Contents

ISSUE 96 Dec 2009

Editor
Stephen Ross

Graphic Design
Maria Bentley & Henry Pippan

Web Design
Maria Bentley & Henry Pippa

Graphics and GIS
Geographics Team

ISSN 1035-9338

Geoscience Australia
GPO Box 378
Canberra ACT 2601 Australia
Cnr Jerrabomberra Avenue &
Hindmarsh Drive
Symonston ACT 2609 Australia

www.ga.gov.au

Chief Executive Officer
Dr Neil Williams

Subscriptions
Stephen Ross
p: +61 2 6249 9263
f: +61 2 6249 9926
www.ga.gov.au/about/corporate/ausgeo_news.jsp

Sales Centre
p: +61 2 6249 9966
f: +61 2 6249 9960
e: sales@ga.gov.au
GPO Box 378
Canberra ACT 2601 Australia

Editorial enquiries
Len Hatch
p: +61 2 6249 9015
f: +61 2 6249 9926
e: len.hatch@ga.gov.au

Australian Government
Geoscience Australia

AUSGEO news
ISSUE 96 Dec 2009

CEO comment

Neil Williams – CEO Geoscience Australia

Recent massive earthquakes and tsunami in our region have led to loss of life in Indonesia, Solomon Islands, Samoa and Tonga. This issue of *AusGeo News* includes a report on the development of the Australian Tsunami Warning System which is now a major contributor to earthquake and tsunami science and warning systems in our region. The system was developed using the scientific and technical expertise at Geoscience Australia, the Bureau of Meteorology and Emergency Management Australia.

North Queensland is one of the most richly mineralised regions of Australia, both in terms of total resources and the variety of commodities and deposit types. To better understand regional geological controls on these resources, especially energy resources, Geoscience Australia, in collaboration with the Geological Survey of Queensland and AuScope, undertook a deep crustal seismic survey in this region in 2007.

In this issue we report the most significant results of the survey and the complementary research and syntheses. The project, which also included university collaborators, identified fundamental new crustal boundaries and provinces in North Queensland and pointed to areas of previously unknown potential for iron oxide-copper-gold, lode gold, uranium and geothermal energy potential.

The predictive 3D geological models being developed to visualise subsurface geological features over a large area are an exciting new development for mineral explorers. Our article describes how inversion of the geophysical data constrained by known geological features is used to generate a model and reports on its application to data from the Perseverance mine in Western Australia.

There is also an article on the new 3D map of the Cooper Basin region which has been identified as highly prospective for geothermal energy. The new map defines the geometries of the Cooper and Eromanga basins and delineates potential heat sources and thermally insulating cover. When combined with the map of predicted temperatures at five kilometres depth, it can be used as a predictive tool for delineating potential geothermal plays.

This issue also includes an update on mineral exploration in Australia in 2008-09. Although Australian and global mineral exploration reached record highs during 2008 it dropped significantly in 2009 as a consequence of the Global Financial Crisis. Australian mineral exploration expenditure fell by 9.7% from a record $2461 million in 2007-08 to $2223 million in 2008-09 according to data from the Australian Bureau of Statistics.

There has been continuing industry interest in the Australian Government's 2009 release of offshore petroleum exploration acreage in the Ceduna Sub-basin of the Bight Basin. This area has been a focus of studies by Geoscience Australia aimed at improving our understanding of its petroleum prospectivity over the last four years. A number of datasets and information products that underpin the release are now available (see the Product news section). Another product which will be of interest to explorers searching for nickel, platinum-group elements, chromium, titanium and vanadium is the Archean mafic-ultramafic magmatic events map. This dataset documents the 26 major Archean magmatic events and their associated mineral deposits across Australia.

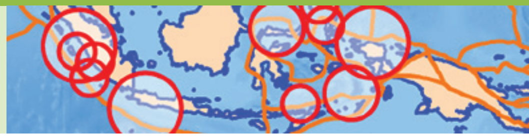
Finally, I wish to thank all our readers for your continuing support and extend best wishes for the festive season and the New Year.

Neil Williams

Australian Government
Geoscience Australia

AUSGEO news
ISSUE 96 Dec 2009

Tsunami warning system fully operational



Major contribution to earthquake and tsunami science and warning systems

Daniel Jaksa

On the morning of Sunday 26 December 2004 a large undersea earthquake generated a massive series of tsunami that combined to cause an estimated 228 000 deaths. The massive earthquake which began below the ocean off the coast of northern Sumatra and the Andaman and Nicobar Islands, has been measured at a magnitude of over 9. This was equivalent to the energy released by about 3.5 million standard atomic blasts. The tectonic plate boundary that separates the Indo-Australian Plate from the Sunda Plate deformed the seabed in a mega-thrust/uplift movement along a 1 200 kilometre long fault over a ten minute period.

> "More recently, massive earthquakes have continued in our region, all located where the Australian tectonic plate meets the surrounding Pacific and Sunda plates."

The massive series of seismic sea waves, or tsunami, devastated the immediate coastal communities of western Indonesia and far off communities in Sri Lanka, India, Thailand, Malaysia, Myanmar, Maldives, Seychelles, Somalia and Tanzania. This was the most devastating earthquake-tsunami event in recorded history. The tsunami waves were recorded by the Australian Bureau of Meteorology on tide gauges around the Australian coast and reached about one metre at Hillarys Harbour in Perth, Western Australia. Measurements of half-a-metre were measured at gauges in Tasmania and New South Wales. Over the following days, reports emerged from coastal communities in Western Australia of damage to moored boats and an increase in the number of people being rescued because of abnormally strong currents resulting from localised tsunami effects.

At the time of the tsunami, Australia relied on the existing Australian Tsunami Alert System, an arrangement between Geoscience Australia, the Bureau of Meteorology, and Emergency Management Australia which provided a limited notification and warning capability. It had no capability for confirming that an earthquake had generated a tsunami, and there were no mitigation and response strategies in place.

More recently, massive earthquakes have continued in our region, all located where the Australian tectonic plate meets the surrounding Pacific and Sunda plates (figure 1). Regrettably, more lives have been lost, along with enormous property losses, in Indonesia, Solomon Islands, Samoa and Tonga from the combined effects of the earthquakes and tsunami.

Australia's response

The day after the Indian Ocean tsunami, the then Prime Minister of Australia, The Hon. John Howard MP, pledged to '… do everything we can as a regional neighbour and regional friend to assist the countries that have been so badly affected'. Consequently, the Australian Prime Minister and Minister for Foreign Affairs and Trade were among the attendees at a Tsunami Disaster Summit organised by the Association of South East Asian Nations (ASEAN) in Jakarta on 5 and 6 January 2005. One of the key outcomes of this Summit was an agreement to establish a regional tsunami warning system.

Consequently, in its 2005–06 Budget the Australian Government provided $68.8 million to develop an Australian Tsunami Warning System (ATWS) over the next four years. The system would meet three major objectives:

1. Provide a comprehensive tsunami warning system for Australia.
2. Support international efforts to establish an Indian Ocean tsunami warning system.
3. Contribute to the facilitation of tsunami warnings for the South West Pacific.

First steps towards an Australian tsunami warning system

The Australian Government was well placed to develop an effective, reliable and durable tsunami warning system which would address Australia's needs, as well as meet regional requirements. It would utilise existing scientific and technical expertise at Geoscience Australia, the Australian Bureau of Meteorology, and Emergency Management Australia, as well as the diplomatic leadership of the Department of Foreign Affairs and Trade.

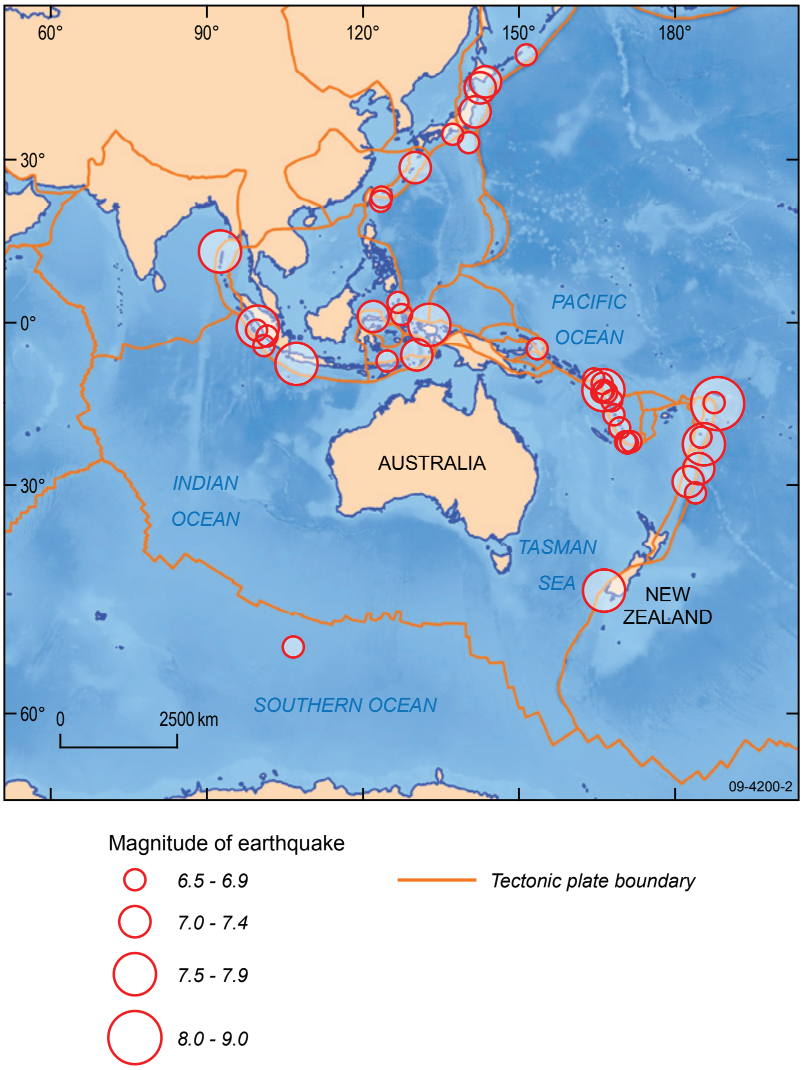


Figure 1. Epicentres of large earthquakes close to Australia's tectonic plate boundaries that have occurred since December 2004.

The Australian Tsunami Warning System (ATWS) began to take shape during the financial year 2005–06 with each of the program collaborators allocated funding over the next four years. The ATWS is defined as an end-to-end system encompassing:

- understanding the hazard through to raising community awareness and preparation
- earthquake and tsunami monitoring, detection and analysis through to public warnings
- evacuation and response.

Since the constitutional responsibilities for these activities fell within all levels of Australian government—federal, state and territory, and some local government—each would be involved in the ATWS to varying degrees.

To build on the existing domestic capabilities of Geoscience Australia's seismic monitoring and analysis systems, the agency was allocated $21 million over the four years. This was to upgrade existing seismic stations, build new seismic stations (both within Australia and overseas), and to access real-time digital seismic data from new and existing international seismic networks. Geoscience Australia would also establish a 24 hour seismic monitoring and analysis capability to compute and advise of any earthquakes in our region that had the potential to cause tsunami within 15 minutes of the earthquake rupture occurring.

The Bureau of Meteorology was allocated $40.5 million over the four years to upgrade their existing tide gauge sea level stations, build new tide gauge stations within Australia and overseas, and to install new tsunameter buoys located in deep ocean locations near subduction zones. The Bureau of Meteorology would also develop a 24 hour tsunami warning service, with a tsunami monitoring and analysis capability. The service would advise of potential tsunami impacts at least 90 minutes before a tsunami generated from undersea earthquakes reached the Australian coastline.

Emergency Management Australia is the Australian Government agency which coordinates training and education in natural hazard mitigation and response. The agency received $7.3 million over the four years to:

- develop an understanding of the tsunami threat to Australia
- develop and present a program of tsunami awareness and preparation for emergency managers, industry and the general community
- oversee a national test of the ATWS toward the end of the four-year implementation.

Because of the substantial international scope of the Australian Government's policies to assist in the establishment of an Indian Ocean Tsunami Warning and Mitigation System and improve capabilities to receive tsunami warnings in the South West Pacific, the Department of Foreign Affairs and Trade was selected to coordinate the cross-portfolio program outlined above.

International coordination

The body responsible for coordinating international efforts in tsunami warning and mitigation is the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The IOC General Assembly XXIII in Paris held in June 2005 confirmed the need to establish an interim tsunami warning system in the Indian Ocean. This would be provided through the existing Pacific Tsunami Warning Center in Hawaii and the Japan Meteorological Agency.

The Paris meeting also adopted resolutions to create three regional Intergovernmental Coordination Groups (ICGs)—for the Indian Ocean, the North-East Atlantic and Mediterranean, and the Caribbean—to establish basin-wide tsunami warning systems. The new ICGs would also contribute to the work of a global Coordination Group on tsunami in collaboration with the existing system covering the Pacific Ocean and other relevant United Nations bodies.

The first session of the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System was held in Perth in August 2005. A key resolution of the meeting was that the IOTWS would be a coordinated network of national systems and capacities. It would also be a part of a global network of early warning systems for all ocean-related hazards. It was agreed that each Member State would have responsibility for issuing warnings within their respective territories.

