gold Deposits of the NT
- Petermann Range map and report

NTGS will continue to produce traditional publications, such as standard-series geological maps and reports. However we will increase the range of thematic products outside of the standard series, as determined by work programs. These will include for example systematic bedrock interpretations of metallogenically important regions using heavy input from our airborne geophysics, and the delivery of an increasing volume of information in GIS form on CD-ROM.

Concluding Remarks

NTGS now has a clear focus on delivering geoscientific data sets that are of direct relevance to mineral explorers. The programs, the projects, the people and the products will all have this focus for the duration of the Exploration Initiative. We will integrate information from industry sources and from our own pro-active projects. The prime thrust will be to develop an understanding of the basement geology with substantial input from geophysics, so that ore-body models can be more effectively applied. A growing emphasis will be placed on surficial geochemistry with a view to collating regional geochemical datasets that may be of comparable value to explorers as the regional geophysics. However it is noticeable that we do not at this stage have any significant regolith project.

Although we will preserve the traditional concepts of standard-series hardcopy maps and publications, these will be desk-top on-demand products. An increasing amount of information will be available digitally, which can be released as it becomes available. CD-ROM remains the favoured vehicle for the release of data for at least the next 12 months, but we will progress to on-line access of data.

This paper is a slight modification of one presented at the Annual Conference of the Darwin Branch at the AIMM in November 1999. Much of this summary on new directions for the Northern Territory Geological Survey can be seen on our website http:\\www.dme.nt.gov.au/ntgs.

FUTURE PROGRAMS

NTGS Regional Manager: Barry Pietsch
Phone: 08 8951-5302
Facsimile: 08 8951-5660
E-Mail: barry.pietsch@nt.gov.au

New work programs will commence this year in the Arunta Province, southern Birrindudu Basin – northern Tanami Region and Rum Jungle Inlier – Pine Creek Orogen. These Regional Geoscience and Mineral Resource Programs are integrated multidisciplinary geoscientific studies designed to better understand geological processes and enhance the perceived mineral prospectivity of the regions.

Currently there is no published, modern regional synthesis of the stratigraphic and structural framework of the Arunta Province. Furthermore broad-based multidisciplinary geoscientific studies have never been carried out in the past, primarily because of the poor exposure and the metamorphic and structural complexity of geological units and lack of quality airborne geophysics.

NTGS, through its **Arunta North** and **Arunta South** projects, aims to produce a coherent regional synthesis by integrating structural and lithological mapping with metamorphic, geophysical, geochemical, geochronological, petrological and metallogenic studies.

Commencement of these two projects represents a progression in focus from the Tanami Region, Tennant Inlier and the Musgrave Block where significant improvement of the geological understanding has been achieved. Based on the new models developed in adjacent regions, the geological relationship between them and the Arunta Province shall be established. This includes application of new gold mineralisation models, to stimulate exploration for economic deposits in this area where sub-economic gold mineralisation is known.

The Arunta Province also hosts small base metal and Ta-W deposits. Anomalous recorded REE levels have probable carbonatite affinities. Deposits of Pb-Zn-Cu in high grade metamorphic rocks and REE occurrences will be studied in detail to provide accurate data to assist future exploration.

In the southern Arunta Province a pilot study to establish parameters for a regional geochemical survey, in conjunction with CRC LEME, has been completed. The regional **Arunta South Geochemical Survey** will generate baseline surface geochemical data in an area which remains underexplored.

The **Birrindudu Project** is centred on the northern extension of exposed basement rocks of the Tanami Region and the southern extremities of the Victoria-Birrindudu Basin Platform sequence (the Birrindudu Group), within the Birrindudu 1:250,000 map sheet and adjacent areas.

The main aim of the project is to complete field-based geoscientific studies of both geological provinces. The emphasis in the Birrindudu Basin will be on stratigraphic mapping, mainly by measuring selected sections. The basement rocks in the project area are predominantly those of Mount Winnecke Formation, which hosts significant gold prospects to the south, and Winnecke Granophyre. The good exposure of rocks in this area will allow establishment of a volcano-sedimentary stratigraphy for the Mount Winnecke Formation, and determination of the structural evolution and igneous geochemistry with a view to furthering our understanding of mineralisation processes.

NTGS will embark on an integrated study of tectonostratigraphic and metallogenic events in the Rum Jungle Mineral Field which incorporates Archaean complexes and adjacent Proterozoic orogenic sediments. This **Rum Jungle Project** will include the participation of Professor Eugen Stumpfl and a research fellow from the University of Leoben, Austria.

Following discovery of uranium at Rum Jungle in 1949, pulses of geological and mining activity have continued to the present day. Many studies on a variety of disciplines have been published, but voids remain in the understanding of geological processes that formed mineral deposits in this area. The Rum Jungle Project will address problems in both the Archaean Complexes and adjacent orogenic sediments. These include uncertainties in stratigraphic correlations and a need for better understanding of the interrelationship between metallogenic, structural, igneous and alteration events. The multidisciplinary studies will centre around an exhaustive examination of existing data, detailed interpretation of newly acquired NTGS airborne geophysical data, the resampling of mineral deposits for mineralogical, petrological, stable isotope and fluid inclusion studies, along with structural analysis and stratigraphic mapping.

GEOPHYSICAL PROGRAMS

Project Leader: Richard Brescianini
Phone: 08 8999-5389
Facsimile: 08 8999-6824
E-mail: richard.brescianini@nt.gov.au

Overview

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

Personnel and Experience

NTGS Geophysics has a staff of four geophysicists, three of whom are Darwin based (Richard Brescianini, Roger Clifton, Andrew Johnstone), and one based in Alice Springs (Kerry Slater). Our collective experience exceeds 28 years in the private sector, and 7 years in state government exploration initiatives.

1999 Airborne Program

During 1999, over 480 000 line kilometres of airborne magnetic and radiometric data were acquired on behalf of NTGS in five separate surveys at an approximate cost of $2.1M. Most of the data were collected along flight lines spaced 400 m apart. Some 200 m data were also acquired **(BONNEY WELL and RUM JUNGLE surveys)**. In addition, ownership and distribution rights for the WGC Pine Creek multiclient airborne survey were purchased by NTGS **(RUM JUNGLE survey)**.

Surveys from the 1999 airborne program were designed to provide additional insight into the following geological terrains:

1. Pine Creek Orogen, including the Pine Creek Goldfield, Cosmo Howley Au deposit, Woodcutters Zn deposit, and the polymetallic deposits of the Rum Jungle Mineral Field **(RUM JUNGLE survey)**
2. Extensions of the Tennant Inlier to the northwest beneath Wiso Basin cover **(SOUTH LAKE WOODS survey)**
3. Exposed Tennant Creek and Davenport Province stratigraphy, with inferred extensions beneath Wiso Basin and Georgina Basin cover **(BONNEY WELL survey)**
4. Basement terrains (Davenport and Arunta Province) buried beneath sediments of the Georgina Basin (**ELKEDRA survey**)
5. Northern margin of the Amadeus Basin **(AMADEUS WEST survey**).

Merging of magnetic data from the 1999 surveys with several existing high resolution surveys in central NT has permitted continuous high resolution coverage to be established across the Tanami, Arunta, Tennant, western Amadeus, Musgrave and southern Georgina regions. This has begun to reveal fundamental crustal relationships highlighted on the 1:2 500 000 Geological Map of the Northern Territory (in press).

Located (ASEG-GDF2 format) and gridded (ER Mapper .ers) digital data from the 1999 airborne program were released into the public domain during December 1999 – January 2000 under NTGS zero pricing policy.

Pre-release raster images of each survey were posted on the NTGS web site to allow clients the opportunity to view the data and submit orders. This had the effect of streamlining the subsequent data release mechanism, enabling timely delivery. To date, over 30 orders have been filled for each survey.

1999 Gravity Program

NTGS participated in a JV with AGSO to collect over 3800 gravity stations in the Tanami region. Stations were collected on 4 km centres, infilling the existing AGSO reconnaissance 11 km coverage. The approximate cost of the survey was $330 000.

The broad aims of the program were to help address the distribution of granitic intrusives and mafic rocks within this poorly exposed terrain, as well as to elucidate the enigmatic, and perhaps doubtful, boundary between the Tanami Region and northern Arunta Province.

Examination of the data has revealed little additional information of a fundamental nature, at least on a regional basis, which could not have been derived from an integrated interpretation of current airborne magnetic and reconnaissance scale (11 km) gravity data.

Consequently, NTGS has temporarily de-emphasized its gravity strategy in this region and may not extend the 4 km coverage into adjacent areas. The results of geological mapping, scout drilling and airborne surveys in the northern Arunta and eastern Tanami regions during the 2000 field season may necessitate NTGS to reconsider gravity surveying of these areas during the 2001 field season.

Magnetic Map of the Northern Territory

A 100 m grid stitch of the Northern Territory magnetics is complete, and will soon be available as the 1:2 500 000 hard copy product Magnetic Map of the Northern Territory – First Edition. This product comprises data from:

- 35 high resolution airborne surveys flown by NTGS during 1981-99 (line spacing 150-500 m)
- 3 high resolution AGSO surveys flown during 1993-98 (200-500 m line spacing)
- Reconnaissance AGSO data, typically acquired along 1.6 km spaced flight lines.

A digital grid of the NTGS component of the data will also be freely distributed.

Geophysical Interpretation Projects

New and existing geophysical data are being used in integrated multidisciplinary geoscientific studies of several under-explored regions of the Northern Territory so as to enhance their perceived mineral prospectivity. In many of these regions, particularly those that are poorly exposed, airborne geophysics is the most complete representation of the geology available. NTGS will henceforth produce a sister product to the traditional surface geology maps at the completion of a program. This map product will be entitled "Integrated Interpretation of Geophysics and Geology".

Ongoing geophysical interpretation products include:

- Musgrave Block: Petermann Ranges and Bloods Range 1:250 000 sheets completed and in press.
- Tanami Region: Tanami and The Granites 1:250 000 sheets at an advanced stage. Anticipated release in late 2000.
- Tennant Creek Province: Tennant Creek 1:250 000 sheet at an advanced stage. Anticipated release in late 2000.

Geophysical Data Issues

During 1999, NTGS addressed several issues relating to the quality and rapid delivery of its airborne geophysical data. We are in a far healthier position today on both fronts compared to the situation 12 months ago. Client feedback is welcomed as part of our desire to continually improve.

NTGS is addressing the management of its inventory of open file private sector (company) geophysical data. The historical reliance on government commissioned surveys, and the injection of significant additional funding through the Northern Territory Exploration Initiative, reduces the requirement to incorporate a substantial number of these open file surveys into the Territory-wide airborne coverage. However, NTGS recognises the importance of these surveys to the exploration industry, and has initiated a project to locate, attribute and web-enable all open file survey metadata. In addition, NTGS is actively negotiating to acquire selected open range surveys on a discounted cost recovery basis for inclusion into the public domain.