Development of the Australian tsunami warning system

The ATWS Implementation Strategy and Plan was developed in August 2005 under the direction of the Australian Government's Department of Prime Minister and Cabinet. It was then submitted to the Cabinet Implementation Unit which oversaw the project and the participating agencies provided quarterly reports.

In 2005 Geoscience Australia monitored 33 seismic stations, known as the Australian National Seismic Network (ANSN), which had been developed for its domestic earthquake monitoring and alert service. By October 2009, this number had increased to 192 and consisted of:

- 19 of the existing ANSN stations
- 28 ANSN stations that had been substantially upgraded
- 9 new ANSN stations within Australia
- 3 new overseas stations built by Geoscience Australia (one in Niue and two in PNG)
- 133 stations from shared international seismic networks.

To increase its robustness the network was redesigned, with digital data communications shared across three separate providers using discrete telecommunication infrastructures. In addition, in September 2008 the Comprehensive Nuclear-Test-Ban Treaty Organization approved the use of its seismic network for tsunami warning purposes.

During the initial stages of the project, the computer architecture of Geoscience Australia's earthquake monitoring, alert and analysis system was significantly upgraded. The software system is based on the Antelope software developed by Boulder Real Time Technologies in Colorado, USA. Antelope is an integrated collection of programs for data collection and seismic data analysis. Further software was developed to provide a graphical user interface to both Antelope and other software modules that were written in-house or provided by other centres. Consequently, the ATWS uses 'moment magnitude' based on P-waves (Mwp), using the algorithm from the Pacific Tsunami Warning Center in Hawaii, to provide consistency in earthquake magnitude estimates in all warnings from all centres.

The computer architecture has been designed to be as robust as possible, with two independent systems operating continuously. One is at the Operations Hub at Geoscience Australia in Canberra, and the other at a business continuity site established at the head office of the Bureau of Meteorology in Melbourne. System upgrades are rigorously controlled through a change-management regime where separate system environments have been created for each of the activities associated with research, development and testing. Once a change has been successfully tested, the upgrade is moved to both environments; firstly to the business continuity system in Melbourne and then to the primary system in Canberra. This stage was completed in July 2007 and at no time since have both systems been inoperable at the same time.

Launch of the warning service

During 2006, Geoscience Australia employed and trained duty staff for round-the-clock earthquake monitoring, analysis and reporting. This culminated in the launch of the Australian Tsunami Warning Centre Operations Hub at Geoscience Australia on 1 December 2006.

The Hub detects earthquakes in the region and examines details such as magnitude, location, and depth, along with other seismic characteristics, to determine whether or not they are likely to cause a tsunami. By July 2007, Standard Operating Procedures for the Duty Seismologist which outlines the actions and timeframes expected of the duty staff when earthquakes occur had been completed.

The Australian Bureau of Meteorology and Emergency Management Australia have worked closely with Geoscience Australia to develop the ATWS. Over the four-year implementation period, the Bureau of Meteorology upgraded and installed new tide gauges across Australia and the South West Pacific, and installed six tsunameter buoys (two south of Java, two in the Coral Sea and two south of New Zealand).

In consultation with emergency management agencies in the Australian states and territories, the Bureau of Meteorology has also developed world-class tsunami warning bulletins. To support the tsunami impact forecasts in these bulletins, the Bureau of Meteorology pre-computed 2 386 deep water tsunami wave height and propagation models. These were generated by generic earthquake rupture parameters over subduction zones in the Indian and Pacific oceans and near the South Sandwich Islands in the southern Atlantic Ocean. These models have been used to develop tsunami forecast impact levels to better inform emergency managers about likely tsunami effects in coastal zones.

The completed warning service was launched in October 2008 along with the official designation of the Joint Australian Tsunami Warning Centre (JATWC), reflecting the joint operations of Geoscience Australia for its seismic monitoring and alerting, and the Bureau of Meteorology for its sea level monitoring and tsunami warning role within the Australian Tsunami Warning System (figure 2). Emergency Management Australia has an important operational role in the warning process. The JATWC alerts Emergency Management Australia of tsunami earthquakes and receives all tsunami warning bulletins from other warning centres around the world. Emergency Management Australia uses this information to inform relevant government agencies and, in the case of significant events, informs the Prime Minister's Office.

Major contributions

In collaboration with Geoscience Australia and the Bureau of Meteorology, Emergency Management Australia conducted a program of emergency management awareness and education seminars across the nation. The program of workshops, *Introduction to Tsunami for Emergency Managers (ITEM)*, were conducted between 2007 and 2009. They provided information on the detection and warning processes, as well as the science of tsunami, and risk modelling methodology and emergency management arrangements.

Emergency Management Australia, in partnership with Geoscience Australia, has produced two nation-wide tsunami hazard assessments.

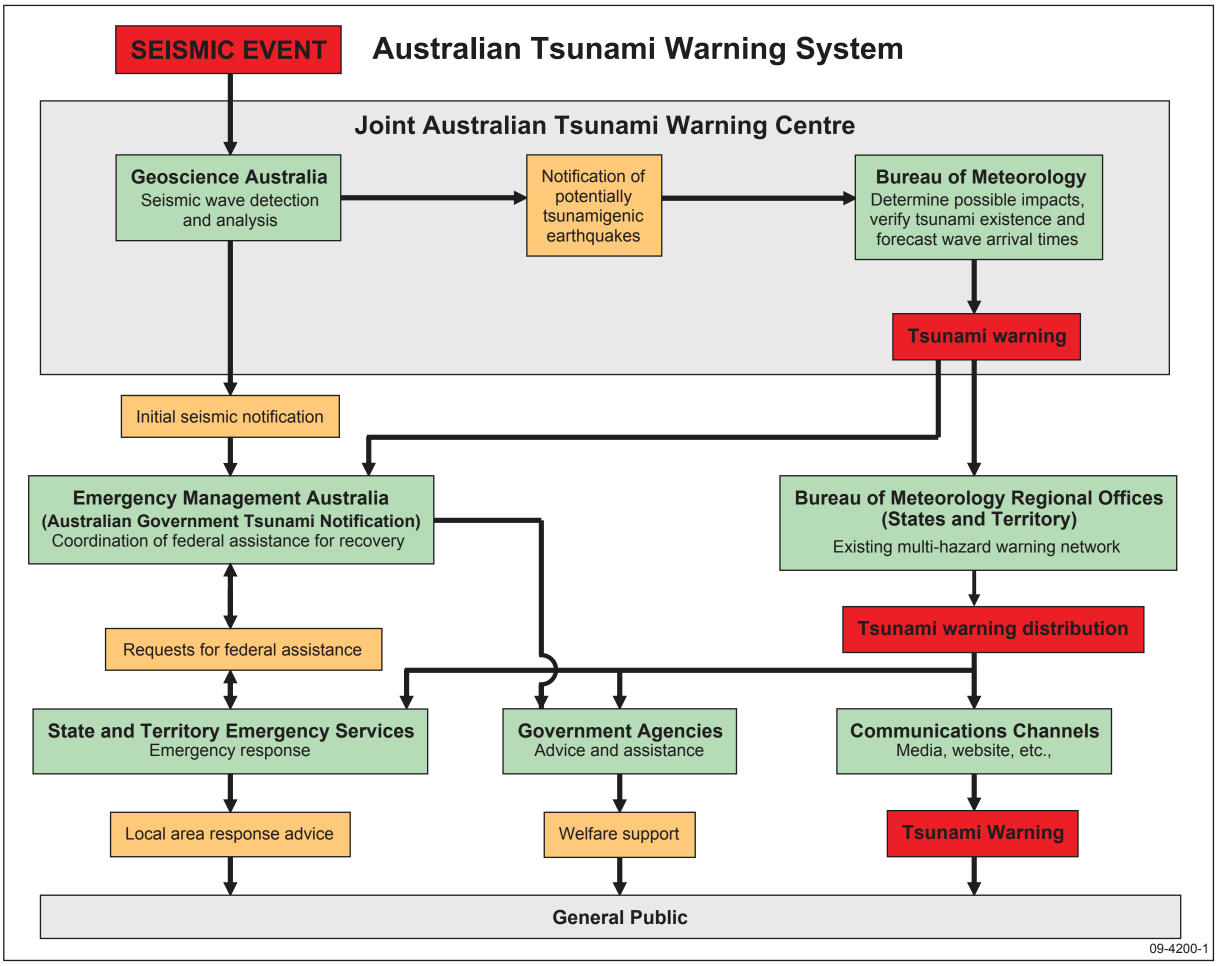


Figure 2. Flow chart outlining the roles of the contributors to the Joint Australian Tsunami Warning Centre operations.

The first assessment, published in 2007, was for a probabilistic tsunami hazard map and the second, published in early 2009, was a nearshore hazard map. In collaboration with the Fire and Emergency Services Authority of Western Australia and Emergency Management Australia, Geoscience Australia has produced tsunami inundation models for a number of communities around the Australian west coast. Geoscience Australia has also produced probabilistic tsunami hazard maps for the South West Pacific (2008) and the Indian Ocean (2009) in partnership with the Australian Agency for International Development (AusAID).

With their extensive experience in running national exercises to test emergency management processes, Emergency Management Australia have been instrumental in testing elements of the ATWS over the four years. In 2006, a test of the existing Australian Tsunami Alert Service was conducted to set a benchmark for the system to demonstrate improvements. In 2008, Emergency Management Australia held a desktop exercise to test their role in alerting government authorities. The final milestone, defined in the ATWS Implementation Strategy and Plan, was 'Exercise Ausnami' when Emergency Management Australia conducted a comprehensive test of the ATWS over two days in June 2009.

Performance measures

With the completion of the ATWS implementation in June 2009 the system became fully operational. Because the system was developed in stages over the four years, statistics on the performance of the system for those earthquakes assessed as having the potential to generate tsunamis have only been collected over the last two years.

Between July 2007, when the system developed from an alert service to a warning service, and 31 October 2009 there have been 125 earthquakes assessed as having the energy and mechanism to generate tsunamis. Not all these tsunami would have the potential to impact Australia, but they were reported internationally in line with our role in both the Indian and Pacific Oceans.

The most important performance measure for the ATWS is the requirement to provide a tsunami warning at least 90 minutes before the impact of a tsunami generated from undersea earthquakes. This measure was met for all 120 earthquakes to 31 October 2009.

The timeliness and accuracy of the earthquake alerts and the tsunami warning bulletins produced by the JATWC are another measure. The average alert time for earthquakes occurring in the Australian region is just under 11 minutes (compared to a required benchmark of 15 minutes). The average time taken to issue the subsequent tsunami bulletin is just under 20 minutes (compared to a benchmark of 30 minutes).

Other performance measures are the accuracy of the magnitude computation and the location of the hypocentre of the earthquake. The initial magnitudes computed are on average within 0.2 of the final computed solution for other centres, and the hypocentre is on average approximately 30 kilometres away from the final computed position. These results are well within expectations.

Future developments

As with all systems, new techniques are continuously developed and implemented to better improve the ATWS. A major priority is to provide a more comprehensive description of the mechanics of earthquakes rather than rely on the magnitude—a definition of the earthquake's strength—and the time and hypocentre which defines the location of the initial rupture.

Current research at Geoscience Australia involves the use of seismic arrays. These are powerful tools for the near-real time detection of the rupture length, direction and duration of very large earthquakes. They will assist to more accurately select the most appropriate tsunami propagation model for forecasting tsunami impacts, and provide more accurate tsunami warnings. Another development is the use of an automated moment magnitude calculator which is likely to improve the average response time by the Geoscience Australia Duty Seismologist.

Towards a regional tsunami watch role

An implementation plan for a system of Regional Tsunami Watch Providers (RTWP) was accepted at the fifth meeting of the Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System in Kuala Lumpur in April 2008. Countries which have the capacity to exchange tsunami warning information, such as earthquake and tsunami warning bulletins, have participated in RTWP trials. To date, Australia, Indonesia and India are exchanging earthquake bulletins for tsunami warning purposes.

After only four years of development, the ATWS is now a major contributor to earthquake and tsunami science and warning systems in the region.

For more information

phone Dan Jaksa on +61 2 6249 9685
email daniel.jaksa@ga.gov.au

Related websites/articles

Asian Tsunami effects in Western Australia (University of Western Australia)

www.seismicity.see.uwa.edu.au/welcome/tsunamis_in_wa/asian_tsunami_in_wa

Intergovernmental Oceanographic Commission, United Nations Educational, Scientific and Cultural Organization

www.ioc-tsunami.org/index.php?option=com_content&task=view&id=20&Itemid=1023

Joint Australian Tsunami Warning Centre (Bureau of Meteorology)

www.bom.gov.au/tsunami/index.shtml

AusGeo News 93: Scientific expertise and emergency management

www.ga.gov.au/ausgeonews/ausgeonews200903/emergency.jsp

Australian Government
Geoscience Australia

AUSGEO news
ISSUE 96 Dec 2009

Expanding our knowledge of North Queensland

Insights into the energy and resource potential from new seismic and complementary data

*Paul Henson, Russell Korsch (Geoscience Australia), Ian Withnall, Laurie Hutton (Geological Survey of Queensland), Bob Henderson (James Cook University) and the North Queensland Project Team**

North Queensland is one of the most richly mineralised regions of Australia, both in terms of total resources, and the variety of commodities and deposit types. To better understand regional geological controls on these resources, especially energy resources, Geoscience Australia, in collaboration with the Geological Survey of Queensland and AuScope, undertook a deep crustal seismic survey in this region in 2007. The survey was conducted under the auspices of Geoscience Australia's Onshore Energy Security Program and the Queensland Government's Smart Mining and Smart Exploration initiatives. AusScope was established under the National Collaborative Research Infrastructure Strategy to characterise the structure and evolution of the Australian continent. This article highlights the most significant results of this survey and complementary research and syntheses, as well as providing links to more detailed reports.