Program for 2000

The following items are on the agenda for 2000:

- Acquisition of over 360 000 line kilometres of airborne magnetics and radiometrics in five surveys. These surveys will cover portions of the Pine Creek Orogen, Batten Trough, Amadeus Basin, and interpreted Tennant Inlier and Tanami Region stratigraphy under Wiso Basin cover.
- Production of the second edition Magnetic Map of the Northern Territory. The addition of data from the 2000 flying program, open file company data and AGSO surveys on Kakadu will increase the proportion of the Territory covered by high-quality magnetic data to over 65%.

- Several preliminary geophysical interpretations, undertaken prior to the commencement of mapping, are tabled for 2000. These include the northern (5 sheets) and southern (4 sheets) Arunta Province, the Victoria-Birrindudu Basin (2 sheets) and the Rum Jungle Complex (1:100 000 scale).
- A radiometric stitch of the central Northern Territory, which involves re-processing and subsequent merging of 4 and 256 channel data from several surveys. This product will assist in the interpretation of regolith and geochemical studies of the region, and provide semi-regional targets for certain deposit styles. Two issues under consideration are the areal scope of the project and the choice of noise reduction technique.
- Web serving of geophysical data. Options being investigated include the implementation of an image web server.

Concluding Remarks

The focus of NTGS geophysical programs is to provide high quality data and interpretations to explorers that will assist in regional target definition and area selection. Airborne surveys still represent the most cost-effective means of maintaining this focus. NTGS has identified the World Wide Web as the preferred conduit through which its data and ideas can be rapidly accessed. All NTGS geophysical products are being designed and packaged with this aim in mind.

THE GEORGINA BASIN: HYDROCARDON HABITAT

Project leader: Greg Ambrose
Phone: 08 8999-5342
Facsimile: 08 8999-6824
E-mail: greg.ambrose@nt.gov.au

The southern Georgina Basin covers an area of 100,000 square kilometres and includes a prospective Middle Cambrian petroleum system which to date has attracted only minor exploration. Only 750 km of modern seismic has been acquired in addition to stratigraphic drilling undertaken by Government agencies and an eight well exploration programme undertaken by Pacific Oil and Gas during the last decade. Most if not all of these wells were drilled outside structural closure but hydrocarbon shows, mainly in the Middle Cambrian, are abundant. The southern portion of the basin is dominated by two depocentres, namely the Dulcie and Toko synclines, which include up to 1200 m and 5000 m of Palaeozoic sediments respectively. The basin was deformed during the Alice Springs Orogeny (Late Devonian – Early Carboniferous) by minor to moderate folding and faulting especially in the south and east.

Recent work by Pacific Oil and Gas has shown that mainly flat lying Ordovician sediments can conceal and disguise earlier Palaeozoic structuring, viz Petermann Orogeny. The presence of common oil shows throughout much of the Cambrian in wells drilled in the Dulcie and Toko Synclines, in addition to a small gas flow from the Ordovician in Ethabuka #1, suggest considerable volumes of hydrocarbons were generated in the southern Georgina Basin. A Russian research group estimated, from pyrolysis data, that in excess of 40 billion tonnes of hydrocarbons has migrated from the Middle Cambrian. Oils extracted from Middle Cambrian sediments are mainly unaltered, mature, aromatic crudes of marine algal/bacterial source affinity.

NTGS has undertaken a review of the southern Georgina Basin incorporating previously unpublished E-log correlations, acquisition of new stratigraphic and regional aeromagnetic data, seismic and field mapping, basin/thermal history modelling and relogging of available core and palaeontological studies. The entire stratigraphic section, from the Neoproterozoic to Devonian, is under review but this paper concentrates on the hydrocarbon potential of the main petroleum system related to the Middle Cambrian Arthur Creek Formation and Thorntonia Limestone.

New E-log correlations from the southern portion of the basin have resulted in a simplification of the previous stratigraphic subdivisions as described in Questa Australia Pty Ltd (1994). Two regional electric log markers denote the base and top of the Middle Cambrian Arthur Creek Formation, and are regional sequence boundaries. The elucidation of these lithostratigraphic markers has greatly clarified the geology of the Middle Cambrian petroleum system. The basal E-log marker denotes a 'hot' carbonaceous shale/siltstone lying unconformably on altered carbonate grainstones of the Thorntonia Limestone. Vugs, fractures and stylolites in the latter result in fair reservoir quality in several wells. Source and seal is provided by the overlying and near ubiquitous basal Arthur Creek Formation 'hot shale' which reaches TOCs of up to 16% and is enriched in microbial source material. This unit was deposited by a rapid transgressive event marked by anaerobic sedimentation, and preservation of organic matter under reducing conditions.

The sediments are oil mature over a wide area of the southern Georgina Basin. The overlying sequence comprises dark dolomitic siltstone and shale with some excellent source potential but poorly developed reservoir facies. The relatively shallow depth of burial and distribution of thermally mature to overmature Cambrian source rocks suggests:

1. Pulse(s) of lateral heat flow from the Arunta Province and,
2. Erosion of up to 1 km of Ordovician sediments which may correspond to orogenic events in the basement.

Shallow water and more oxygenated conditions prevailed in the upper Arthur Creek carbonates and reservoir quality 'shoal' grainstones (K>1110md), offer reservoir potential and possibilities for stratigraphic entrapment. There was considerable structural growth in the main depocentres during deposition of the Arthur Creek Formation until sedimentation was terminated by minor uplift, erosion and peneplanation prior to deposition of Arrinthrunga Formation. This unit has a regional sheet like extent with occasional source and reservoir facies, but seal is problematical. Late Cambrian structuring (Petermann Orogeny) variably eroded this sequence prior to deposition of the Ordovician Tomahawk Beds. As earlier alluded to a thick Ordovician sequence was probably variably eroded prior to Devonian sedimentation. There followed a period of faulting and minor deformation in the Late Devonian – Early Carboniferous (Alice Springs Orogeny). Basin modelling is currently underway and is targeting the relative timing of oil generation compared with the various structural events.

The main target petroleum system relates to the Thorntonia Limestone/Arthur Creek Formation reservoir – source couplet. Reservoir quality in the former is variable and has been affected by diagenetic and post-diagenetic alteration processes, but DST results from several wells are encouraging. The unconformably overlying Arthur Creek 'hot shale' is a regional seal and world class source rock, with expulsion occurring via well developed fracture systems observed in core. The main challenges to a commercial discovery are migration and entrapment. It is suggested the Thorntonia Limestone is best targeted as a structural play but relatively thin grainstone 'shoals' and sandstones in upper Arthur Creek Formation present opportunities for stratigraphic entrapment.

References

Questa Australia Pty Ltd, 1994. Georgina Basin petroleum study. *Northern Territory Geological Survey*.

GEORGINA BASIN

Project staff: Pierre Kruse, John Dunster, Greg Ambrose
Phone: 08 8999-5451
Facsimile: 08 8999-6824
E-mail: peter.kruse@nt.gov.au

The Georgina Basin project involves geological mapping, stratigraphic drilling, airborne geophysics, petroleum reservoir and source rock mapping, biostratigraphy, sequence stratigraphic analysis and basin modelling to improve our understanding of the basin and enhance its resource prospectivity. It is divided into a Southern module (1999-2001), a Central module (2002-) and possibly an Eastern module in collaboration with GSQ.

The current Southern module involves geological remapping of Tobermory, Sandover River and a small portion of Hay River 1:250 000 sheet. Its resource focus is on petroleum and base metals.

1999 field activities commenced in June with a reconnaissance excursion from Mt Isa to Alice Springs, ably guided by John Draper (GSQ) and John Laurie (AGSO), to examine every Neoproterozoic to Ordovician formation in the eastern and southern Georgina.

Geological remapping then commenced on Tobermory map sheet. One-quarter of Tobermory was remapped by AGSO in the 1980s, their results embodied in the Hay River-Mount Whelan 1:250 000 special and Toko 1:100 000 preliminary maps. NTGS mapping therefore commenced on adjoining Tarlton Downs, and this property was covered by season's end – an area equivalent to one 1:100 000 sheet. Mapping of the included Arunta Province rocks by John Dunster disclosed a widespread unit of migmatitic quartzofeldspathic gneiss punctuated by four granite bodies. Mapping by Pierre Kruse led to recognition of three rock units in the formerly undivided Neoproterozoic, and improvements in depiction of the Cambrian-Ordovician succession in Tarlton Range.

Fully cored drillhole NTGS99/1 was drilled on Marqua property to obtain a complete core record of the Marqua Formation. This formation was the only Cambrian unit in the southern Georgina which had not been fully cored. The drillhole reached a total depth of 608.6 m and intersected basal Arrinthrunga Formation (Upper Cambrian) and the entire Marqua and Hay River Formations (Middle Cambrian) before bottoming in Palaeoproterozoic migmatite. Both Middle Cambrian units are pyritic throughout, and the Hay River Formation also shows minor galena. Both units include intervals of pyritic-carbonaceous shale, and RockEval analyses of six samples yielded Tmax in the range 446-462°C and TOC 1-3.4% - a promising petroleum source rock.

As the basis for an improved sequence stratigraphic analysis of the basin, 21 cored drillholes from the southern Georgina were selected for lithological logging to decimetre scale. Fifteen of these were logged in 1999. To establish precise age control on the succession, drillholes were sampled for biostratigraphy in collaboration with John Laurie (AGSO). This will allow comparison with the established agnostine trilobite biozonation, and hopefully lead to the construction of linked biozonations for brachiopods, hyoliths and possibly molluscs, which can be applied elsewhere in the basin. Results will be compiled with the lithologs and downhole geophysics in the sequence stratigraphic analysis. Core was also sampled for geochemistry and SHRIMP U-Pb dating.

The southern Georgina is prospective for base metals, including Mississippi Valley and shale-hosted (sedex) types. The Trackrider and Boxhole-Turkey Creek Pb-Zn prospects (on Elkedra and Huckitta respectively) were examined in 1999. Both are in dolostone of the Arrinthrunga Formation (Upper Cambrian). At Trackrider, disseminated galena has been scavenged by a ferruginous and manganiferous zone along the unconformity between dolostone of Arrinthrunga Formation and sandstone of the overlying Tomahawk beds. Some has been remobilised into younger calcrete. At Boxhole-Turkey Creek, galena occurs in two styles in the upper Arrinthrunga Formation: associated with and rimming barite masses in stromatolitic dolostone; and as cubes and blotches in massive and brecciated chertified dolostone. On Tobermory, exploration activity along the Marqua Monocline has identified Hay River Formation, Red Heart Dolostone (Lower Cambrian) and Wonnadinna Dolostone (Neoproterozoic) as prospective for MV-type Pb-Zn. All these prospects have been explored using geochemical, geophysical and drilling methods, thus far without delineating a viable resource. Overall best Pb and Zn assay values to date are in excess of 2%.

Except in the Marqua Monocline, the evident potential for shale-hosted (sedex) Pb-Zn has apparently not been tested. The sedex model requires igneous activity (to mobilise metal-bearing fluids in the sedimentary pile), large synsedimentary faults, a platform-basin transition, evaporites and some evidence of mineral occurrence. The southern Georgina arguably meets all these criteria. Suitable host pyritic-carbonaceous shale (also considered a world-class petroleum source rock) is available in Arthur Creek and Marqua Formations; the transition between these basinal anoxic sediments and correlative platform sediments to the north remains to be precisely located. Prominent faults transect the southern basin margin. Evaporites are common in the Arrinthrunga and (Middle Cambrian) Chabalowe Formations, and mineral occurrences are known. While there is no igneous component within the Cambrian-Ordovician basin fill, major early Ordovician tectonism, including high-grade metamorphism, is now known to have taken place to the south in the adjoining Arunta Province; apparently, it is this which has driven the basin margin sedimentary pile through the oil-generation window.