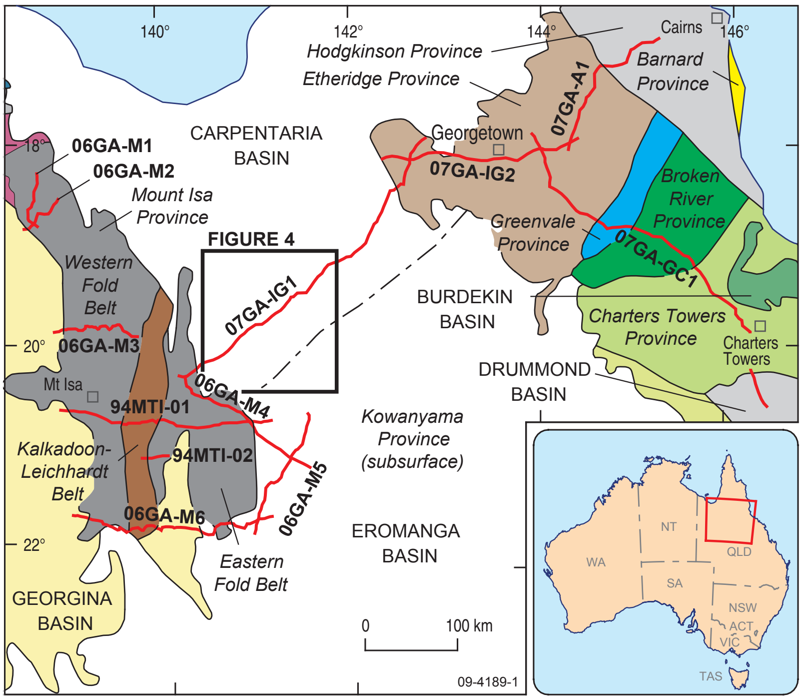


Figure 1. Map of North Queensland showing geological provinces, basins and seismic traverses that form the 2007 Isa–Georgetown–Charters Towers seismic survey. The map also shows the locations of previous seismic surveys acquired in 1994 and 2006.

Geological background and data acquisition

North Queensland (figure 1) consists of three geological elements:

- Paleo- to Mesoproterozoic basement, including the Mount Isa and Etheridge Provinces
- Paleozoic to Mesozoic rocks of the Tasman Orogen
- Neoproterozoic to Cenozoic basin systems that overlie mostly Proterozoic basement.

Proterozoic basement rocks, particularly in the Mount Isa Province, contain world class sediment-hosted zinc-lead and iron oxide-copper-gold resources as well as significant, though largely unexploited, uranium resources. The Tasman Orogen in North Queensland hosts a variety of granite-related commodities, including gold-copper and tin-tungsten as well as lode gold and volcanic-hosted massive sulphide zinc-lead-copper deposits. The basins contain major phosphate deposits and have potential for uranium and possibly geothermal energy.

In mid 2007, 1381 kilometres of 2D seismic reflection data were acquired along four traverses

**Contributors to this article include: Nick Williams, Natalie Kositcin, Alison Kirkby, David Champion, David Huston, Richard Chopping, Richard Blewett, Aki Nakamura, Josef Holzschuh, Ross Costelloe and Roger Skirrow (Geoscience Australia).*

(07GA-IG1, 07GA-IG2, 07GA-GC1 and 07GA-A1: figure 1), with magnetotelluric data collected along the first three traverses. Nakamura et al (2009) provide the technical details of the data acquisition and processing, and the seismic and magnetotelluric data from these traverses can be downloaded through the Geoscience Australia website. Additional data acquisition was undertaken by Geoscience Australia and the Geological Survey of Queensland to assist with interpretation of the seismic data, and to better understand the geological and tectonic history of North Queensland. This included targeted geochronology and geochemistry, as well as new gravity acquisition along the seismic survey traverses. 3D inversion modelling of the geophysical data was also undertaken.

Major results of the seismic survey

The results of the seismic survey, including exploration implications were presented at a workshop as part of the North Queensland Exploration and Mining Conference in May 2009 (Camuti and Young 2009). Presentations can be downloaded through the Geoscience Australia website. The following major features have been recognised in the seismic data:

- A major, west-dipping, Paleoproterozoic (or older) crustal boundary, which is interpreted as a suture, separates relatively non-reflective, thick crust of the Mount Isa Province from thinner, two layered crust to the east (figure 2). This boundary is also imaged by 2D inversions of magnetotelluric data and 3D inversions of aeromagnetic and gravity data.
- East of the Mt Isa Province, the highly reflective lower crust has been subdivided into three seismic provinces—Numil, Abingdon (figure 2) and Agwamin (not shown)—which are not exposed at the surface. Broadly similar neodymium model ages from granites sampled at the surface above the Numil and Abingdon Seismic Provinces suggest that both provinces may have had broadly similar geological characteristics. By contrast,

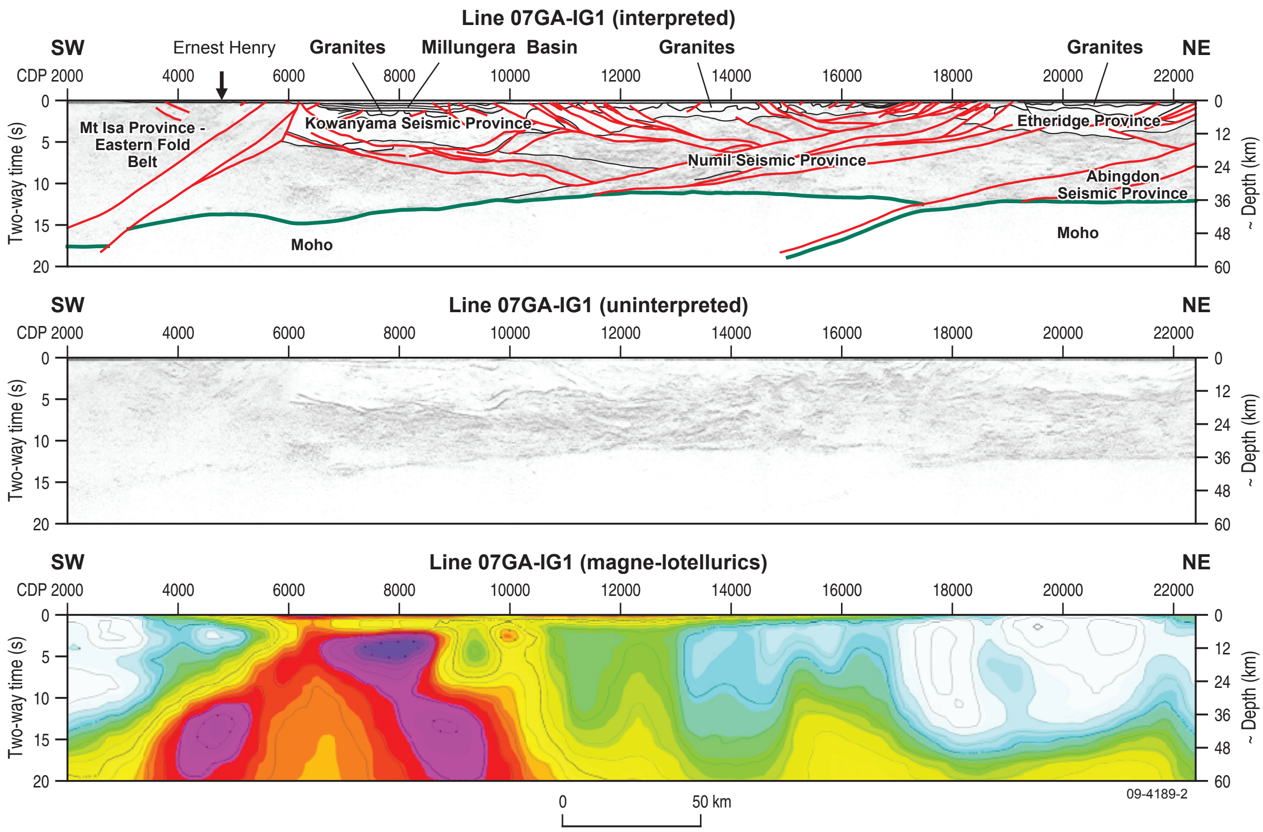


Figure 2. Images of traverse 07GA-IG1 showing (from top to bottom) interpreted seismic section, uninterpreted, migrated seismic section, and electrical resistivity from 2D inversions of magnetotelluric data.

granites sampled above the eastern Agwamin Seismic Province have much younger neodymium model ages, implying a significantly younger, possibly Grenville-age (1300-1060 million years or Ma) component in the lower crust.

- To the west of Croydon, a second major crustal boundary also dips west or southwest, offsetting the Moho and extending below it (figure 2). This is interpreted as a fossil subduction zone. This marks the boundary between the Numil and Abingdon Seismic Provinces, and is overlain by the Etheridge Province in the middle crust.
- A previously unknown basin, the Millungera Basin, was imaged below the Eromanga-Carpentaria basin system (figure 2). The geometry of internal stratigraphic successions, and of the post-depositional thrust margin, indicate that the original succession was much thicker than preserved today. The basin is interpreted, in part, to unconformably overlie granite bodies. The age of this basin is poorly constrained between late Paleoproterozoic and Mesozoic.
- In the east, the Greenvale and Charters Towers Provinces have been mapped on the surface as two discrete provinces (figure 1). The seismic interpretation suggests that these two provinces are continuous in the subsurface, and also extend northwards to beneath the Hodgkinson Province, originally forming part of an extensive Neoproterozoic-Cambrian passive margin.
- Continuation of the Neoproterozoic-Cambrian passive margin at depth beneath the Hodgkinson and Broken River Provinces suggests that these provinces (which formed in an oceanic environment, possibly as an accretionary wedge at a convergent margin) were thrust westwards onto the older continental passive margin.

Tectonic history of North Queensland

Based on the new seismic interpretation, with support from existing and new geochronological and geochemical data, 3D inversion of geophysical data (Chopping and Henson 2009), and geological synthesis (Kositcin et al 2009), the authors have proposed a new, possibly controversial tectonic model (figures 3a and 3b) for the evolution of North Queensland (see Camuti and Young 2009 and Chopping and Henson 2009):

- ≥*1860 Ma*. The eastern margin of the Mount Isa Province is interpreted to have been a west-dipping, convergent plate margin, with the combined Numil–Abingdon Seismic Province located to the east (figure 3a). Supporting this hypothesis is the occurrence of rocks with arc-like affinities in the Kalkadoon–Leichhardt belt which may be related to

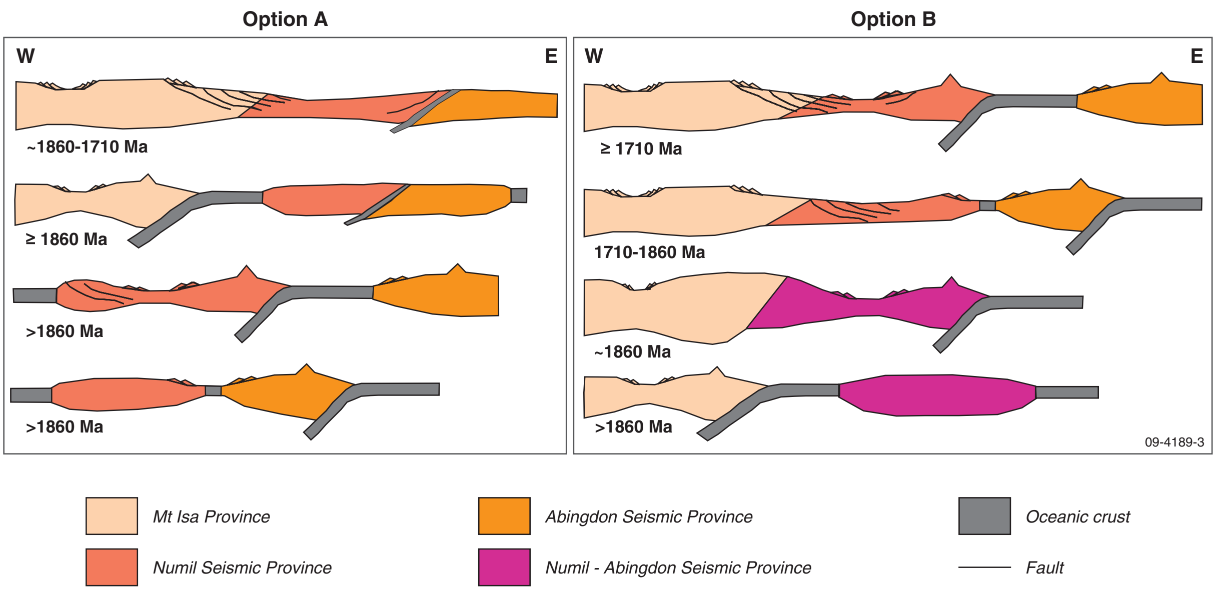


Figure 3a. Preliminary model for the tectonic evolution of North Queensland showing alternative evolutions prior to 1710 Ma.

subduction processes. If correct, docking of these provinces could have occurred at or before ~1860 Ma, and explains the change in reflectivity observed between the Mount Isa Province and the Numil–Abingdon Seismic Province (figure 2).

- ≥*1710 Ma.* Although the minimum age of the amalgamation of the Numil and Abingdon Seismic Provinces is constrained by the ~1710 Ma age of the overlying Etheridge-Kowanyama Province, the actual age is unconstrained. There are two possible explanations (figure 3a): (a) prior to the docking of the conjoined Numil-Abingdon Province with the Mount Isa Province (that is, ≥1860 Ma), or (b) after this docking (that is, between 1860 and 1710 Ma). Present data do not allow discrimination between these two alternatives. In both options, the Numil and Abingdon Provinces, given similarities in their seismic character, are interpreted to have originally been contiguous before being rifted apart, probably as a consequence of backarc extension related to slab roll-back. In the first explanation, backarc extension and subsequent subduction to form the Numil–Abingdon fossil subduction zone happened prior to the docking of the conjoined Numil–Abingdon Seismic Province with the Mount Isa Province (figure 3a). In the second explanation, the conjoined Numil–Abingdon Seismic Province is interpreted to have docked with the Mount Isa Province at or before 1860 Ma. Following docking, subduction migrated outboard, with backarc extension rifting the originally conjoined seismic provinces to form a marginal sea. Subsequently, subduction migrated inboard and consumed the marginal sea to form the imaged fossil

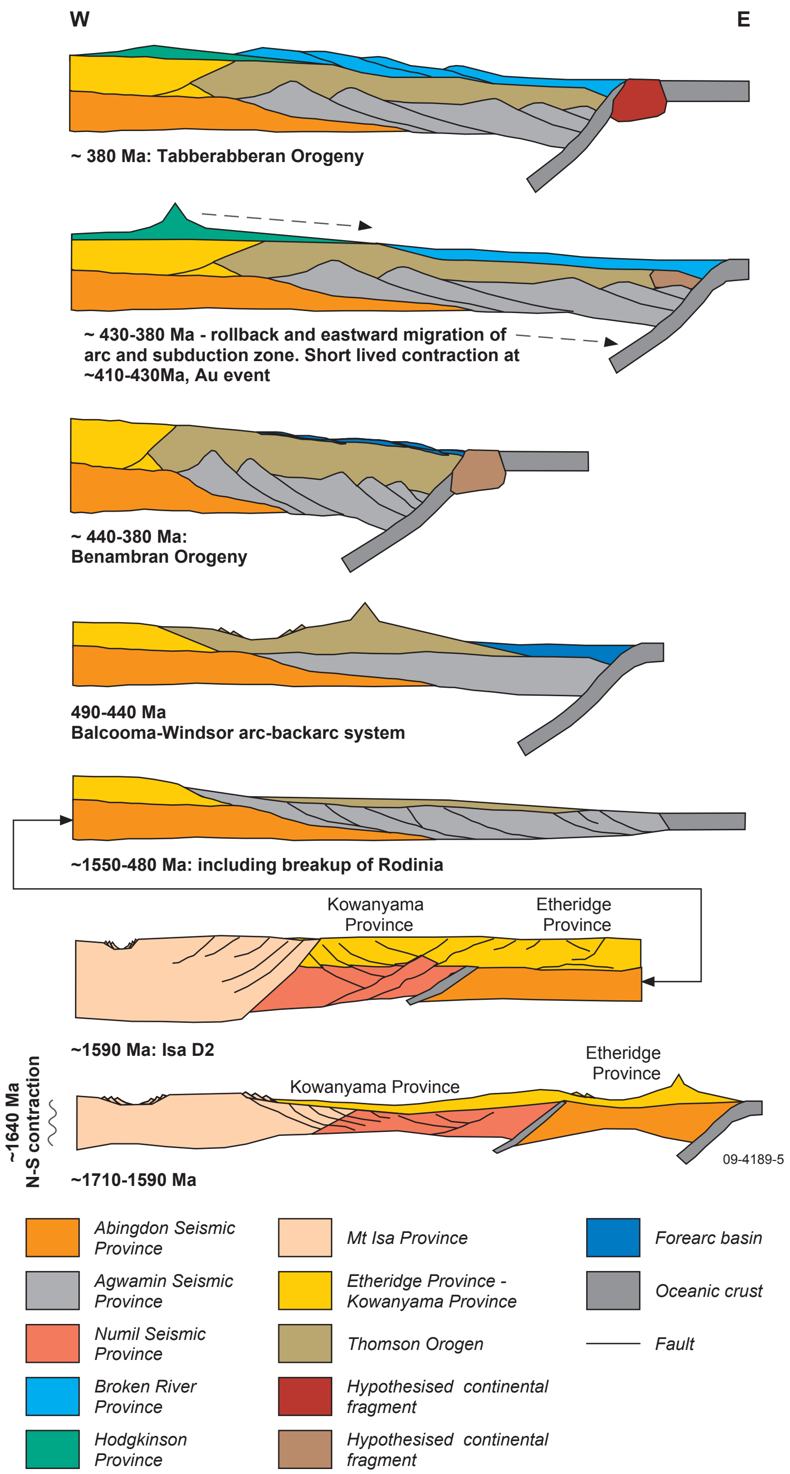


Figure 3b. Preliminary model for the tectonic evolution of North Queensland showing evolution after 1710 ma.

subduction zone, with final docking between 1860 Ma and 1710 Ma. An east-west directed contractional event between 1740 Ma and 1710 Ma in the Mount Isa Province (Betts 1999) may be a consequence of this docking.

- *1710–1590 Ma*. Following the amalgamation of the Numil and Abingdon Seismic Provinces, west-dipping subduction may have initiated to the east of the Abingdon Seismic Province (figure 3b), resulting in the development of an arc (for which there is no exposed evidence). The Etheridge Province is thought to have developed within a backarc position related to this arc. Further to the west, the Kowanyama and Mount Isa Provinces were also being extended, initiating significant deposition of sedimentary successions in the Kowanyama and Mount Isa Provinces that are temporal equivalents of units in the Etheridge Province.
- *~1590 Ma*. At 1590 Ma, a major ~east-west contractional event produced significant shortening in the Mount Isa and Kowanyama provinces (figure 3b), with coeval high grade metamorphism in the Etheridge Province. Inversion occurred on pre-existing extensional faults and new thrusts also developed. Overall thickening of the crust was coincident with the age of peak metamorphism in the Etheridge and Mount Isa Provinces.
- *~1550–490 Ma*. After a long quiescent period, extensional tectonic processes associated with the breakup of Rodinia (~800 Ma) affected the Agwamin Seismic Province and the overlying Neoproterozoic Thomson Orogen, producing a passive continental margin, with oceanic crust located approximately to the southeast (figure 3b).
- *490–430 Ma*. A period of west-dipping subduction formed an accretionary wedge and the Balcooma–Windsor arc-backarc system on the eastern margin of the Etheridge Province (figure 3b). At ~440 Ma, an arc collided with the continental margin producing significant shortening of the Agwamin Seismic Province and units in the overlying Thomson Orogen, and overthrusting of the accretionary wedge during the Benambran Orogeny at 440–430 Ma.
- *~430–360 Ma.* Following arc accretion, west-dipping subduction recommenced, generating the arc-forearc units of the Broken River Province and accretionary wedge units of the Hodgkinson Province (figure 3b). Rollback produced an eastward migration of the subduction zone and associated arc, forearc and accretionary wedge. Subduction was terminated by the 380–360 Ma Tabberabberran Orogeny possibly associated with accretion of an arc from the east. This event (or the later Hunter-Bowen Orogeny) thrust the Hodgkinson Province and parts of the Broken River Province units westward over older units. Alternatively, the event may have been driven by shallowing of the subduction zone, putting the upper plate into contraction, which could explain the almost total lack of magmatism in the period 390–360 Ma.

Metallogenic significance of seismic results

Some of the features identified in the seismic survey are also inferred to have metallogenic significance. The most significant include:

- *Isa–Numil boundary.* The interpretation that the eastern margin of the Mount Isa Province was a suture, suggests that the ~1860 Ma (or older) calcalkaline magmatic rocks in the Kalkadoon–Leichhardt Belt may represent a magmatic arc and, as such, have potential for porphyry copper-gold and other magmatic-hydrothermal deposit types. Of more significance is the recognition that iron oxide-copper-gold deposits of the Cloncurry district are located in the hangingwall to this suture. This is in a similar structural setting to that of Olympic Dam which sits in the hangingwall of an interpreted suture between Proterozoic and Archean crustal blocks in the Gawler Craton (Lyons & Goleby 2005). Using gravity and magnetic data to map the Mount Isa boundary indicates that rocks undercover to the north of 07GA-IG1 have potential for iron oxide-copper-gold deposits.
- *Crustal-penetrating shear zones, Croydon area*. A series of crustal-penetrating shear zones, with apparent dips to the southwest, were recognised in the northeast part of the 07GA-IG1 traverse in the hangingwall of the fossil subduction zone (figure 2). By analogy with the

relationship between crustal penetrating shear zones and lode gold deposits in the Eastern Goldfields Province (Goleby et al 2004), we regard the surface extension of these shear zones to have potential for lode gold deposits, an interpretation supported by the Croydon goldfield, which lies along strike from the shear zones and has produced over 60 tonnes of gold bullion.

3D maps and geophysical modelling

To help define the 3D architecture of the study area, inversions of gravity and magnetic data were generated. Inversions produce 3D models of density and magnetic susceptibility variations in the subsurface that allow prediction of the geometry and type of buried rocks (figure 4). The only geological constraints used in the inversion models were basic 3D province definitions derived from seismic data. A striking feature in the gravity inversion results is a sublinear belt of high-density material extending roughly north–south through Ernest Henry, then heading south-southeast and passing just to the west of Duchess. This trend may represent a major corridor in the Mount Isa Province. The entire Mount Isa Province itself is characterised by high-magnetic susceptibility.

The eastern boundary of the Mount Isa Province, imaged on traverse 07GA-IG1 as a west-dipping series of reflections, is clearly imaged as a strong west-dipping boundary in both the gravity and magnetic inversions. The inversions track the boundary away from the seismic line, particularly to the north. To the south the location is uncertain, although extension along a major gradient mapped in gravity data is favoured. They also image the Ernest Henry iron oxide-copper-gold deposit as being associated with a small dome of high-magnetic susceptibility material extending from depth.

The inversion results confirm the presence of the Millungera Basin as a relatively low density and low-magnetic susceptibility feature extending away from traverse 07GA-IG1. In addition,

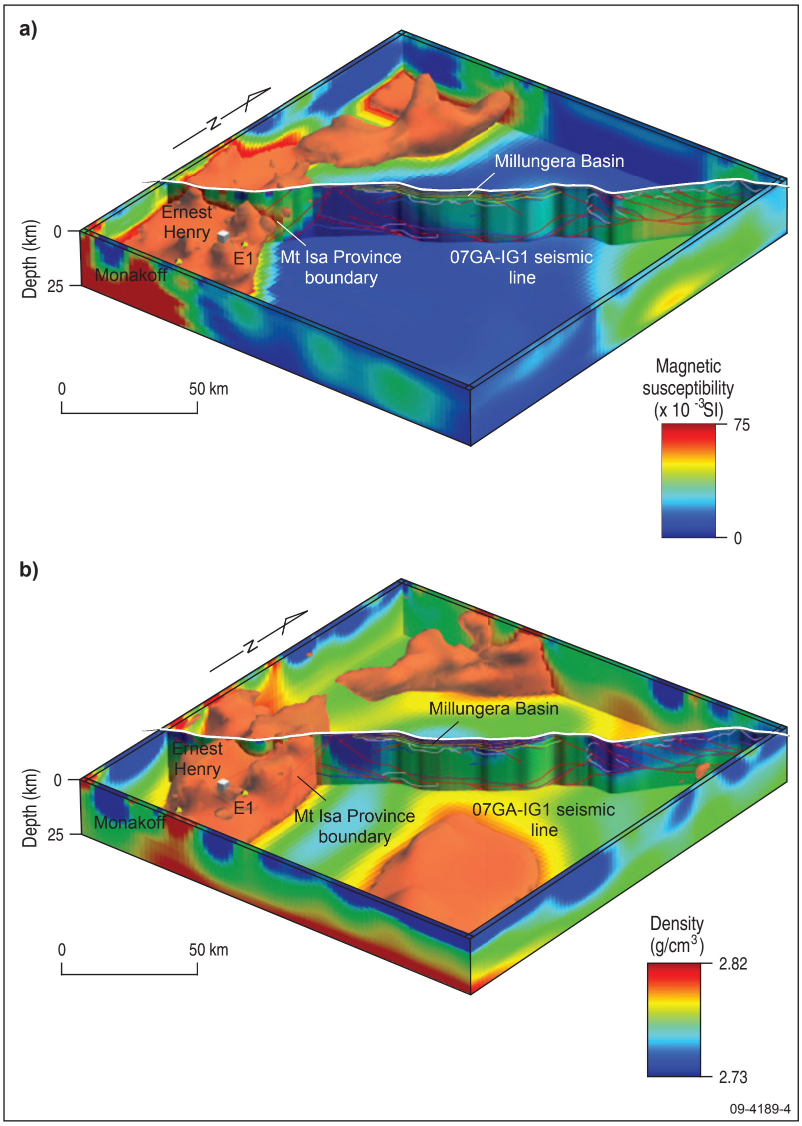


Figure 4. Images showing a) magnetic and b) gravity inversions along the eastern margin of the Mount Isa Province. The top image shows a subset of the 3D magnetic inversion along the eastern margin of the Mount Isa Province. The predicted magnetic susceptibilities are draped on the 07GA-IG1 seismic line with the seismic interpretation. An isosurface contains all cells with magnetic susceptibilities > 75 × 10^{-3} SI. The bottom image shows a similar subset of the 3D gravity inversion, with predicted densities > 2.78 grams/cubic centimetre enclosed by an isosurface.

the inversions predict the physical properties of four possible granitic bodies interpreted from seismic data beneath the Millungera Basin. The westernmost and easternmost of these possible granites have the lowest predicted density, consistent with a more felsic composition that would favour concentration of heat producing elements. As the easternmost granite is also under the thickest sedimentary pile, it perhaps represents a more favourable target in terms of geothermal potential.