MUSGRAVE BLOCK PROJECT

Project staff: Dorothy Close, Chris Edgoose and Ian Scrimgeour
Phone: 08 8951-5668
Facsimile: 08 8952-7762
E-mail: dorothy.close@nt.gov.au

Objective

To provide a geological framework to a poorly known terrain using modern, integrated geoscientific techniques. Main aims are to: subdivide the relatively undifferentiated Musgrave basement, review the stratigraphy of the Neoproterozoic rift sequence underlying the Amadeus Basin, define the structural and metamorphic development of the 560-520 Ma Petermann Orogeny, and define areas of economic prospectivity.

Overview

A regional approach to the analysis of the Musgrave Block has been lacking since the pioneering work by the BMR in the 1960s. The basement terrain straddles three State and Territory boundaries and the majority of the terrain lies under Aboriginal land trust agreement. This has resulted in prolonged negotiations for access and a disparity of knowledge across borders. NTGS commenced mapping in the northeastern Musgrave Block in the late 1980s, and this work, along with specialised studies in other parts of the terrain by AGSO and PhD students highlighted the need for a review of this section of the Musgrave Block.

As a result of the 560-520 Ma intraplate Petermann Orogeny, there has been considerable structural interaction between Mesoproterozoic Musgrave basement and Neoproterozoic sediments of the southern Amadeus Basin and proto-basin rift sequence. Therefore this earlier stratigraphy is included in the remapping of the region.

Regional Geology

The oldest rocks in the NT section of the Musgrave Block comprise felsic, mafic and peraluminous gneisses with precursor ages of 1600-1550 Ma. These gneisses range in metamorphic grade from granulite to amphibolite as a result of deformation during the 1200 Ma Musgravian Event. These older gneisses form a minority of outcrop whilst the area is dominated by 1190-1150 Ma granite suites.

Further igneous activity at 1080-1040 Ma produced minor granite bodies, the intrusion of the layered ultramafic Giles Complex, the Alcurra dolerite dyke swarm and bimodal extrusives. The mafic and felsic volcanic flows associated with this period of igneous activity form the basal units of a rift sequence centred over the western portion of the Musgrave Block. They are correlated with the 1075 Ma Tollu Volcanics in WA. These bimodal extrusives are interleaved with sediments and form pillow structures within basalt flows suggesting a subaqueous environment. Subsequent shallowing of the rift basin resulted in deposition of locally derived conglomerates, redbeds, quartzites and alluvial plain sediments.

Unconformably overlying the rift sediments are Neoproterozoic units of the southern margin of the intracratonic Amadeus Basin. These comprise a basal quartzite (Dean Quartzite), overlain by carbonate and shale (Pinyinna beds) then quartz sandstone (Ininndia and Winnall beds). Dolerite dykes of the 820 Ma Amata Dyke Swarm form an arcuate pattern through the western Musgrave Block and extend to the southeast as the Gairdner Dyke Swarm in Gawler Craton and Stuart Shelf. Basalt flows and spillite in Bitter Springs Formation (northern Pinyinna bed equivalents) are thought to be associated with Amata dykes.

Deposition in the Amadeus Basin was interrupted by exhumation of large sections of the Musgrave Block during the intraplate 560-520 Ma Petermann Orogeny. This orogenic event formed an east-west mobile belt with north-vergent tectonic transport on the northern margin under conditions of oblique compression. Intensity of deformation across the northern section of the belt is variable, with pervasive fabrics forming in the west and discrete shear zones in the east. The dominant regional scale structure formed during this event is the shallowly south dipping Woodroffe Thrust. This structure juxtaposed rocks with a pervasive mylonitic fabric formed under high P granulite conditions against lower grade upper amphibolite rocks.

The upper crustal expression of the Petermann Orogeny involved northward emplacement of an internally duplexed basement wedge along a detachment zone of structurally interleaved basement and basal Amadeus sediments (Piltardi Detachment Zone). This basement wedge was inserted into Neoproterozoic sediments of the Amadeus Basin with the Winnall and Inindia beds being detached and backthrust southwards to accommodate the resultant shortening. Flexural downwarping in front of this basement wedge formed the Mount Currie sub-basin, into which was deposited coarse fluvials of the Neoproterozoic to Cambrian Mount Currie Conglomerate and Mutitjulu Arkose.

Economic Potential

Due to access difficulties, the northern Musgrave Block and southern Neoproterozoic Amadeus sediments, including the proto-Amadeus rift sequence, have been relatively under explored. Recent NTGS mapping has incorporated assay sampling in the western region to help define areas of potential prospectivity.

Base Metal, PGEs and Gold

Elevated levels of base metals have been found in several gossans in the Neoproterozoic Pinyinna beds on the Amadeus Basin. The highest assay results were from within the high strain Piltardi Detachment Zone, and yielded 87 ppm Co, 0.15% Cu, 0.44% Pb, 0.33% V and 0.22% Zn. Other gossans within less deformed Pinyinna beds produced up to 2 ppm Ag, 8 ppb Au, 20 ppb Pt and 2 ppb Pd.

Within the Musgrave basement, scattered gossans over the granitic units contain minor enrichment in Cu (10-90 ppm), Zn (50-110 ppm) and lesser amounts of Pb. Sheared granite within the Piltardi Detachment Zone contains small copper deposits with ~ 2% Cu. Mafic dykes within the basement show elevated levels of Cu (30-95 ppm), Pb (15-170 ppm) and Zn (150-180 ppm).

Additional potential for base metal mineralisation occurs within the rift sequence underlying the Amadeus Basin. Deformed basalt within this sequence yields elevated values of Ag (4.5 ppm), Cu (1.1%), 130 ppm Zn.

The highest Ag values (89 ppm) are from undeformed quartz veins that cross cut granites and mafic volcanics within the rift sequence. These veins also yield anomalous Cu (1.94%), Pb (2.08%) and Au (101 ppb).

The only significant Au enrichment (0.19 ppm) was found in a deformed quartz vein within the Piltardi Detachment Zone. Anomalous levels of Bi (1.5%) and Cu (1.45%) were also present.

Nickel and Chromium

Minor outcrops of lateritised pyroxenite from the ultramafic Giles Complex produced assay results of 1.0% Ni, 0.55% Cr and 77 ppm Co.

Summary

Two main phases of base metal and gold remobilisation are evident in the northwestern Musgrave region. The first is syn-deformational during the Petermann Orogeny, with elevated values from deformed quartz veins in shear zones and highly strained host rocks within the Pinyinna beds and rift volcanics. Fluids associated with this remobilisation are probably derived from metamorphic dewatering of the rift sequence and basal Amadeus Basin sediments during compression.

The second phase of mineralisation is evident in late, undeformed quartz veins which may be associated with the 400-300 Ma Alice Springs Orogeny.

NTGS Products

Kulgera 1:250 000 mapsheet and explanatory notes	published 1993
Petermann Ranges 1:250 000 map and explanatory notes	published 1999
Ayers Rock 1:250 000 map and explanatory notes	due 2000
Bloods Range and Hull 1:100 000 maps and explanatory notes	due 2000
Umbeara 1:100 000 map and explanatory notes	due 2000
Northwest Musgrave special edition 1:250 000 map	due 2000
Musgrave Block (NT) synthesis report (including 1:500 000 map)	due 2000

NEW GEOLOGICAL MAP OF NORTHERN TERRITORY AND REGIONAL CONCEPTS

Project leader: Masood Ahmad
Phone: 08 8999-5276
Facsimile: 08 8999-6824
E-mail: masood.ahmad@nt.gov.au

Introduction

The existing and now outdated 1:2 500 000 map of NT was published in 1976 and was compiled from BMR first generation 1:250 000 maps. Second edition maps are now available for about half of NT and cover Pine Creek Orogen, McArthur Basin, Tennant Inlier, Murphy Inlier, Musgrave Block and parts of Arunta Province. In the past two decades, considerable geochronological data has also been gathered using more precise conventional and SHRIMP U-Pb zircon ages. NTGS and AGSO have completed airborne magnetic/radiometric surveys over a large part of NT, providing an insight to the sub-surface geology. There is therefore a large amount of new data available to compile an updated geological map of NT.

Consideration was given to various presentation styles including a generalised outcrop map and it was decided to show solid geology without Cainozoic cover. Such an exercise involves substantial subjective interpretation but the ensuing map will be clear and simple enough to highlight the similarity and differences between various tectonic domains. There are currently over 2000 named lithostratigraphic units in NT and they need to be grouped into readily identifiable regionally significant packages. The legend has to be simple but still should show significant lithostratigraphic information as well as spatial relations. The current geological time scale for the Proterozoic coincides little with the natural rock groupings, so functional chronometric groupings gain more importance. Given the above constraints, the NT map design and layout follows the WA geological map with modifications to enhance the spatial and temporal distribution of the lithostratigraphic packages.

Legend Design and Regional Concepts

NT has been divided into two principal tectonic domains: the North Australian Craton (NAC) and the Central Australian Mobile Belts (CAMB). This is used to divide the Proterozoic on the map into two tectonically different sequences of well recognised stratigraphy (NAC) and metamorphic complexes (CAMB). Igneous complexes are shown separately, but as far as possible major volcanic sequences are included within the enclosing sedimentary formation and are shown with different colour and symbol.

The best studied Proterozoic strata are the Pine Creek Orogen (PCO) and McArthur Basin sequences, providing a reference datum for other orogenic domains and platform sequences of the North Australian Craton. These are relatively less deformed, underwent mainly low grade or no metamorphism, and PCO was subjected to one major orogenic event (Barramundi Orogeny 1880-1850 Ma). It is possible to recognise and correlate the sedimentary ± volcanic packages in these domains with some certainty. The Proterozoic is divided into 10 well recognised unconformity-bounded regional packages (*P1* to *P10*, see below). Except for the Neoproterozoic which relates to *P10*, other recently proposed packages do not correspond to Proterozoic chronostratigraphic subdivisions. A convenient chronometric scale is used to define the boundaries of these packages. Phanerozoic is subdivided according to the conventional geological time scale.

CAMB represent polydeformed linear belts of medium to high-grade metamorphic terrains which underwent repeated deformation from ~1850 to Carboniferous. There are essentially two belts. The older northern belt (central and southern Arunta Province) shows similarities with Pan African belts in cyclic tectonic and igneous activity over a long period. The southern belt, representing the younger Musgrave Block and parts of the southern Arunta Province, is an extension of the Albany Fraser belt and has similarities to Grenvillean belts. Black and Shaw (1995) identified seven tectonic event/orogenic periods in the Arunta Province ie 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). In the Musgrave Block, Scrimgeour *et al* (1999) described two major tectonic events, ie Musgravian Event (1200 Ma) and Petermann Orogeny (580-520 Ma).