North Queensland geodynamic and mineral system synthesis

Over the last year, Geoscience Australia's Onshore Energy Geodynamic Framework Project has undertaken a geodynamic synthesis of North Queensland, from the Paleoproterozoic to Recent (Kositcin et al 2009), to:

- better understand the tectonic and geodynamic setting of existing mineral deposits within North Queensland
- provide a predictive capability, within the synthesised geodynamic framework, for extending potential regions of known mineralisation and identifying new mineralisation styles and commodities.

Geological data were synthesised on a regional, largely orogenic, basis to identify geological events and geodynamic cycles. The synthesis involved the compilation of available published (and unpublished) state geological survey data and data in the scientific literature. All data were captured in Geoscience Australia's internal PROVINCES and EVENTS databases and used to produce digital time-space-event plots for each region within North Queensland, which allowed comparison between regions and the identification of major geological events and geodynamic cycles.

To better understand the geodynamic setting of, and spatial relationships between known mineral deposits, a synthesis of significant mineral deposits in North Queensland was produced to help delineate possible extensions of mineralised belts based on our geodynamic interpretation. The team also used the geodynamic synthesis to predict areas of mineral potential outside known mineralised districts or provinces. Prediction of mineral prospectivity conducted at the North Queensland scale provides a first-order guide to area selection for mineral exploration (Kositcin et al 2009).

Energy potential

Data generated during this project as well as existing data summarised in the synthesis (Kositcin et al 2009) were used to assess the potential of North Queensland for uranium and geothermal energy resources (Huston 2009). This assessment has highlighted a number of targets which are considered to have potential.

The energy assessment confirmed potential for uranium-bearing iron oxide-copper-gold deposits to the north of the Cloncurry district, highlighting zones of hematite and sulphide alteration (Chopping and Henson 2009) as potential targets. Moreover, the broad decrease in metamorphic grade from south to north in the Isa Province suggests that the northern parts of the province may have greater potential for uranium-rich systems as these appear to be high level systems (Skirrow et al 2007), which would be more likely to be preserved in lower grade rocks.

The energy assessment also highlighted potential for metasomatic uranium deposits such as the Valhalla deposit, along the margins of the Leichhardt River Fault Trough, particularly where it is juxtaposed against uranium-rich granites, for example those of the Sybella suite. Potential for sandstone-hosted uranium deposits is inferred along the western margin of the Eromanga Basin, where it onlaps onto Proterozoic basement enriched in uranium (Huston 2009).

In addition to highlighting potential for uranium mineralisation, data being generated as part of this project is being used to better understand the geothermal potential of the Millungera Basin. This basin, which appears on the 07GA-IG1 seismic line and on the eastern ends of the 2006 Mount Isa seismic traverses (06GA-M4 and 06GA-M5), is coincident with several negative anomalies in the Bouguer anomaly map. These anomalies have been interpreted as granites which could contain high concentrations of radioactive (heat-producing) elements. The seismic interpretations have been used to define the distribution of Millungera Basin sediments. Using this interpretation together with 3D gravity inversion modelling of rocks beneath the basin, six granite bodies have been defined within basement directly beneath the basin. Forward thermal modelling is currently being performed on the results of the inversions to identify possible scenarios for the subsurface temperature distribution and ascertain the potential for a geothermal resource.

Conclusions

Interpretation of deep crustal seismic data, combined with geophysical inversion modelling, geological and metallogenic synthesis, energy potential assessment and geothermal modelling, have identified fundamental new crustal boundaries and provinces in North Queensland, providing important constraints on the geodynamic history of the area, and pointing to areas of previously unknown potential for iron oxide-copper-gold, lode gold, uranium and geothermal energy potential. Some results (including seismic data and interpretations) are online and can be accessed through the references or through the Onshore Energy Geodynamic Framework web page. Explorers are encouraged to use the data in this report and related documents to develop and test models for the tectonic and metallogenic evolution of North Queensland and to develop new concepts for targeting mineral resources.

Acknowledgements

This paper is a product of the North Queensland Project Team, and we thank the following members of the team for their contributions: Bridget Ayling, Terry Brennan, Martyn Hazelwood, Leonie Jones, Lex Lambeck, Bridgette Lewis, Tony Meixner, Terry Mernagh, Peter Milligan, Narelle Neumann, Malcolm Nicoll, Indrajit Roy, Erdinç Saygin, Anthony Schofield, Simon van der Wielen (Geoscience Australia), Tom Blenkinsop, Bill Collins, Richard Wormald (James Cook University), Chris Fergusson (University of Wollongong), Marnie Forster and Gordon Lister (ANU). Dean Hoatson and Leonie Jones provided comments that improved the final version of this article.

For more information

phone Paul Henson on +61 2 6249 9138
email paul.henson@ga.gov.au

phone David Huston on+61 2 6249 9577
email david.huston@ga.gov.au

References

Betts PG. 1999. Palaeoproterozoic mid-basin inversion in the northern Mt Isa terrane, Queensland.Australian Journal of Earth Sciences 40:735–748.

Camuti K & Young D (eds). 2009. Northern Queensland Exploration and Mining 2009 and North Queensland seismic and MT workshop. Australian Institute of Geoscientists Bulletin 49.

Chopping R & Henson PA. 2009. 3D map and supporting geophysical studies in the North Queensland region. Geoscience Australia Record 2009/29.

Goleby BR et al. 2004. Deep seismic reflection profiling in the Archean northeastern Yilgarn Craton, Western Australia: implications for crustal architecture and mineral potential. Tectonophysics 388:119–133.

Huston DL (ed). In press. An assessment of the energy, mineral and geothermal potential of North Queensland. Geoscience Australia Record.

Kositcin N et al. 2009. Geodynamic synthesis of the North Queensland region and implications for metallogeny. Geoscience Australia Record 2009/30. Available at: www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=69159

Lyons P & Goleby BR. 2005. The 2003 Gawler Craton Seismic Survey: notes from the Seismic Workshop held at Gawler Craton State of Play 2004. Geoscience Australia Record 2005/19. Available at: www.ga.gov.au/products/servlet/c</S&catno=63538

Nakamura A et al. In press. Mt Isa–Georgetown–Charters Towers deep crustal seismic reflection survey 2007 (L184, L185 and L 186). Geoscience Australian Record.

Skirrow RG et al. 2007. Timing of iron oxide Cu-Au-(u) hydrothermal activity and Nd isotope constraints on metal sources in the Gawler Craton, South Australia. Economic Geology 102:1441–1470.

Related websites/articles

Onshore Energy Geodynamic Framework Project

www.ga.gov.au/minerals/research/national/oegf/index.jsp

Australian Government
Geoscience Australia
AUSGEO news
ISSUE 96 Dec 2009

Reliable subsurface models for mineral exploration

Inversion of geophysical data produces predictive 3D models

Nicholas Williams (Geoscience Australia), Douglas Oldenburg and Peter Leliévre (University of British Columbia–Geophysical Inversion Facility)

The ability to visualise subsurface geological features and materials over a large area is a critical time- and money-saving tool for mineral explorers. Geoscience Australia and University of British Columbia – Geophysical Inversion Facility (UBC-GIF) researchers have developed a new method for rapidly building 3D geological models using only limited exploration observations. These models are key inputs for generating predictive 3D images of the subsurface from geophysical observations.

Without such geological models, the task of developing reliable 3D Earth images from observed geophysical data alone is akin to solving a sudoku puzzle without any clues – there are too many possibilities. The geological models are the equivalent of the clues in the sudoku puzzle; they make it much more likely to find a useful solution.

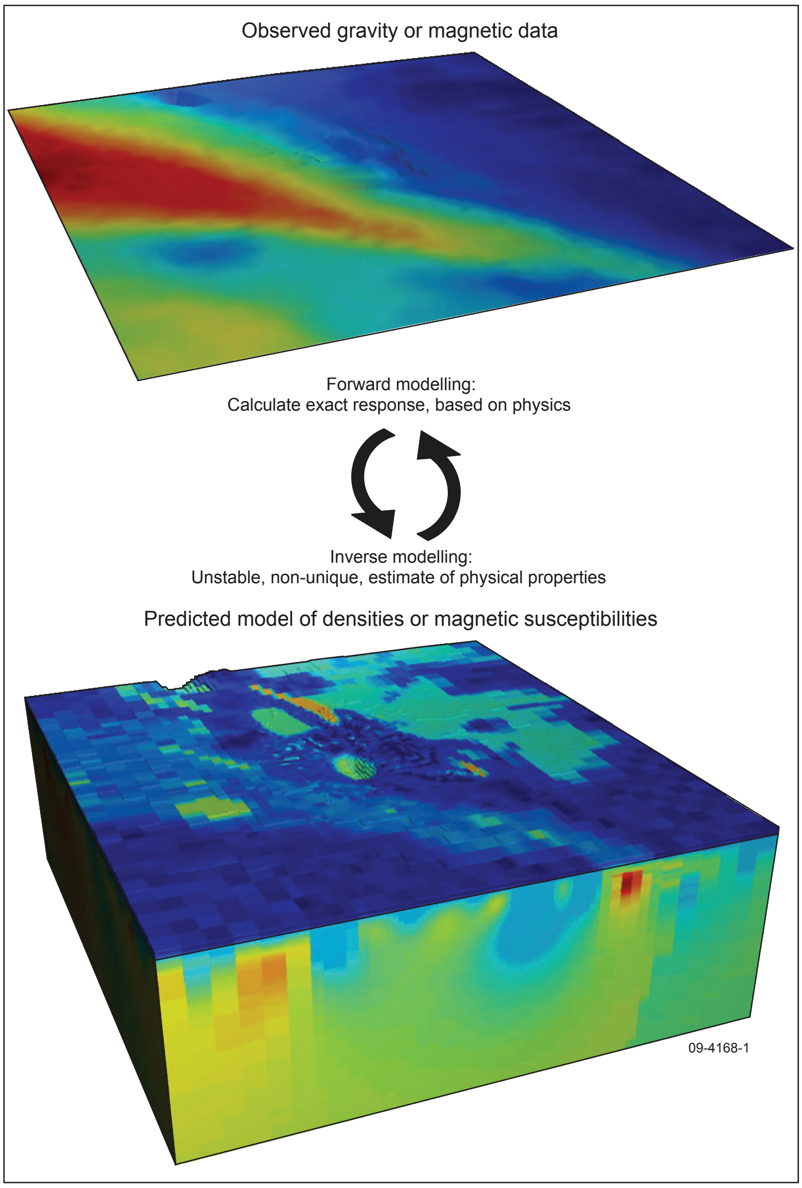


Fig 1. Geophysical inversion generates a 3D physical property model capable of explaining observed geophysical data.

Modelling the subsurface

Geophysical data provide a cost effective means of visualising aspects of the Earth's subsurface over a large area. Geophysical datasets are often presented as a 2D image of the observations made at the surface or from the air, but with some additional steps a 3D representation of the subsurface can be produced. These extra steps involve inversion of the geophysical data.

Geophysical inversion is a mathematical process that seeks to extract a model, or suite of models, that represent the subsurface distribution of physical properties that can explain an observed geophysical dataset (figure 1). A limitation of inversions is that they provide non-unique results; many models could be generated that produce the same geophysical response or image.

The most desirable model is one that explains the observed geophysical data and also reproduces known geological features. This can only be achieved by including any available geological information into the inversions as constraints which restrict the range of possible results based on geological knowledge. The inversion will then seek a 3D model that explains the geophysical observations while also reproducing the expected geology.

One approach to achieving this integration is to specify a full 3D model of geological observations and interpretations to the inversion and test the hypothesis that those interpretations are consistent with the geophysical data (McGaughey 2007; McInerney et al 2007; Oldenburg and Pratt 2007). However, in greenfields mineral exploration where geological knowledge is limited, it may be impossible to define a reliable 3D model everywhere in the region of interest.

"The most desirable model is one that explains the observed geophysical data and also reproduces known geological features."

The 'sparse data' approach

An alternate approach is to supply only the available sparse geological observations to the inversion to generate a prediction about the subsurface distribution of geological features required to satisfy both the known geological constraints and the observed geophysical data. This approach has the added benefit that most geological interpretation can be postponed until after the inversions have been performed. This reduces the lead time to recover an inversion result and enables the results of inversions to be used in decisions to acquire further geological and geophysical data or to assist with geological interpretation.

The authors have developed a new model-building method for preparing the geological constraints required for this 'sparse data' approach. It is specifically targeted for use with the UBC-GIF GRAV3D and MAG3D gravity and magnetic inversion programs (Li and Oldenburg 1996; Li and Oldenburg 1998). The UBC–GIF inversion approach allows geological constraints to be assigned to each cell within a 3D model using four sets of parameters:

- A reference property which provides the best estimate of the mean physical property (density or magnetic susceptibility) in the cell.
- A smallness weight which provides an estimate of the reliability of the assigned reference property.
- Lower and upper physical property bounds indicating the limits on the property range that can be assigned to the cell. These effectively represent a confidence interval on the supplied reference property.
- Smoothness weights controlling the variation in properties between each adjacent cell in each direction.

The inversion will generate a physical property model with a property for each cell that lies between the defined bounds and is as close as possible to the supplied reference property, while still reproducing the observed geophysical data. If possible, the reference model physical properties will be matched more closely in those cells that have the highest reliability or smallness weights.

Assigning observations to the model

There are two main classes of observations that can be utilised in building a physical property model from geological data: 1) measurements of physical properties and 2) observations or interpretations of rock types or alteration styles. Physical property measurements are most directly related to building a physical property model; however they may not be collected systematically. Observations of geology are far more common and are available in published surface maps for all of Australia. Since most geological units and rock types have characteristic (but not necessarily unique) physical properties, observations of rock types and alteration may be used as a proxy for actual property measurements. A key component of building a physical property model based on rock type observations is therefore to link the geological observations to appropriate physical property information. This is done early in the model building process via the semi-automated creation of a physical property database for the model.

Once the physical property database is created, the model building routine loads the various data files containing those geological observations and extracts the 3D coordinates at which the observations occur. The data that can be used include text files of surface sample property measurements, drill hole and drill core property measurements and geology logs, ArcView shapefile polygon surface and basement geology maps, cross section or reflection seismic interpretations, and full 3D models if available. The physical property database is used to convert geological observations into appropriate physical property estimates.

The reference model depicting the expected geology is populated by calculating the mean of the most reliable property measurements or estimates in each cell. A confidence interval at a specified percentage level of confidence (typically 95 per cent) gives property bounds that limit the likely range of properties. The spatial distribution of observations within a cell is used to assign smallness weights to each cell indicating the reliability of the reference property for that cell, so that poorly-sampled cells have a lower reliability than well-sampled cells.

Expanding the model beyond observations

The constraining physical property model created thus far is based only on the geological data and is only enforced where observations are available. In well-studied areas, a significant number of the cells may be constrained by observations. However, in data-poor environments, such as early exploration stages, few cells will have constraints. Given that there is usually some continuity of geological units along their strike and dip, an option is provided to extrapolate the observed data a short distance into surrounding cells. The method calculates an ellipsoidal buffer zone to represent the zone of influence around each data cell. The shape and orientation of the buffer zone depends upon the observed or inferred structural orientation. The longest buffer axis extends along the strike in the dip plane. The shortest buffer axis lies perpendicular to the dip plane.

All cells within a buffer zone are assigned the same best property estimate used for the reference model cell at the centre of the buffer. The reliability of constraints in the buffer is reduced with increasing distance from the original geological observations by reducing the smallness weight and expanding the assigned property bounds with distance from the observation. Where several buffers overlap, weighted average property estimates, smallness weights and bounds are calculated that reflect the distance from each observation, as well as the reliability of the original observations.

Smoothness weights

Smoothness weights define how smoothly the physical properties in the recovered inversion should vary between adjacent cells. There are three main geological scenarios to which smoothness weights can be usefully applied:

- Allowing sharp changes in properties across geological contacts where they are known.
- Promoting smooth extrapolation of properties away from observation locations into cells that lack observations, as an alternative to using buffers.
- Retaining the natural variability or roughness in physical properties observed in the reference model.

These situations may arise individually, or in combination, and each is handled automatically within the model building program.

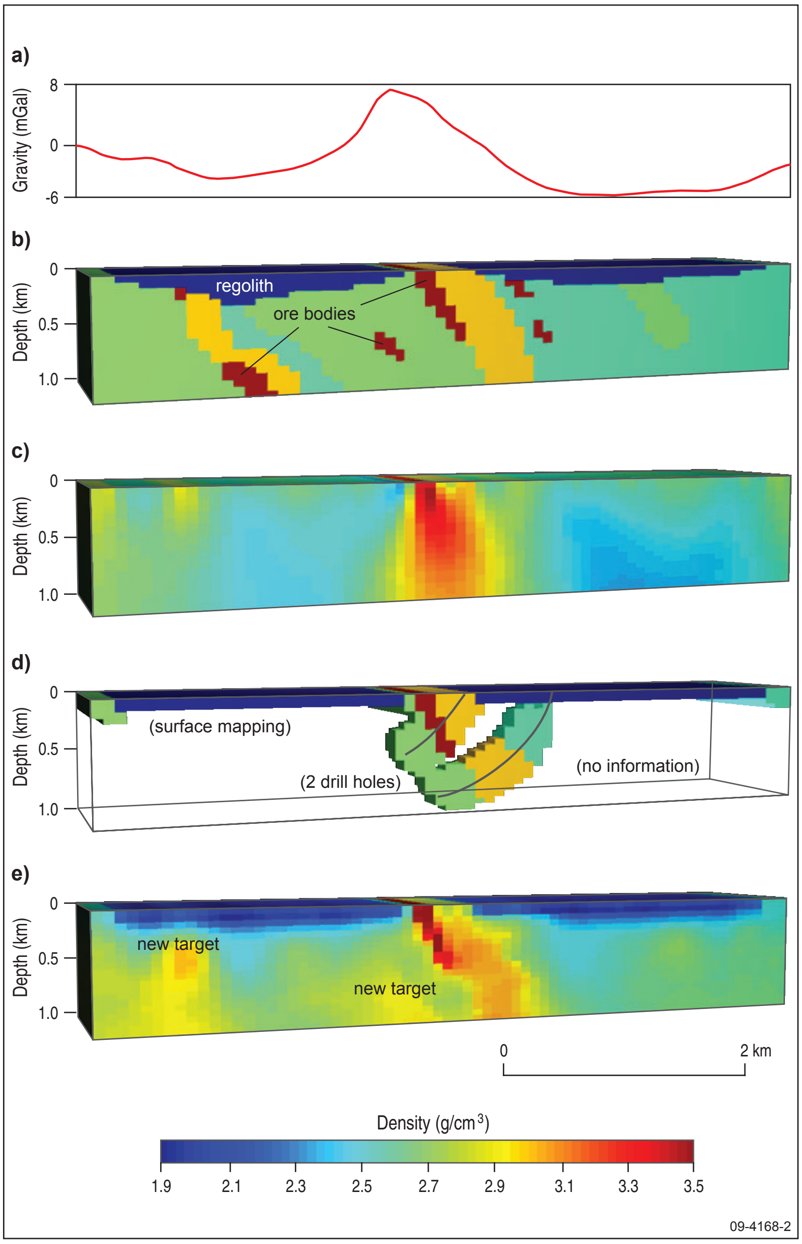


Fig. 2. A simple synthetic example demonstrating the effect of including constraints based on surface mapping and two hypothetical drill holes (d) in a gravity inversion. Although both the geologically-unconstrained (c) and constrained (e) results explain the observed gravity data (a) equally well, the constrained result is a much more reliable predictor of the true geology (b).

Synthetic example

The benefit of including a constraining model based on just the available geological observations in an inversion can be demonstrated using a simple synthetic gravity inversion. Figure 2a shows a profile through the gravity response calculated from the 3D synthetic model of known densities which are shown in cross-section view in figure 2b. When the full gravity data set is inverted using default settings in the UBC-GIF GRAV3D program, a smooth 3D density model is recovered that explains the observed gravity data, as shown in figure 2c.

Basic surface mapping, two drill holes, and some density measurements can be combined by using the methods outlined earlier. This generates a model of expected densities (figure 2d) as well as bounds constraints, smallness weights and smoothness weights. When this information is included in the gravity inversion, the predicted densities give a much more accurate depiction of the true subsurface (figure 2e). This final inversion result can be more reliably used for further exploration or targeting. The non-uniqueness of inversions is demonstrated by the fact that all three models shown in figure 2 (b, c, and e) reproduce the observed gravity response equally well.

Application

An example of the constraints that can be built using sparse geological data from the Perseverance komatiite-hosted nickel sulphide deposit in Western Australia is shown in figure 3. This example uses all available geological information surrounding the deposit to create density constraints for gravity inversions. The available data (figure 3a) includes Geoscience Australia and Geological Survey of Western Australia surface and basement geology map polygon shapefiles, a drilling database supplied by BHP Billiton with geology logs and density measurements, and density measurements on variably-weathered surface rocks. This data can be used to create a set of geological constraints based on the raw geological observations (figure 3b), with an indication of the confidence in that model (figure 3c). Ellipsoidal buffers with radii between 50 and 200 metres depending on the type of observation, were used to extrapolate the observations using the dominant north-northwest strike and subvertical dip (figure 3d). The constraints are enforced most strongly where cells are well sampled with density measurements or geological observations (higher smallness weights and tighter bounds). Weaker constraints are applied where cells are poorly sampled or where constraints have been extrapolated based on

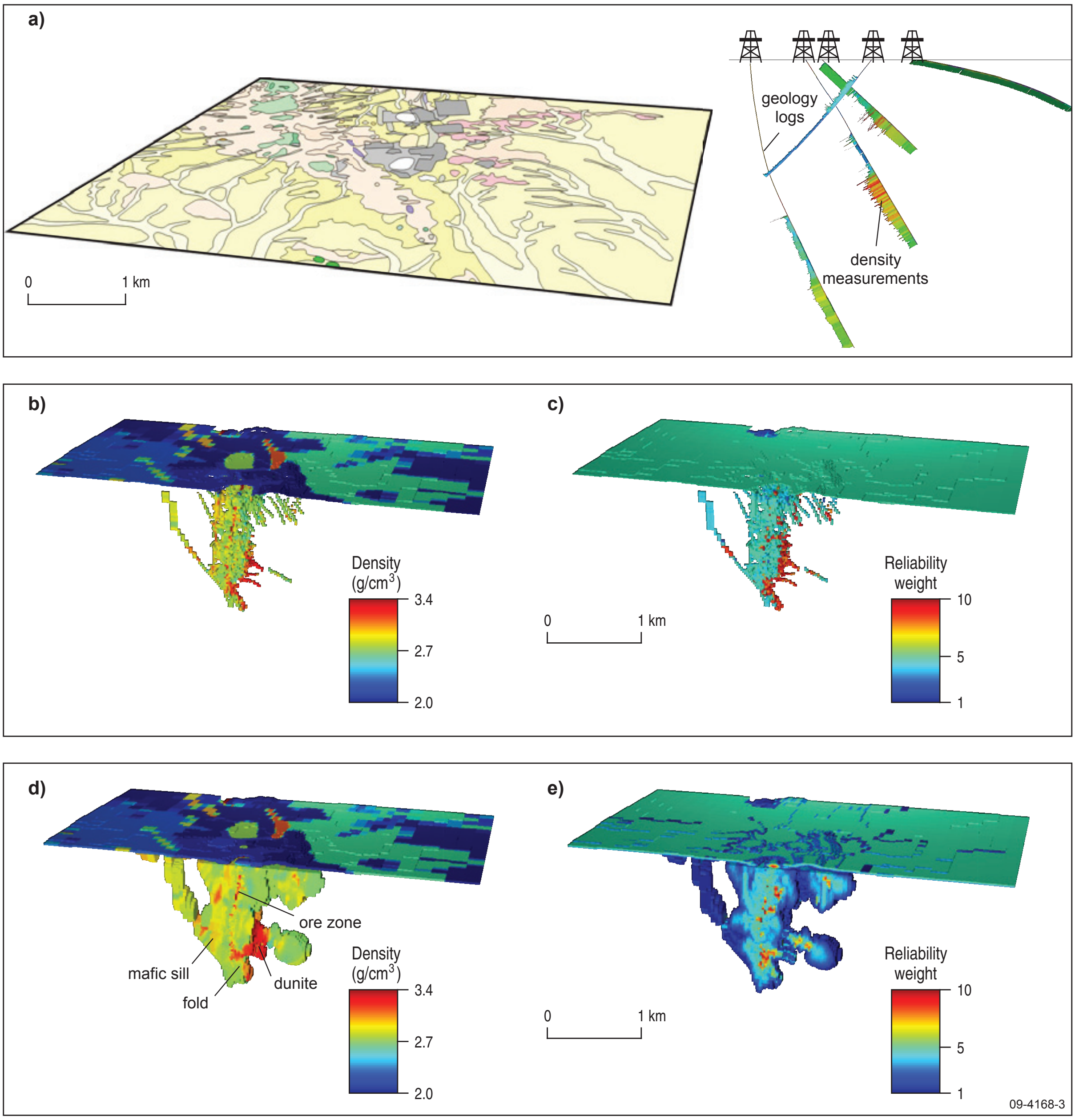


Fig. 3. An example of the types of constraints that can be built in a well-understood near-mine environment around the Perseverance Nickel-sulphide deposit in Western Australia. Observed rock types or density measurements in mapping or drilling (a) are converted into constraints, including a density model (b) and an indication of the reliability of that model (c) based on the type of data and distribution of samples. The constraints can then be extrapolated based on known structural orientations to get enhanced models of density (d) and reliability (e).