North Australian Craton

Orogenic Domains

Orogenic domains of the NAC are typified by the Pine Creek Orogen, exposing a complete unconformity bound sequence between underling Archaean basement (~2.5 Ga) and basal arenites (~ 1.72 Ga) of overlying McArthur Basin. This succession is divided into rift, sag and flysh sequences followed by syn- to post-orogenic granites and largely coeval felsic volcanics with intervening sediments mostly confined to rift-bound grabens. Five packages *P1* to *P5* are identified on the map legend. *P1* and *P2* surround Archaean domes but others are regionally widespread. The Tanami Region may also have a complete sequence but only *P3* and *P4* are identified so far. Tennant, Murphy and Arnhem Inliers expose flysh packages *(P4)* and subsequent syn (~1.86 Ga) and post orogenic (~1.83 Ga) granite, felsic volcanic and sedimentary rocks *(P5)*. All of these orogenic domains have undergone one major orogenic event – the 1880-1850 Ma Barramundi Orogeny – and remained as stable craton thereafter. The strata were deformed and metamorphosed (generally lower greenschist, in places amphibolite facies, and granulite facies only in Arnhem Inlier) during the Barramundi Orogeny. Post orogenic granites resulted in superimposed contact metamorphism. Two major periods of granitic activity are recognised at 1866-1850 and 1825 Ma. Mafic volcanics are present in the *P3* and *P4* intervals.

North Australian Platform Cover

The North Australian Platform Cover (NAPC) represents unconformably overlying, little deformed or metamorphosed post-Barramundi platform sequences of the NAC. Well documented amongst these is the McArthur Basin providing a reference datum for Victoria, Birrindudu and Nicholson Basins and Ashburton and Davenport Provinces. Rawlings (1999) identified five distinct packages in the McArthur Basin. Four of these unconformity-bounded packages have great regional significance and can be identified throughout NAPC, starting with a rift sequence comprising fluvial to shallow marine arenites, bimodal volcanics and shallow intrusives *(P6).* This sequence is followed by a stromatolitic and evaporitic carbonate-arenite-shale package mostly confined to fault-bounded rifts *(P7).* The third package is regionally extensive and represents stromatolitic carbonate and arenite deposited in sag basins *(P8).* Predominantly shallow marine arenite deposition in epicontinental basins represents the fourth package *(P9).* Major igneous activity is confined to *P6* (mostly bimodal volcanics and shallow intrusives) and *P9* (mostly mafic intrusives).

Central Australian Mobile Belts

High-grade metamorphism, repeated tectonic activity, limited geochronological constraints and lack of surface exposure make regional correlation and identification of individual packages extremely difficult. Although four packages are tentatively defined and correlated with strata in the NAC, they may represent deposition in an entirely different geological terrain. Collins and Shaw (1995) have identified ten lithological assemblages. These are simplified into four somewhat regionally extensive sequences. The Lander assemblage represents a sequence of meta-turbidites and is assigned to *P4*. The Strangways assemblage includes felsic and mafic granulites probably representing bimodal volcanism. This along with Cadney and Bunghara assemblages is correlated with *P5*. The Harts assemblage includes pelite, carbonate, quartzite and amphibolite and represents shallow marine to intertidal sediments and bimodal volcanics. The Harts, Bonya and Reynolds assemblages are correlated with *P6*. The Chewing, Simpson and Maddern assemblages comprise orthoquartzite and felsic volcanics. These are shown as one unit and are correlated with *P7* to *P9*. The pre-Dean Quartzite rift package in the Musgrave Block and southwest Arunta represents felsic meta-volcanics and meta-arenites. These are assigned to *P9*. Granitic activity shows a southward younging trend with major events at 1.8-1.7 Ga, 1.5-1.6 Ga and 1.2-1.1 Ga.

Centralian Superbasin

P10 represents the Neoproterozoic which following Walter *et al* (1995) is subdivided into four sequences ($P10_1$ to $P10_4$). These were deposited in the intracratonic Centralian Superbasin, developed through extension culminating in the Early Cambrian seafloor spreading. It forms the base of the Amadeus, Georgina and Ngalia Basins and the sequence was subjected in places to the 580-520 Ma Petermann Orogeny. $P10_1$ is a sequence of carbonates, evaporites and fine siliclastics (Heavitree Quartzite and Bitter Springs Formation and equivalents). $P10_2$ is marked by glaciogenic sediments followed by silt and shale with interbedded carbonates and sandstones (Areyonga and Aralka formation and equivalents). $P10_3$ represents glaciogenic sediments at the base followed by siltstone, shale, and sandstone and carbonate (Olympic, Pioneer and Pertatataka Formations and equivalents). The glaciogenic sediments in the Victoria Basin are also assigned to this sequence. $P10_4$ represents a dominantly arenaceous sequence (Arumbera Sandstone and equivalents). Bukalara Sandstone and Wessel Group in the Arafura Basin are considered to be the time equivalent of $P10_4$.

Phanerozoic Basins

Because of little deformation or metamorphism, correlation and layout of Phanerozoic sedimentary basins can be done with confidence and using straightforward chronostratigraphic subdivision. These basins are divided into Palaeozoic and Mesozoic offshore basins (Arafura, Bonaparte and Carpentaria Basins), Palaeozoic inland basins (Amadeus, Ngalia, Georgina, Wiso and Daly Basins) and Carboniferous to Mesozoic inland Basins (Pedirka and Eromanga Basins).

Cainozoic Cover

Unconsolidated Cainozoic cover is omitted except for Quaternary sand, silt and clay in the coastal estuaries and mid Tertiary sand, silt, clay, calcrete and limestone in inland palaeodrainages, and sandstone on Bathurst and Melville Islands.

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PALAEOPROTEROZOIC STRATIGRAPHY AND CORRELATIONS OF THE TANAMI REGION, NORTHERN TERRITORY- PRELIMINARY RESULTS.

Project Team: Marc Hendrickx, Dr. Leon VandenBerg, Andrew Crispe, Kerry Slater, Alison Dean, Dr. Andrew Wygralak, Dr. Julie Smith

Phone: 08 8951-1661

Facsimile: 08 8951-1660

E-Mail: marc.hendrickx@nt.gov.au

Palaeoproterozoic rocks in the Tanami region occur as widely separated, discontinuous, deeply weathered or silicified outcrops which complicate the task of understanding the geology of the region. However with the provision of detailed geophysical data, detailed mapping and drilling by exploration companies over the past two decades and more recently by NTGS, sufficient information is now available to more accurately define the geology of the Tanami region.

The region was first mapped by BMR between 1971 and 1974 (Blake *et al* 1979). They recognised four units in the Palaeoproterozoic: Tanami Complex (with five constituent units) overlain unconformably by Pargee Sandstone, Mount Winnecke Formation and Supplejack Downs Sandstone. The Tanami Complex comprises metasediments and volcanics which were divided into five units based on different proportions of rock types and geographic separation (Blake *et al* 1979). These units: Killi Killi Beds, Mount Charles Beds, Nanny Goat Creek Beds, Nongra Beds and Helena Creek Beds were thought to be lateral equivalents. Detailed mapping and geophysical interpretation (**Figure 1**) by NTGS during 1999 has extensively revised the stratigraphy (**Table 1**).

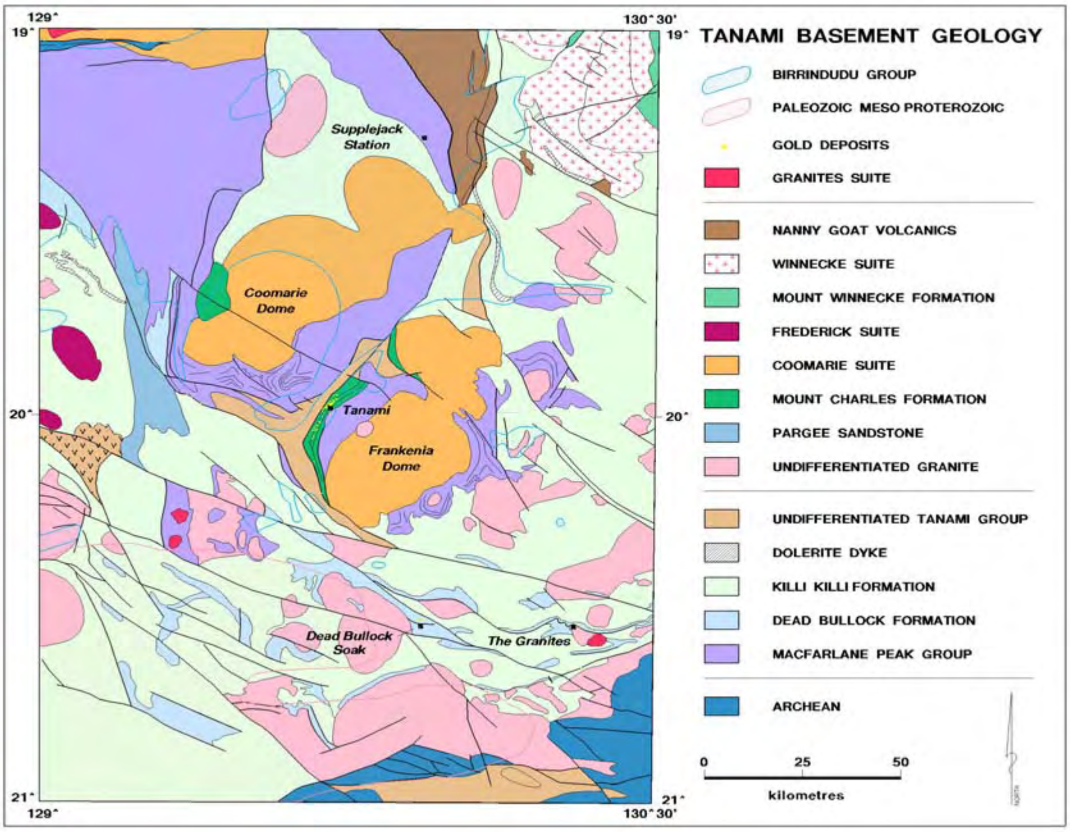

Figure 1 Summary of the basement geology of the Tanami and The Granites 1:250 000 map sheet areas.

Table 1 Comparison of stratigraphic nomenclature between Blake et al, 1979 and this report

<table>
<tr><td colspan="6">Blake et al 1979</td><td colspan="3">This report</td></tr>
<tr><td rowspan="3">Birrindudu Group</td><td colspan="5">Coomarie Sandstone</td><td rowspan="3">Birrindudu Group</td><td>Coomarie Sandstone</td><td rowspan="3">Supplejack Downs Sandstone</td></tr>
<tr><td colspan="5">Talbot Well Formation</td><td>Talbot Well Formation</td></tr>
<tr><td colspan="5">Gardiner Sandstone</td><td>Gardiner Sandstone</td></tr>
<tr><td colspan="6">Supplejack Downs Sandstone</td><td rowspan="3">Pargee Sandstone</td><td colspan="2">Nanny Goat Volcanics</td></tr>
<tr><td colspan="6">Mount Winnecke Formation</td><td colspan="2">Mount Winnecke Formation</td></tr>
<tr><td colspan="6">Pargee Sandstone</td><td colspan="2">Mount Charles Formation</td></tr>
<tr><td rowspan="3">Tanami Complex</td><td rowspan="3">Mount Charles Beds</td><td rowspan="3">Killi Killi Beds</td><td rowspan="3">Nanny Goat Creek Beds</td><td rowspan="3">Nongra Beds</td><td rowspan="3">Helena Creek Beds</td><td>Tanami Group</td><td colspan="2">Killi Killi Formation

Dead Bullock Formation</td></tr>
<tr><td colspan="3">MacFarlane Peak Group</td></tr>
<tr><td colspan="3">Browns Range Metamorphics</td></tr>
<tr><td colspan="6">Archean</td><td colspan="3">Archean</td></tr>
</table>

The revised stratigraphy is similar to other Palaeoproterozoic successions in northern Australia, in particular the Pine Creek and Halls Creek orogens (**Figure 2**). The geological history is also similar to the Wopmay Orogen in northwest Canada (Hoffman and Bowring 1984).

The oldest rocks are Archean gneiss and schist which occur in the Billabong Complex southeast of The Granites and in a fault bound slice south of Browns Range Dome which we have named Browns Range Metamorphics (**Figure 1**). Zircon dating of Browns Range Metamorphics (AGSO OZCHRON database) reveals Archean ages from enclaves in granitic gneiss (metamorphic age of 1882 Ma) and from detrital grains in sandstone west of Browns Range Dome in Western Australia. It is possible that Browns Range Metamorphics are metamorphosed equivalents of MacFarlane Peak Group.

In the Palaeoproterozoic we have identified an early rift stage (MacFarlane Peak Group) dominated by mafic volcanics and volcaniclastics with minor clastic sediments and calcsilicates. The group shows lithological similarities to parts of Ding Dong Downs Volcanics, dated at 1910 Ma, and Biscay Formation, dated at 1880 Ma (Blake *et al* 1998). A major difference is the absence of mapped felsic volcanics in MacFarlane Peak Group.

MacFarlane Peak Group is overlain by a thick succession of clastic sediments (Tanami Group) representative of a passive margin sequence. The lower part of Tanami Group comprises carbonaceous siltstone with minor banded iron formation and calcsilicate (Dead Bullock Formation). It is characteristic of deposition in an oxygen starved basin. The formation is lithologically similar to the South Alligator Group in the Pine Creek Orogen (Koolpin Formation) and to parts of Biscay Formation in the Halls Creek Orogen. The upper part of Tanami Group consists of a thick monotonous sequence of turbiditic sediments (Killi Killi Formation). The unit is lithologically similar to the upper Olympio Formation in the eastern Halls Creek Orogen (Blake *et al* 1998) and to Burrell Creek Formation (Finness River Group) in the Pine Creek Orogen.

Dolerite sills intrude both MacFarlane Peak Group and Tanami Group. Individual sills are up to 200 m thick and consist of fine to coarse metadolerite. They predate the first deformation event in the Tanami region. The sills are probably similar to Woodward Dolerite (Halls Creek Orogen) and Zamu Dolerite (Pine Creek Orogen).

MacFarlane Peak and Tanami groups were deformed, metamorphosed and intruded by granite during a major orogeny around 1845-1840 Ma. This event is correlated with the Barramundi Orogeny in the Pine Creek Orogen and with the Halls Creek Orogeny in northern Western Australia.

Major mountain building was followed by localised extension. A thick sequence of conglomerate, sandstone and minor siltstone (Pargee Sandstone), interpreted to represent post orogenic molasse, was deposited in a shallow marine environment west of the Coomarie Dome. Pargee Sandstone shows lithological similarities with the Moola Bulla Formation in Halls Creek. Equivalent units have not been recognised in either Pine Creek Orogen or Tennant Inlier. Localised extension further east led to the formation of a small inter continental rift subsequently filled with pillow basalt and turbiditic sediments (Mount Charles Formation).

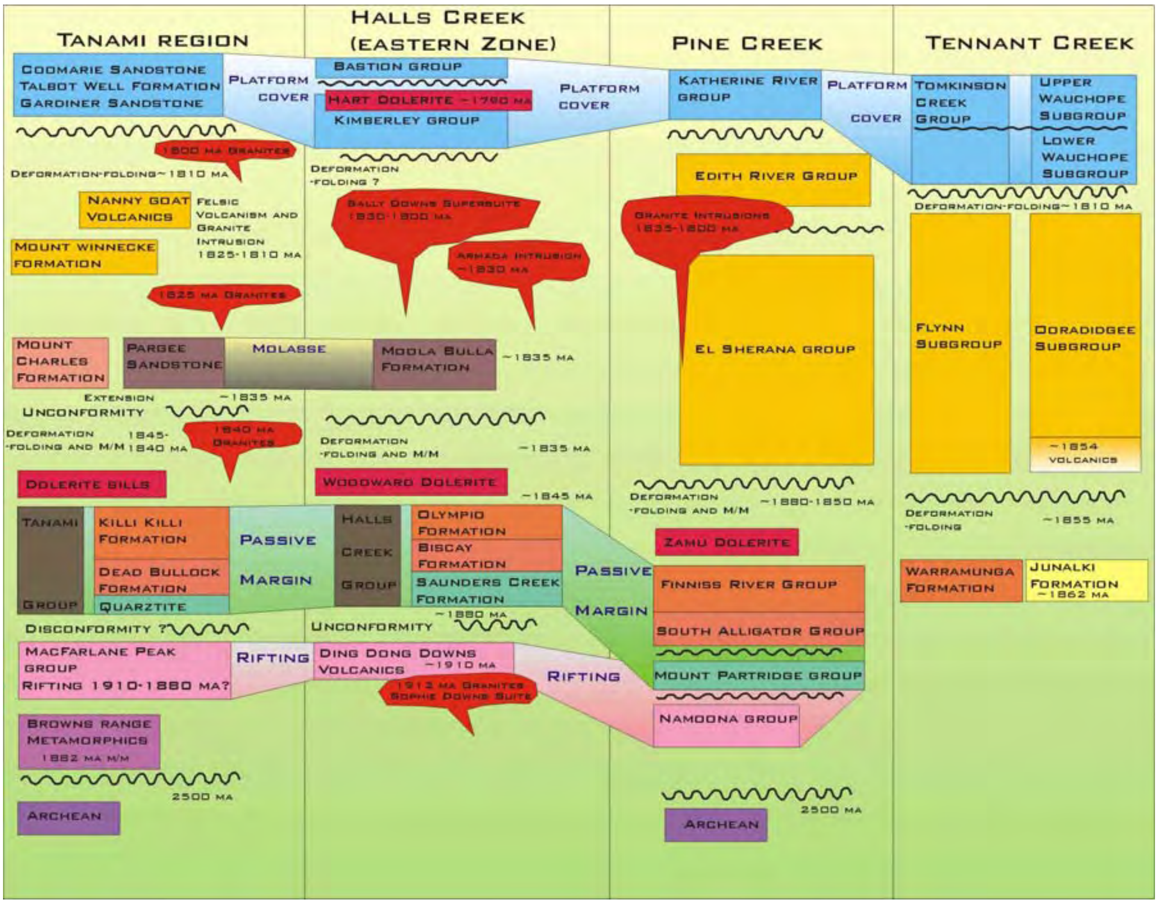

Figure 2 Correlation chart for the Tanami, Halls Creek, Pine Creek and Tennant Creek areas

Widespread granite intrusion and volcanism affected the north Australian craton between 1830-1810 Ma. In the Tanami Region we recognise three granite suites and two volcanic complexes associated with this protracted thermal event (**Figure 1**). The Coomarie Suite comprises large I-type plutons with a low to moderate magnetic response (Coomarie, Frankenia and Browns Range domes). The Frederick Suite occurs close to the WA border and consists of smaller, rounded I-type plutons with high magnetic response. Winnecke Suite comprises large I-type plutons and related volcanics (Mount Winnecke Formation). These have variable magnetic responses and mainly outcrop in BIRRINDUDU. Zircon dating indicates an age of 1825-1815 Ma for Mount Winnecke Suite. Nanny Goat Volcanics occur in northern TANAMI and consist of ignimbrite, rhyolite and high level porphyry dated at 1816 Ma. Dating of samples from the Coomarie and Frederick suites is in progress.

Significant deformation at 1810-1800 Ma affected Pargee Sandstone, Mount Charles Formation, Mount Winnecke Formation and Nanny Goat Volcanics. A series of post orogenic I-type granites (Granites Suite) were emplaced at 1800-1795 Ma.

The Birrindudu Group, a 2 km thick sequence dominated by quartz arenite with minor carbonate, was deposited onto a subdued landscape sometime after intrusion of the Granites Suite. Geophysical interpretation indicates the presence of basalt high in the sequence south of Browns Range Dome. The group is lithologically similar to Tomkinson Creek Subgroup in the Tennant Inlier and has a similar structural style and magnetic response. It may correlate with the Bastion Group in the Halls Creek Region.

Birrindudu Group and basement rocks were deformed, probably prior to deposition of Limbunya Group at around 1650 Ma . Deformation was dominated by thin skinned processes which resulted in thrust faulting within the Birrindudu Group. Movement on the east trending Trans-Tanami system of faults occurred during this time but may represent reactivation of older structures. Offsets in the distribution of Cambrian Antrim Plateau Volcanics suggest additional movement occurred on these faults during the King Leopold and/or Alice Springs orogenies.

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PRELIMINARY STRUCTURAL ANALYSIS OF THE TANAMI REGION

Project staff: Leon Vandenberg, Marc Hendrickx, Andrew Crispe
Phone: 08 8951-5662
Facsimile: 08 8952-7762
E-mail: leon.vandenberg@nt.gov.au

Preliminary results indicate that the Tanami Region has been subjected to at least eight regional deformation events (BE_1, D_1-D_{7+}). An initial basin forming event (BE_1) is stratigraphically inferred and suggested to have involved regional extension and/or subsidence of the Archean basement. The first four deformation events (D_1-D_4), together with an early M_1 regional greenschist to amphibolite facies metamorphic event, characterise the Barramundi Orogeny (~1845 Ma).

D_1 structures are variably orientated due to later deformation and are characterised by asymmetric, disharmonic F_1 fold couples. Within siliceous units the S_1 axial planar fabric is a discontinuous, anastomosing dissolution-style cleavage. Within siltstone units the S_1 fabric is a slaty cleavage.

Fabric-porphyroblast overprinting relationships indicate that M_1 occurred late syn-to post-D_1. Peak M_1 metamorphic assemblages are biotite-andalusite-plagioclase-kfeldspar (+/-garnet, sillimanite) in pelitic units, and garnet-biotite (+/-cordierite) in semipelitic units (eg Scrimgeour and Sandiford 1993). Calculated PT conditions from these assemblages indicate T ~600^0C and P ~3.5 kbar (ie 10-14km depth; Scrimgeour and Sandiford 1993), suggesting burial at shallow-to-mid crustal depths during D_1.

D_1 and M_1 fabrics are deformed by more open D_2 fold structures, oriented mainly north. Within pelites and lower grade equivalents the S_2 fabric is a spaced crenulation and/or crenulation cleavage (0.1 - 1 cm). Rare oblique F_1 and F_2 fold interference structures are also observed (eg mushroom style).