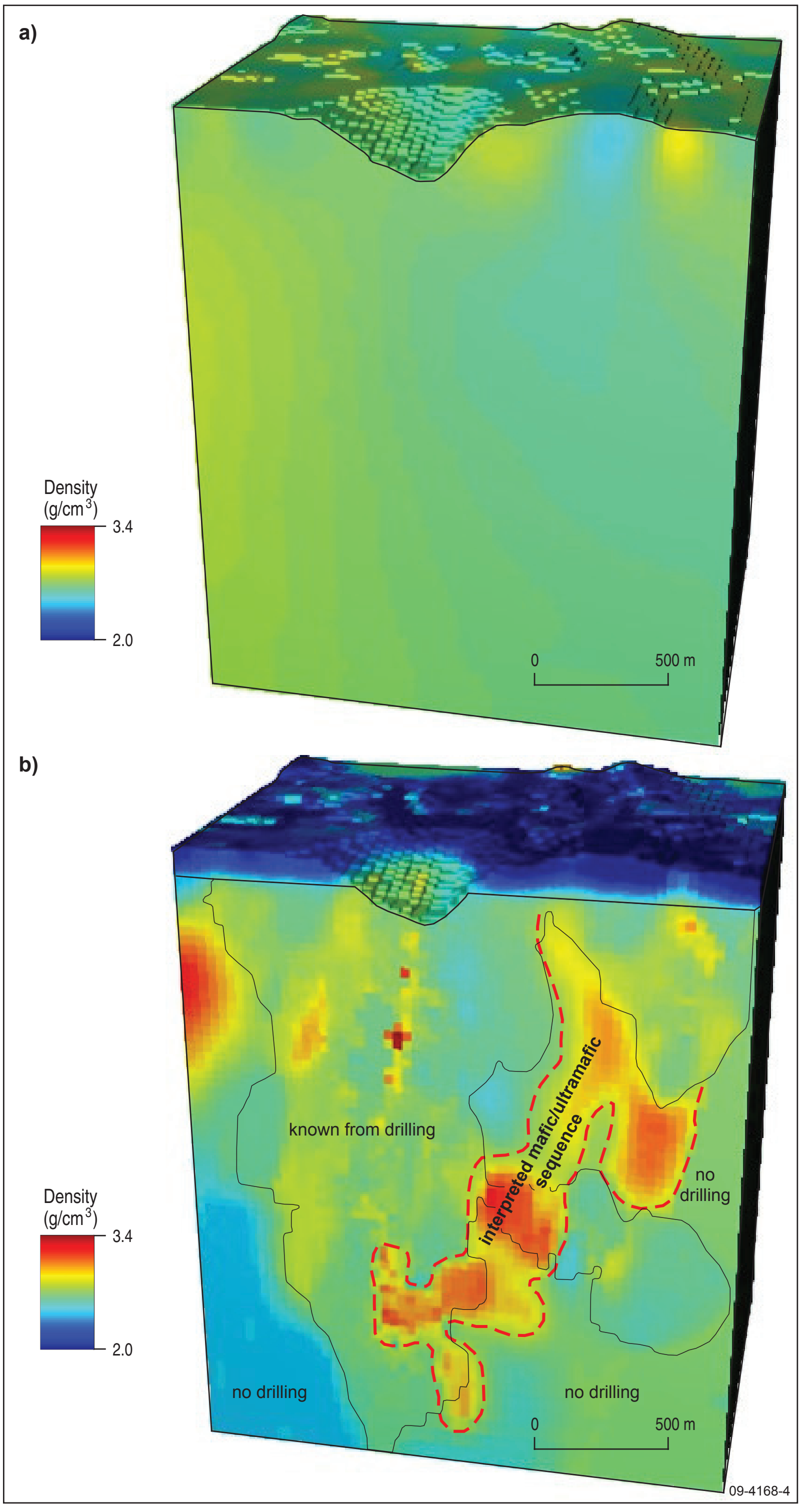


Fig. 4. Comparison of the default, geologically-unconstrained gravity inversion result (a) and the result obtained when using the geological constraints shown in figure 3d-e, built using the model-building approach (b). Both models explain the observed gravity data, but the geologically-constrained result reproduces low density regolith at the surface and predicts the extension of a large mafic/ultramafic sequence (dashed line) beyond the limited drilling intercepts (fine solid line).

nearby observations (figure 3e). Strong data-based constraints are specified in 2.8 per cent of the model cells and weaker extrapolated constraints are defined in an additional 17.2 per cent of the model.

Even prior to running the inversions, the constraint models provide a unique view of some of the geological features at Perseverance. The density reference model in figure 3d shows several known geological features including a dense dunite core, and maps, in 3D, a fold intersected by only limited drilling at a depth of 1500 metres. It also shows patches of the dense massive sulphides and thin subvertical mafic and ultramafic units west of the Perseverance open pit.

Inversion of the gravity data using these constraints provides a much more detailed and reliable prediction of the subsurface than can be obtained using the gravity data alone, as shown in figure 4. Although both models explain the gravity data equally well, the geologically-constrained result (figure 4b) also reproduces the known geology, including the low density regolith layer at the surface, and by doing so uncovers a more complex distribution of densities at depth. Based on these results predicted continuity of an important mafic/ultramafic sequence beyond existing drilling intercepts will assist in deep near-mine exploration.

Summary

The sparse constraint model builder provides a quick and efficient means of automatically producing data-based constraining models for geophysical inversions. Although specifically developed for use with the UBC–GIF inversion programs, the treatment of the different types of geological information could be applied for use in any inversion or modelling algorithm. The procedure itself is primarily a data management routine to provide a systematic and repeatable way of combining geological observations and physical property measurements into a single, self-consistent model. When used in inversions, the constraints provide a means to effectively combine geological observations with geophysical data, to produce holistic predictive models of the subsurface. Geoscience Australia's Onshore Energy and Minerals Division has been using these techniques in its North Queensland and Gawler-Curnamona regional programs to recover more reliable 3D subsurface models as part of its ongoing Onshore Energy Security Program.

Physical property data are integral to holistic interpretations since they provide the critical link between geology and the observed geophysical responses. An understanding of the expected physical properties is therefore a crucial component in any geophysical interpretation. The method outlined here demonstrates an efficient way to use physical property measurements to develop constraints for inversions. It is hoped that this provides justification for acquiring more property measurements in the field. Geoscience Australia is currently planning the development of a national rock property database to improve the availability of reliable physical property measurements.

Acknowledgements

This study was conducted as part of a PhD research program undertaken at the University of British Columbia – Geophysical Research Facility in Vancouver, Canada. It was sponsored by Geoscience Australia, the *pmd*CRC*, Anglo American, Anglo Gold Ashanti, Barrick Gold, BHP Billiton, Geoinformatics Exploration Canada, Teck, Vale Inco, Xstrata, and the Natural Sciences and Engineering Research Council of Canada. BHP Billiton is thanked for permission to publish the Perseverance deposit example.

For more information

phone Nick Williams on +61 2 6249 5807
email nick.williams@ga.gov.au

References

Li Y and Oldenburg DW. 1996. 3-D inversion of magnetic data. Geophysics. 61(2): 394–408.

Li Y and Oldenburg DW. 1998. 3-D inversion of gravity data. Geophysics. 63(1): 109–119.

McGaughey J. 2007. Geological models, rock properties, and the 3D inversion of geophysical data. In: B. Milkereit (ed), Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration, 473–483.

McInerney P et al. 2007. Improved 3D geology modelling using an implicit function interpolator and forward modelling of potential field data. In: B. Milkereit (ed), Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration, 919–922.

Oldenburg DW & Pratt DA. 2007. Geophysical inversion for mineral exploration: A decade of progress in theory and practice. In: B. Milkereit (ed), Proceedings of Exploration 07: Fifth Decennial International Conference on Mineral Exploration, 61–95.

Related websites/articles

Geoscience Australia's Onshore Energy Geodynamic Framework Project
www.ga.gov.au/minerals/research/national/oegf/index.jsp

The Geophysical Inversion Facility at The University of British Columbia
www.eos.ubc.ca/ubcgif/

Geologically-constrained UBC–GIF gravity and magnetic inversions with examples from the Agnew-Wiluna greenstone belt, Western Australia, PhD Thesis by Nicholas Williams
hdl.handle.net/2429/2744

Australian Government
Geoscience Australia

AUSGEO news
ISSUE 96 Dec 2009

Cooper Basin region now in 3D

New 3D map assists geothermal exploration

Tony Meixner

The new 3D Cooper Basin map will aid explorers in a region identified as highly prospective for geothermal energy. The newly produced map incorporates the two fundamental components which define a hot rock geothermal play: the potential heat source (high-heat producing granites) and the thermal insulation (overlying sediments).

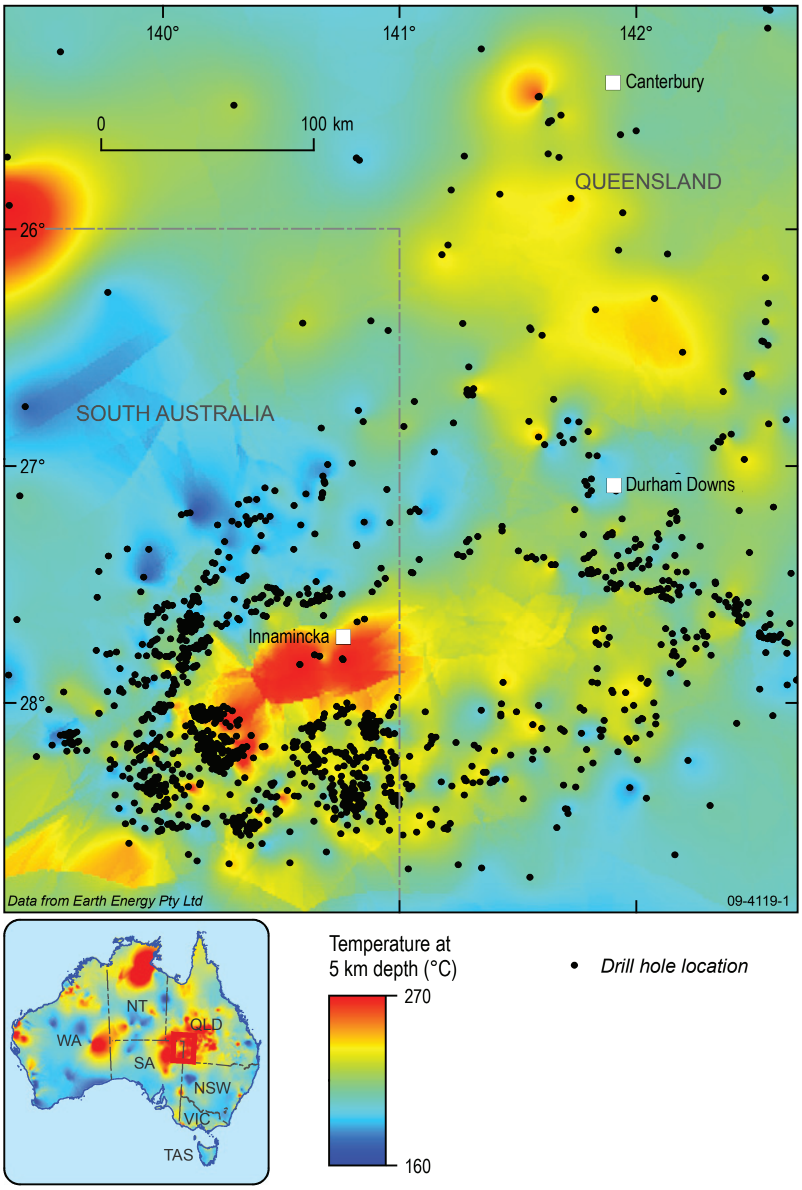


Figure 1. Predicted temperature at five kilometres depth (Chopra & Holgate 2005) including well locations.

By delineating the 3D geometries of both the known high-heat producing granites and inferred granitic bodies that may be high heat producing, and the overlying sedimentary basins, potential hot rock geothermal plays are identified.

This study was carried out by Geoscience Australia's Geothermal Project as part of its Onshore Energy Security Program which provides pre-competitive information to support mineral and energy resource exploration.

The Cooper Basin region

The Cooper Basin region straddles the Queensland/South Australia border, and is coincident with a prominent anomaly on a map of predicted temperature at five kilometres depth (figure 1). The region forms part of a broad area of anomalously high heat flow attributed to Proterozoic basement rocks enriched in naturally occurring radioactive elements. High-heat producing granites, including granodiorite of the Early to Mid-Carboniferous Big Lake Suite, intrude the basement beneath the Cooper and Eromanga basin sequences.