D_3 faults cut D_1 and D_2 structures, however the kinematic history of D_3 remains uncertain.

D_4 structures are characterised by northeast to east striking chevron folds and kinkband structures. S_4 fabrics are generally fracture style cleavages within siliceous units. Mineralogically differentiated S_4 cleavages within less siliceous lithologies are rare. These observations suggest that basement rocks formerly at mid-crustal depths during D_1 and D_2 were by D_3 and D_4 times at significantly higher crustal levels.

Deposition of Mount Charles Formation, subsequent intrusion of the Coomarie granite Suite (~1824-1810 Ma; inferred) and extrusion of associated felsic volcanics are consistent with local/regional? extensional basin formation. D_1-D_4 structures are not observed at this level in the stratigraphy (**Figure 1**).

D_6 shear zones, thrust faults and oblique slip thrusts dissect the region and constitute major bounding structures. D_6 structures operated after the emplacement of the Coomarie Granite Suite and are spatially coincident with several significant gold deposits (eg Bonsai, Jims, and the Tanami mine corridor). In the Tanami mine corridor numerous small-scale D_6 thrusts, backthrusts, layer-parallel decollemont and breccia horizons indicate strong rheological controls in the formation of a significant network of structures at upper crustal levels. Au mineralisation at The Granites and Dead Bullock Soak is coincident with localised post-Barramundi shear zones/faults within suitable lithologies and fold structures, although at a deeper crustal level than the Tanami corridor.

D_{7+} thrust faults and oblique slip thrusts cut all earlier structures and have affected folding within the overlying Birrindudu Group cover sequence (ie post 1770-1660 Ma).

Later stages of structural evolution of the Tanami Region involved interaction of several granite-cored structural domains during northwest-southeast to north-south regional shortening (**Figure 2**). It is also suggested that a change in regional stress conditions (from east-west shortening during D_1 and D_2, to more northwest-southeast to north-south shortening during D_3-D_{7+}), reflects a shift away from the influence of collisional orogenic processes to the north west (eg the Hall Creek Orogenic zone), to the influence of a long-lived crustal scale transpressional shear zone in the south of the Tanami Region (eg King Leopold orogenic zone; Krapez 1999, Sheppard *et al* 1999).

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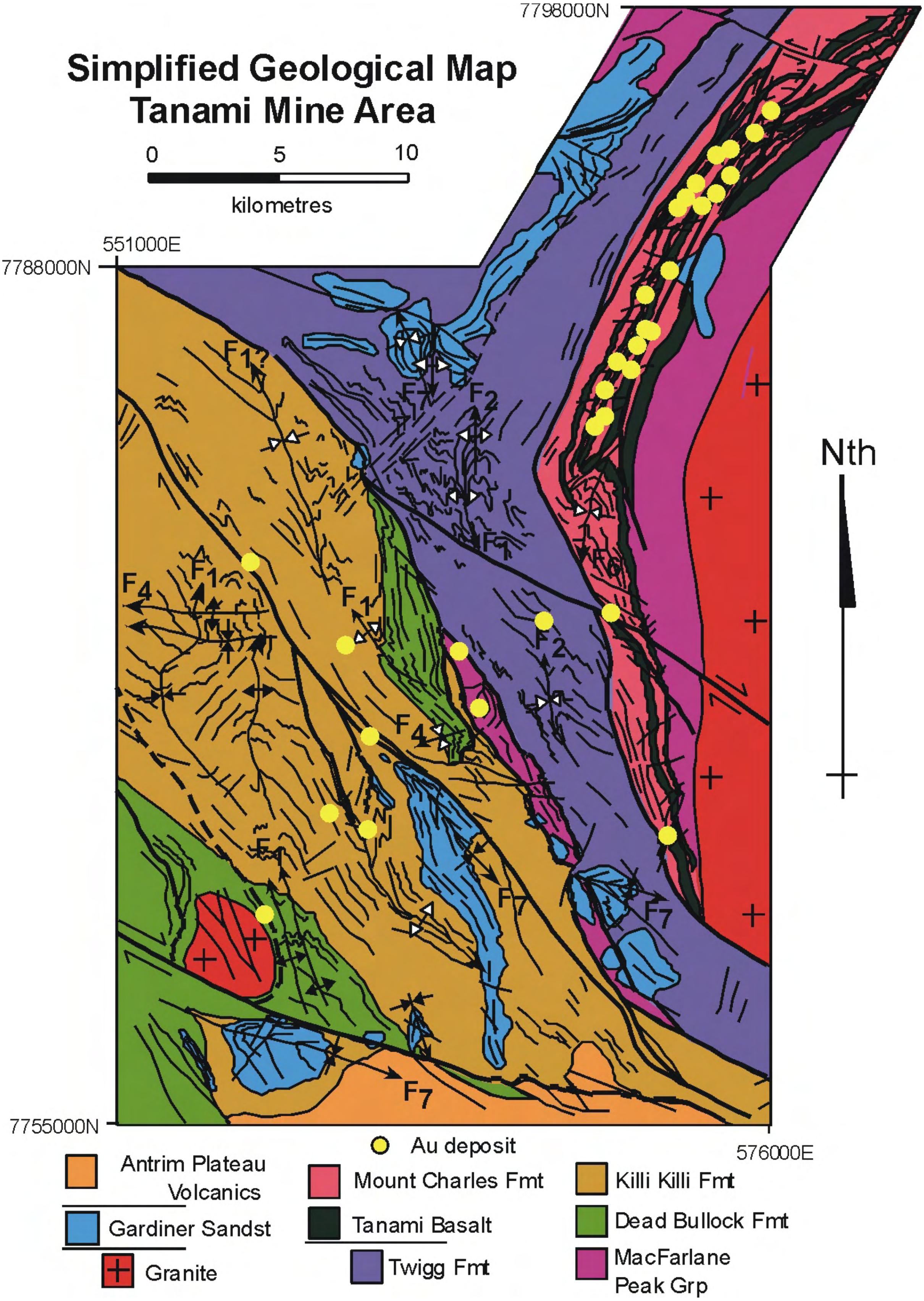

Figure 1 Simplified geological map of the Tanami mine area.

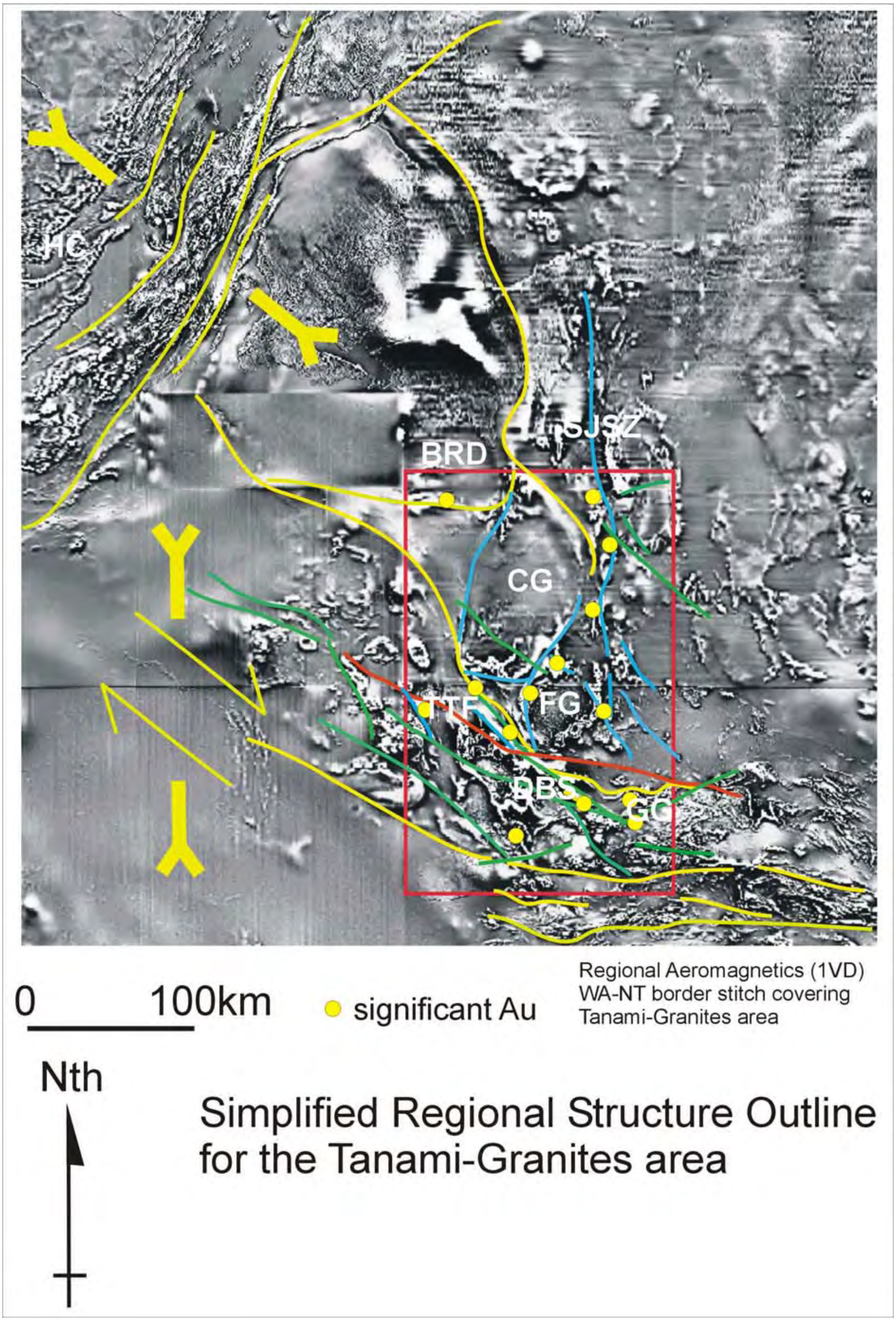

Figure 2 Simplified regional structure outline for the Tanami Region (red box outline).

GOLD MINERALISATION OF THE TANAMI REGION

Project leader: Andrew S. Wygralak
Phone: 08 8999-5441
Facsimile: 08 8999-6824
E-mail: andrew.wygralak@nt.gov.au

The Tanami Region is one of the emerging gold provinces in Australia. In the past decade it has produced 2.7 Moz Au and has a current resource of 6.3 Moz Au. Past production has come from three goldfields: Tanami, The Granites and Dead Bullock Soak (DBS).

Metallogenic studies at these goldfields form part of a major NTGS regional geoscience project commenced in mid 1999 which includes geological, geophysical and regolith mapping as well as structural, petrological and geochronological studies.

Much of the Tanami Region comprises Palaeoproterozoic (1910-1850 Ma) sedimentary and volcanic sequences deformed and metamorphosed (sub greenschist to amphibolite facies) during the 1880-1850 Barramundi Orogeny. Additional sequences were deposited after the Barramundi Orogeny. The sequence was subsequently intruded by different phases of post orogenic I-type granites and affected by apparently coeval felsic volcanism. Seven deformational episodes (D1 to D7) are outlined.

The principal metallogenic questions in this region are why the existing gold deposits are located where they are, and where to look for more mineralisation. A regional program of fluid inclusion microthermometry, Raman microprobe and stable isotope analyses of auriferous and barren quartz veins was initiated in order to establish the physicochemical parameters, origin and evolution of hydrothermal fluids.

The most comprehensive fluid inclusion study was conducted at Callie (DBS), where the relationship between pre-, syn- and post-ore generations of veining is most clear and allows the tracing of fluid evolution. Results are summarised in **Table 1**.

Table 1 Summary of fluid inclusion study at Callie

Stage	Homogenisation temp. (^oC)	Salinity (wt% NaCl equiv.)
Pre-ore quartz veins	200-400	6-8
Ore stage quartz veins	310-330	7-9
Post-ore quartz veins	200-230	12-20
Late carbonate veins (post-ore)	90-130	13-26

There is a trend of decreasing temperature and increasing salinity from pre- through syn- to post-ore vein generations. At the ore stage, CO_2 bearing fluid was introduced. Varying vapour/liquid ratios of CO_2 indicate effervescence (fizzing out). The only other gas detected at Callie by Raman microprobe was N_2, occuring in significant amounts (up to 100% in some inclusions). Loss of CO_2 caused by a pressure drop in rising fluid would increase pH and provide a gold precipitation mechanism. Stable isotope data show calculated fluid composition of $\delta^{18}O = 5.9 \pm 2$ ‰ and δD = minus 85 to –58 ‰. Such values fall within the magmatic range and partly overlap the metamorphic range.

At The Granites goldfield, ore-stage fluids had a temperature range of 260-280^{o}C and salinity of 4-8 wt% NaCl equivalent. The dominant gas phase is CO_2 (90% of all inclusions are CO_2-rich). Other gases include N_2 and CH_4. Methane was probably produced as a result of CO_2-rich fluid reacting with graphite bearing host rocks. This reduction may also have been the mechanism for gold precipitation. Calculated fluid composition based on stable isotope data is $\delta^{18}O = 2.6 \pm 2.7$ ‰ and δD = minus 71 ‰. Depleted (relative to Callie) $\delta^{18}O$ values are probably an effect of CO_2-H_2O fractionation. Calculated fluid values fall within both magmatic and metamorphic range and probably represent mixed magmatic and contact metamorphic fluids.

Fluid characteristics at Tanami goldfield are different. The ore stage fluid had a lower temperature, range of 140-220^{o}C. This is consistent with other observed features indicating low temperature such as the presence of collomorphic silica and 'comb' textures in quartz. The salinity of the fluid was in the range 2-8 wt% NaCl equivalent. Raman microprobe analyses indicated that fluids are completely degassed, further indicating low pressure conditions and shallow depth of formation. The main gold precipitation mechanism at Tanami was probably loss of pressure and temperature. Calculated fluid composition shows a relatively wide range of $\delta\,^{18}O$ = 1.2 to 5 ‰ and δD = -69 to –37 ‰. Such a range is again consistent with low temperature veins emplaced at shallow depth by magmatic fluid. Major influx of meteoric water can also be inferred from extensive regional propyllitic alteration of basalt.

Fluid inclusion data indicate that the depth of formation of ore stage veins at Callie was 4.6 km, The Granites 1.8-3.8 km and Tanami 100–400 m.

Two mineralisation models are proposed:

Tanami Goldfield

Mineralisation is located within a post-Barramundi, moderately folded (D6+) terrain, in an elongated zone ("Tanami Corridor") between two large granitic intrusions (Frankenia and Coomarie domes). The granites provided a large heat source, which apart from providing an influx of magmatic fluid, activated circulation of meteoric water in overlying basalt and sediments. Circulating water formed numerous convective cells, extracted gold from the host rocks and precipitated it as a result of decreasing pressure and temperature. There was no well-defined focusing mechanism (such as a major fault or shear) and mineralisation formed at a shallow depth range of 100–400 m, in a multitude of small orebodies controlled by 020º and 060º trending fractures.

DBS and The Granites goldfields

Mineralisation is hosted by strongly deformed (D1) rocks. Mixed magmatic and metamorphic fluids were circulated at a moderate depth range of 1.8-4.6 km. The circulation was caused by a concentrated (pointed) heat source provided by an apex of intruding granite. Fluids circulated within a shearing regime and were focused into preexisting shears (”structural corridor” at Callie and “Trans-Tanami fault zone” at The Granites) where they formed a small number of relatively large orebodies.

Mineralisation in all three goldfields can be also incorporated into one model. Such a model includes a single fluid system. The rising and gradually cooling fluids contemporaneously precipitated gold in the sheeted vein system at Callie, provided a source of gold for the BIF horizons at The Granites and DBS, and finally, after reaching shallow depths and losing volatile components, precipitated gold in basalt-hosted Tanami goldfield deposits.

As yet there is no direct data on the age of mineralisation (for example Ar–Ar dating of hydrothermal sericite from the wallrocks of auriferous veins). Such work will be conducted as the project progresses.

TENNANT CREEK BEDROCK INTERPRETATION

Project Leader: Andrew Johnstone
Phone: 08 8999-5340
Facsimile: 08 8999-6824
Email: andrew.johnstone@nt.gov.au

The focus of this project is to construct a basement map covering Tennant Creek 1:250 000 sheet, in which there is only 20% outcrop. A mineral prospectively map may also be produced. Geophysical interpretation and recent geological mapping will be integrated to build a basement map of value to mineral explorers.

The interpretation uses AGSO magnetic and radiometric data, flown over Tennant Creek 1:250 000 sheet. The survey was flown north-south at 60 m height with a 200 m line spacing, and was released in May 1999.

Interpretation of the geophysics has been a joint effort with Nigel Donnellan who has extensive experience in Tennant Inlier. Interpretation sessions used geological overlays and geophysical images. In the future interpretation sessions will be completely digital, run in a GIS environment and focused over one or two weeks using project geologists, geophysicists and outside experts.

The Tennant Creek mineral province has produced in excess of 150 t Au and 318 000 t Cu, plus significant amounts of Bi, Se and Ag from over 130 mines (Donnellan *et al* 1999). Known mineralisation is mainly hosted by ironstones in Warramunga Formation and Flynn Subgroup and could be related to iron oxide copper gold (IOCG) deposit class. There are geological similarities with the Eastern Succession in Queensland which hosts deposits such as Eloise, Mt Elliott, Osborne, Starra and Ernest Henry. Exploration in the Tennant Creek region has traditionally focused on locating magnetic ironstones which host mineralisation. Exploration for giant IOCG deposits such as Ernest Henry and Olympic Dam has only recently begun in the area. There is also potential for non-magnetic examples of classic Tennant Creek mineralisation. Eldorado, Argo and Nobles Nob all contained zones of hematitic hosted ore.

There are two areas of regionally active magnetic crust (magnetic flare ups) on Tennant Creek sheet which have IOCG potential. These magnetic flares may be caused either by regional alteration with attendant release of magnetite, or thermal conversion of pre-existing hematite to magnetite. These processes may be related to intrusions. There are a number of gravity anomalies associated with these magnetic areas that could enhance the IOCG potential.

The discovery of Chariot deposit by Normandy/PacMin, and Billy Boy by Giants Reef, has created renewed interest in the field. Detailed geophysical interpretation shows there may be a number of previously unrecognised (buried) areas of prospective Warrumunga and Flynn stratigraphy. These areas extend to the east, south and possibly west of the known core area. One example is the similarity between magnetic signatures of the host rocks of Edna Beryl and Billy Boy deposits.

A new 400 m spaced airborne magnetic survey was flown south of Tennant Creek on behalf of NTGS by AGS in 1999. The survey covers the northern Lander River, Bonney Well and Frew River 1:250 000 Sheets. A strip of 200 m infill was also collected directly south of the Tennant Creek survey to tie in with 200 m AGSO data. This new data set indicates extensions of Tennant Creek stratigraphy into northern Bonney Well sheet. Normandy has actively explored an area of this stratigraphy known as the Rover field.

Basement interpretation maps are expected be completed by June 2000. Ongoing integration will incorporate radiometric and semi-detailed gravity data. Mineral deposit, drill hole, satellite and geochemical data will be also integrated into the interpretation.

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TENNANT INLIER, ITS STRATIGRAPHY AND CORRELATION

Project Leader: Nigel Donnellan
Phone: 08 8951-5666
Facsimile: 08 8951-5660
E-Mail: nigel.donnellan@nt.gov.au

The stratigraphy of the Tennant Inlier and possible correlations with the Arunta Province and the Pine Creek Orogen have been studied as part of the 'Tennant-Tanami Link' program.

Historically, the Tennant Inlier is geographically well defined. It includes the outcrop extent of Palaeoproterozoic rocks in the Davenport and Murchison Ranges of the Davenport province in the south, and the Short, Whittington and Ashburton Ranges of the Ashburton province in the north. The central part of the Inlier, the Tennant Creek province, is generally more recessive but does include dissected remnants of a regionally extensive peneplain, the Ashburton Surface, which includes Mount Samuel, and McDouall and Honeymoon Ranges.

The Taylor and Crawford Ranges represent an obvious extension of the Inlier, and aeromagnetic data indicate that the stratigraphy extends over a much wider area. This geophysical continuity is obscured in outcrop by Palaeoproterozoic to Mesoproterozoic rocks, which outcrop in the northernmost Ashburton Ranges (equivalent to the McArthur and Roper Groups of the McArthur Basin). Neoproterozoic to Palaeozoic rocks of the Georgina and Wiso Basins conceal Palaeoproterozoic geology to the east and west respectively, and there is widespread surficial cover. It is expected that geologically meaningful terrain boundaries will emerge, resulting in a more rational subdivision of northern and central Australia.

A structural framework for the Tennant Inlier is presented in **Table 1**. It includes components of two orogenic cycles, the Barramundi and Davenport Orogenies. The Barramundi Orogeny is regionally widespread in northern Australia, and Etheridge *et al* (1987) recognised rift, sag and synorogenic turbiditic flysch phases of sedimentation associated with it. However, only the flysch phase of this orogenic cycle, is represented in outcrop in the Tennant Inlier (the turbiditic, tuffaceous Warramunga Formation). Syn- to immediately post-tectonic intrusive and extrusive rocks, predominantly dacitic to rhyolitic ignimbrites, of the Barramundi Igneous Association (BIA) are well represented in the central area of the Tennant Creek province.

Unfortunately, a clear litho- or tectono-stratigraphic break has not yet been identified within the Flynn and Ooradidgee Subgroups which would correspond with the apparent time break between the ~1850 (1862-1837) Ma Tennant Creek Supersuite and the ~1820 (1829-1816) Ma Treasure Suite of Wyborn *et al* (1998). Extrusive felsic magmatism may be associated with continuing, localised extension from late in the Barramundi orogenic cycle into the early stages of the Davenport orogenic cycle, notwithstanding penecontemporaneous compression in the Warramunga Formation basin. An analogy can be drawn with the transverse-fault basins of the Betica Cordillera in Spain (Debelmas and Mascle 1998).

A transition from rift to sag phases of sedimentation in the Davenport geosyncline is coincident with the Ooradidgee/Wauchope Subgroup boundary, and the corresponding Flynn Subgroup/Tomkinson Creek Group boundary in the northern extension of the Davenport geosyncline in the Ashburton province. Tomkinson Creek Group, and Wauchope and Hanlon Subgroups of the Hatches Creek Group correlate with Tawallah Group of the McArthur Basin. A tectonic break at this level in the stratigraphy is called the Murchison Event (~1810 Ma) and is correlated with the Stafford Tectonic Event (~1830 Ma) in the northwestern, and the Early Strangways Orogeny (~1780 Ma) in the northeastern, Arunta Province. This indicates deformation is diachronous.

The Junalki Formation immediately underlies the Unimbra Sandstone (Wauchope Subgroup, Hatches Creek Group), north of Murchison Syncline. This Formation comprises rhyodacitic to rhyolitic crystal-lithic tuff, and minor andesitic to dacitic lava near the top of the Formation. It changes from more volcanic dominated at the base with interbedded tuffaceous volcanic and volcaniclastic rocks, to predominantly volcanilithic sandstone and siltstone upwards. The Junalki Formation was previously interpreted as a correlative of the 1849 Ma Yungkulungu Formation which similarly varies from a lower, predominantly volcanic to an upper, predominantly sedimentary succession. However, lithological similarity of the Junalki Formation with the undifferentiated former Warramunga Group rocks on northeastern Bonney Well 1:250 000 map sheet was noted. A new date for the latter is 1862 Ma (Smith 1999). These volcanic rocks are more deformed than other Flynn Subgroup and the Ooradidgee Subgroup volcanic and sedimentary rocks. Junalki Formation therefore extends from southern Tennant Creek to northern Bonney Well map sheets and is considered to be a time equivalent of the Warramunga Formation.

A hiatus was identified by Haines *et al* (1991) within the Wauchope Subgroup, at the base of the Coulters Sandstone on Barrow Creek 1:250 000 map sheet. There is a local, but widespread erosional unconformity at this level in the stratigraphy throughout the Davenport province (Blake *et al* 1987), and a change from fluviatile to shallow marine sedimentation throughout the Inlier. A regional disconformity is suggested which is coincident with the onset of the Early Strangways Orogeny of the Arunta Province. This hiatus is not contemporaneous with deformation in the Tennant Inlier which, as noted above, was 30-40 my earlier during the Murchison Event. A similar hiatus is postulated within the Yiyintyi Sandstone, of the Tawallah Group in the McArthur Basin, between alluvial fan/fluviatile sedimentation and shallow marine to intertidal sedimentation. Correlation between the Tennant Inlier and the Pine Creek Orogen suggests that rocks comparable with the South Alligator and Mount Partridge Groups might be present at depth in the Tennant Inlier. This has relevance to the possibility of an extra-basinal source for the Tennant Creek ironstones. The Warramunga Formation is lithologically similar to the Tollis Formation which has recently been included in the Finniss River Group (Hein pers comm in Kruse *et al* 1994). These turbiditic sequences are both consistent with sources reflecting the onset of K-rich felsic magmatism (the BIA). Needham *et al* (1988) contrasted the volcanilithic composition of Tollis Formation with the more quartzose Burrell Creek Formation greywackes which they attributed to a distal, relatively mature source. Lithological equivalents of Burrell Creek Formation have not been recognised in the Tennant Inlier so far.

The prominent northwest trending, en echelon dome and basin folds which dominate the Wauchope Fold Belt and its more northerly orientated continuation in the Ashburton province are correlated with the Late Strangways Orogeny. The ~1710 Ma Devils Suite (Wyborn *et al* 1998), is syn- to post-tectonic with respect to this deformation, named the Davenport Orogeny in the Tennant Inlier.

It is suggested that both the Barramundi and the Davenport Orogenies in the Tennant Inlier are explicable by Mitchell and Reading's (1978) strike-slip orogenic cycle. This may help resolve the conflict between those proposing actualistic and those non-actualistic models for orogenesis in northern Australia (eg Windley 1992 and Etheridge *et al* 1987 respectively). A number of authors (eg Compston 1995) have pointed out similarities between the Barramundi and Wopmay Orogenies (North America) suggesting that this orogenic style is quite widespread in the Palaeoproterozoic.

The Davenport/Strangways Orogeny does not appear to have an associated flysch cycle of sedimentation, in contrast with widespread turbidites of the Barramundi Orogeny. This may partly be a problem of recognition given the higher metamorphic grade of part of the Arunta Province. Geochemical studies will assist the interpretation of protolith, the tectonic context of source terrains and help constrain correlations between metamorphosed supercrustal rocks. These studies, together with ongoing geochronological investigations, will help constrain regional geophysical interpretations and litho- and tectono-stratigraphic correlations. However, a significant degree of diachroneity is probable, and geochronology will not necessarily preclude tectono- and litho-stratigraphic correlations. Given the paucity of outcrop, detailed isotopic studies of granitic rocks may help characterise Archaean and early Proterozoic crustal elements, which are inferred to constitute the framework of the North Australia Craton prior to the Barramundi and Strangways orogenic cycles and their correlatives.

Table 1 **Working structural history of the Tennant Inlier**

	Dominant structures	Youngest strata affected	Deformed intrusive units	Orogenic episode
D3/D3'	Shears, faults and folds, trending NE and NW	Tomkinson Creek Group Devils Suite in part Hanlon and Wauchope Subgroups	Davenport (eg Elkedra Granite, Warrego Granite?)	Orogeny~1710 Ma
D2/D2'	Shears, faults and folds, trending WNW and / or ENE (conjugate set trends NNE and / or NNW)	Flynn Subgroup Ooradidgee Subgroup Bullion Schist	Treasure Suite Ooralingie Granite'late' porphyries	Murchison Event~1810 Ma
D1	West trending folds and faults	Warramunga Formation	Tennant Creek Supersuite, including 'early' porphyries	Barramundi Orogeny~1850 Ma

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GEOLOGY AND RESOURCE POTENTIAL OF THE BIRRINDUDU-VICTORIA BASINS

Project Leader: Peter R. Beier
Phone: 08 8999-5214
Fax: 08 8999-6824
Email: peter.beier@nt.gov.au

Introduction

Proterozoic strata in the Birrindudu-Victoria basins cover an area of 140 000 km^2 incorporating the Birrindudu, Limbunya, Wave Hill, Waterloo, Victoria River Downs, Auvergne, Delamere, Port Keats and Fergusson River 1:250 000 map sheets. The sedimentary succession, up to 6 km thick, is relatively undeformed and comprises mainly marine deposits dominated by siltstone, sandstone and dolostone. The sedimentary rocks deposited in a broad, mostly stable mixed carbonate-clastic platform environment. They are underlain by basement of older metamorphic and granitic rocks, and flanked by Phanerozoic volcanic and sedimentary rocks.

Original mapping established that the Birrindudu-Victoria and McArthur basins contain rock types of similar age and share a similar geological history. Numerous mineral occurrences have been documented from the Victoria River region and the conditions responsible for the formation of hydrocarbons and base metal mineral deposits in the McArthur Basin also potentially occur in the Birrindudu-Victoria basins. Second edition mapping has concentrated on erecting basic stratigraphic and facies information to facilitate correlation with other north Australian Proterozoic basins. This data will provide a framework to model sedimentary fill in sequence stratigraphic terms, to determine facies architecture and prospectivity, and to model basin development. The NTGS is currently processing stratigraphic sections, including gamma-ray spectrometer data collected over the past three years in GEOLOG format. Hence the preliminary results address regional and local stratigraphic findings that may enhance our understanding of the mineralisation potential of the Birrindudu-Victoria basins.

Preliminary Results

Deposition in the Birrindudu-Victoria basins includes several basin phases of intracratonic sag that partly corresponds to the component lithostratigraphic groups. Preliminary geochronology indicate the Limbunya Group may be correlated with McArthur Group and possibly Namarinni Subgroup of the Tennant Inlier, and Bungle Bungle Dolomite of the Osmond Basin in Western Australia. In addition to some pending SHRIMP age determinations of tuffite from Limbunya and Wattie Groups, acritarch micropalaeontology is being utilized to aid regional correlation of Tijunna and Auvergne Groups in the Victoria Basin. The occurrence of aragonite cementstones (coxco needles) similar to those in the Campbell Springs Dolostone have now been recognized in four Palaeoproterozoic terrains and may provide a useful correlative tool in other north Australian basins.

The occurrence of ferroan carbonate lozenges that form along and adjacent to faults, diastems, fractures and joints are evidence of fluid movement by subsurface $FeCl_2$-rich brines. These siderite marbles have previously been interpreted as pseudomorphs after gypsum and incorrectly used to define outcropping Amelia Dolomite (J Warren, written communication 1999). The presence of ferroan carbonate is not formation, specific but rather indicates late diagenetic flushing by basinal brines.

Recent NTGS stratigraphic drilling completed a stratotype section through the Bullita Group in the Victoria Basin. Drillhole 99VRNTGSDD1, located adjacent to a structural closure, was drilled in an area with anomalous lead stream sediment values and intersected Skull Creek and Timber Creek Formations. The absence of Bardia Chert (previously mapped as a stratigraphic member of the Skull Creek Formation) confirmed our interpretation from field work that it is a Tertiary duricrust. The occurrence of epigenetic galena, pyrobitumen and live oil bleeds may indicate potential for Mississippi Valley-type, Century and Irish-style mineralisation plays in the lower Bullita Group. Drillhole 99VRNTGSDD2 provides a stratotype section through the Kidman, Battle Creek and Bynoe Formations and Weaner Sandstone. Low energy subtidally deposited clastics and minor shallow marine clastics and carbonates are typical. Battle Creek Formation was found to contain poorly developed thin black shale units, and Bynoe Formation comprises dominant subtidal facies. However outcrop preserves a more cyclic depositional sequence with thicker shallow marine evaporitic facies. In this regard the upper Bullita Group has scope for syngenetic stratiform sediment-hosted base metals similar to the McArthur River ore body.

Currently 18 km of outcrop, drill core and wireline logs are being captured digitally at 1:100 scale to provide base line stratigraphic data for the Birrindudu-Victoria basins. This fundamental data will allow recognition of regional stacking patterns of sedimentary cycles used to correlate sequences, interpret palaeoenvironments and allow basinwide comparison of outcrop and downhole logging patterns. This data may provide additional information in areas characterized by poorly outcropping units. This is especially important given that base metal deposits commonly occur in these recessive rock types. These geological logs will be augmented by close spaced rockchip sampling to determine background geochemical values for selected units in the basins, including Margery, Fraynes, Timber Creek and Skull Creek Formations.

Outcome and Expected Products

An integrated stratigraphic and facies evolution model is the major project outcome. This will include a chronostratigraphic framework and basin architecture model for the Birrindudu-Victoria basins. This will be presented in an NTGS Report including a revised 1:500 000 interpretive solid geology map and composite stratigraphic outcrop and down hole logs. Second edition 1:250 000 digital geology maps and explanatory notes will be produced for Auvergne, Limbunya, Delamere and Victoria River Downs. It is also anticipated that a well completion report for 99VRNTGSDD1 including sedimentology, base metal and petroleum geochemistry will be released.