These high-heat producing granites form a significant geothermal play being targeted by Australia's first hot rock development by Geodynamics Limited at Habanero, near Innamincka in South Australia.

> "The region forms part of a broad area of anomalously high heat flow attributed to Proterozoic basement rocks enriched in naturally occurring radioactive elements."

The relationship between high heat flow, high temperature gradient and anomalous heat production in the Big Lake Suite is well recognised. The thick sedimentary sequences of the overlying Cooper and Eromanga basins provide a thermal blanketing effect resulting in temperatures as high as 270° C at depths of less than five kilometres. There is a high probability that corresponding geothermal plays exist in association with other granitic bodies lying beneath the Cooper and Eromanga basins. For the most part, the location and characteristics of these bodies are poorly understood and accurately identifying them is an important first step towards any future geothermal exploration in this region.

The Cooper region Bouguer gravity field is shown in figure 2a and the Z-horizon (top of basement) is shown in figure 2b. Two northeast-trending gravity lows broadly coincide with the Nappamerri and Tenappera troughs. These are bounded by northeast-trending gravity highs which are similarly associated with two structural ridges. In the northeast of the study area, two prominent structural lows coincide with low gravity anomalies. Thus, there is a broad regional correlation between known basin structure and the gravity field, suggesting that the distribution of low-density basin sediments is of significance.

There is, however, evidence that density variations in the basement are contributing to the gravity field. Gravity lows that are coincident with the Nappamerri and Tenappera troughs extend beyond the trough boundaries (figure 2b). A number of intense, discrete gravity lows lie within

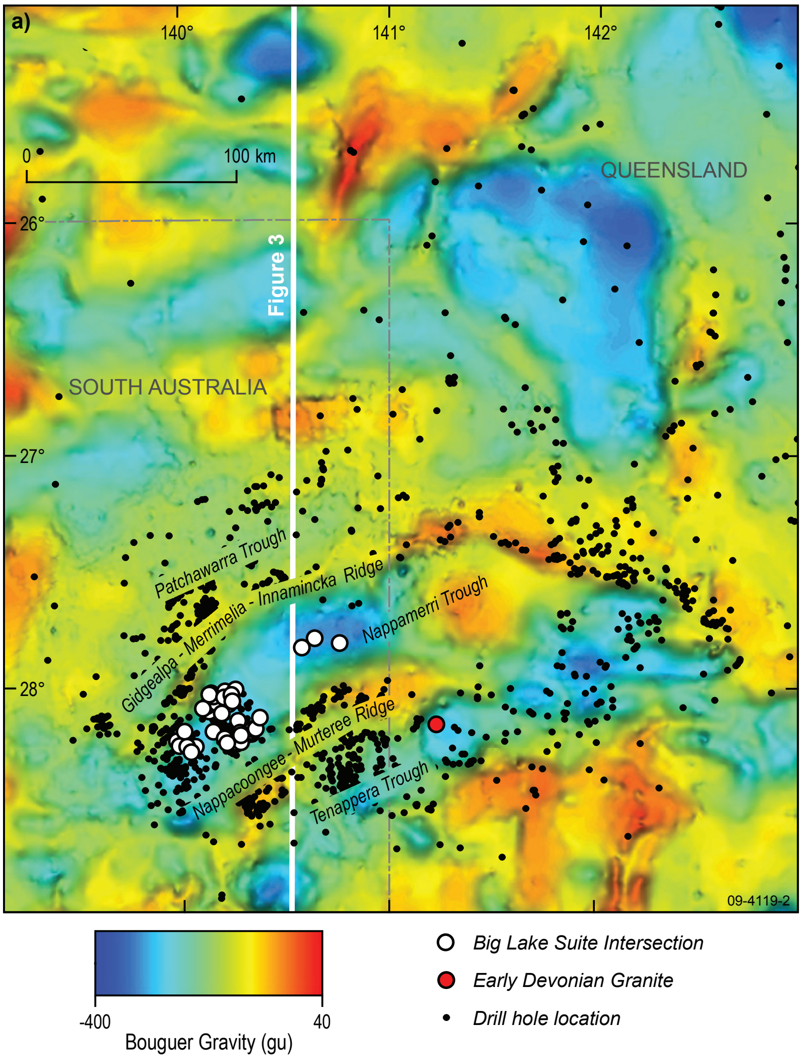


Figure 2a. Gravity image showing drill-hole locations (Big Lake Suite intersections in white; early Devonian granite in red). The major structural elements of the Cooper Basin and the location of the north-south section in figure 4 (white) are also shown.

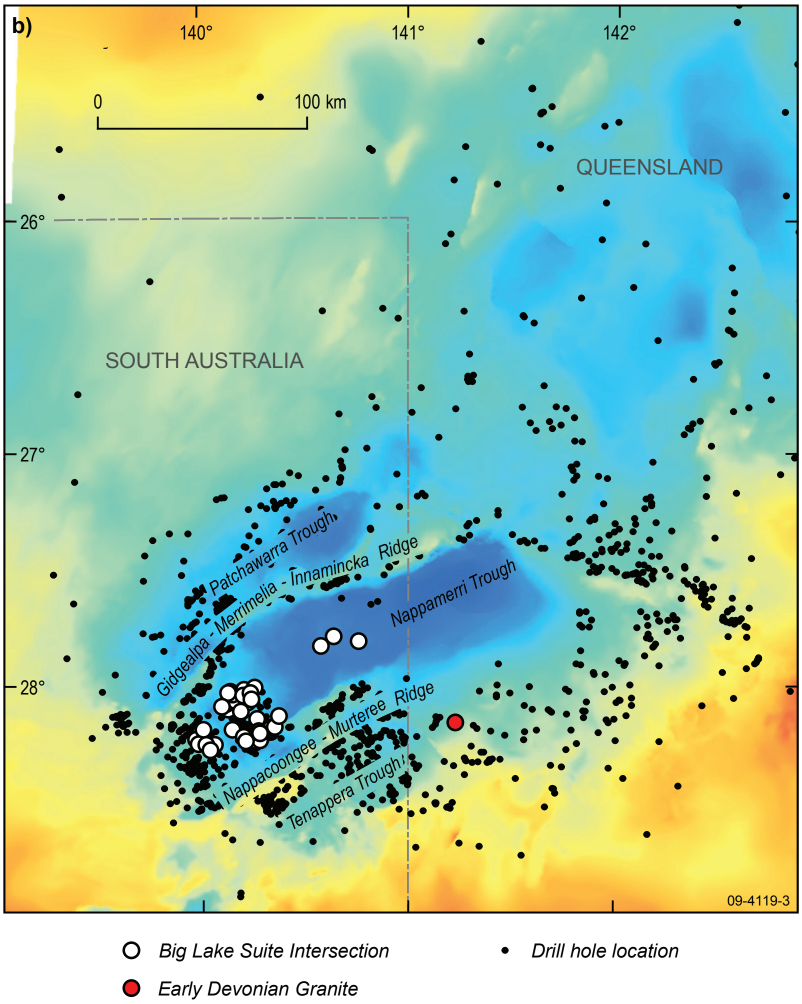


Figure 2b. Z-horizon image compiled from existing open file seismic sections, industry interpretations and 1300 well intersections (PIRSA 2008). This surface represents the base of the stacked Cooper and Eromanga basins. The Z-horizon ranges from 815 to 4496 metres below the topography.

the broader northeast trends, in some cases coinciding with granite intersections in the Nappamerri and Tenappera troughs. In the northwest of the study area where the Eromanga Basin lies directly on basement, there are a number of prominent gravity lows that are not associated with any known basin structure.

The gravity field is therefore influenced by both the thickness of basin sediments and by density variations in the basement. For this study, the gravity lows are interpreted as being sourced primarily from relatively low density granitic bodies that have intruded the basement. This assumption is supported by two lines of evidence. Firstly, all granite well intersections coincide with gravity lows and secondly, the nature of the basement which consists of Cambro-Ordovician Warburton Basin and Early Palaeozoic and Proterozoic elements. These basement units have been deformed and metamorphosed to such an extent that the densities of the constituent units will be generally higher than granites that intrude these units.

Constructing the 3D map

The 3D map, which covers an area of 300 by 450 kilometres by 20 kilometres depth, was constructed in part using 3D inversions of Bouguer gravity described by Li and Oldenburg (1998). Gravity inverse modelling is a process whereby adjustments are made to a density model, in the form of a mesh of rectangular prisms, until there is an acceptable fit between the predicted response of the model and the observed gravity data. Where density observations are available, it is possible to constrain the inversion to match the supplied density values to within a specified upper and lower bound. Where no density observations are available the inversion can be left unconstrained.

The inversion model consisted of a mesh with a cell size of two kilometres lateral and 250 metres vertical lengths. The smaller vertical cell size used in this study was to accommodate the high resolution of the Z-horizon (figure 2b) which represents the base of the stacked Cooper and Eromanga basins. Density values were assigned to the individual cells of the reference model based on whether the centre of the cell falls below the Z-horizon (basement) or between the Z-horizon and the topographic surface (Cooper and Eromanga basin sediments). The inversions were forced to match the basin

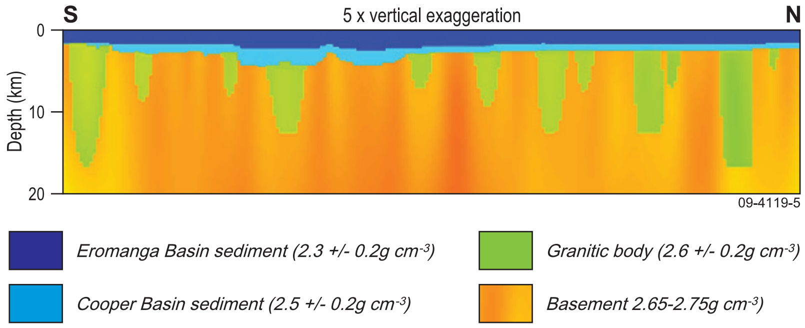


Figure 3. North-south density section through the final gravity inversion model (see Figure 2a for location). The densities of the Eromanga Basin sediments (dark blue: 2.3 +/- 0.2 g cm^{-3}), Cooper Basin sediments (light blue: 2.5 +/- 0.2 g cm^{-3}) and the granitic bodies (green: 2.6 +/- 0.2 g cm-^{3}) were constrained to a narrow density range, while the basement (yellow-red: 2.65–2.75 g cm^{-3}) was left unconstrained.

sediment density, 2.4 grams per cubic centimetre (g cm^{-3}) based on a Bureau of Mineral Resources seismic refraction study, to within ± 0.2 g cm^{-3}. Although a density was assigned to the basement (2.67 g cm^{-3}), the corresponding upper and lower bounds were set such that they encompassed all likely rock densities.

The inversion models of the basement have smooth variations in density. However, discrete boundaries can be constructed by producing 3D contour surfaces of the basement, termed iso-surfaces. A series of iso-surfaces were generated, based on a range of density values, enclosing successively larger regions of low density. The geometry of the regions is lobe-like with the maximum lateral extent at or near the top of the basement and gradually reducing in lateral extent at depth. A gravity edge mapping technique was used to select the optimal iso-surface to constrain the sub-sediment lateral extent of the low density lobes.

A series of separate inversions were generated by assigning three different densities to the enclosed 'granite' lobes. The densities selected (2.55, 2.6 and 2.65 g cm^{-3}) cover a range of typical granite densities and were constrained by specifying ± 0.02 g cm^{-3} as an upper and lower bound. A large proportion of the low density lobes had total depths of less than eight kilometres. However, a number of lobes, coincident with the more intense gravity anomalies, were considerably deeper with total depths up to 20 kilometres. Granites with these larger depth extents were considered geologically unrealistic and were restricted by specifying a maximum cut-off depth for the low density lobes. Three additional models were generated for each of the above granite densities by assigning different levels of maximum cut-off depths of 8, 12, and 16 kilometres.

Results of the nine inversions were analysed by inspecting the regions of basement immediately below the base of the modelled granitic bodies. If the density of the granite is too high and/or its depth extent is too low, then the inversion result will incorporate an anomalous region of low density in the basement directly beneath the modelled granite. Conversely, if the density of the modelled granite is too low and/or its depth extent is too large, then an anomalous region of high density will be generated at the base of the granite. The inversion model which produced the most 'neutral' result had a density of 2.6 g cm^{-3} assigned to the modelled granites and a maximum cut-off of 12 kilometres depth (figure 3). The final 3D map of inferred sub-sediment granitic body distribution is shown in figure 4.

Conclusion

The 3D map indicates that a large volume of granitic material exists within the basement of the Cooper and Eromanga basins. A number of these granite bodies, such as the Big Lake Suite granite shown in figure 4, are coincident with anomalies in the map of predicted temperature at five kilometres depth, indicating that they may have high-heat-producing compositions. A number of interpreted granite bodies do not correspond to temperature anomalies, indicating some granite compositions may have low radioelement concentrations.

The 3D map, which also defines the geometries of the Cooper and Eromanga basins, delineates both potential heat sources and thermally insulating cover. Thus the 3D map can be used as a predictive tool for delineating potential geothermal plays when used in conjunction with the map of predicted temperature at five kilometres depth.

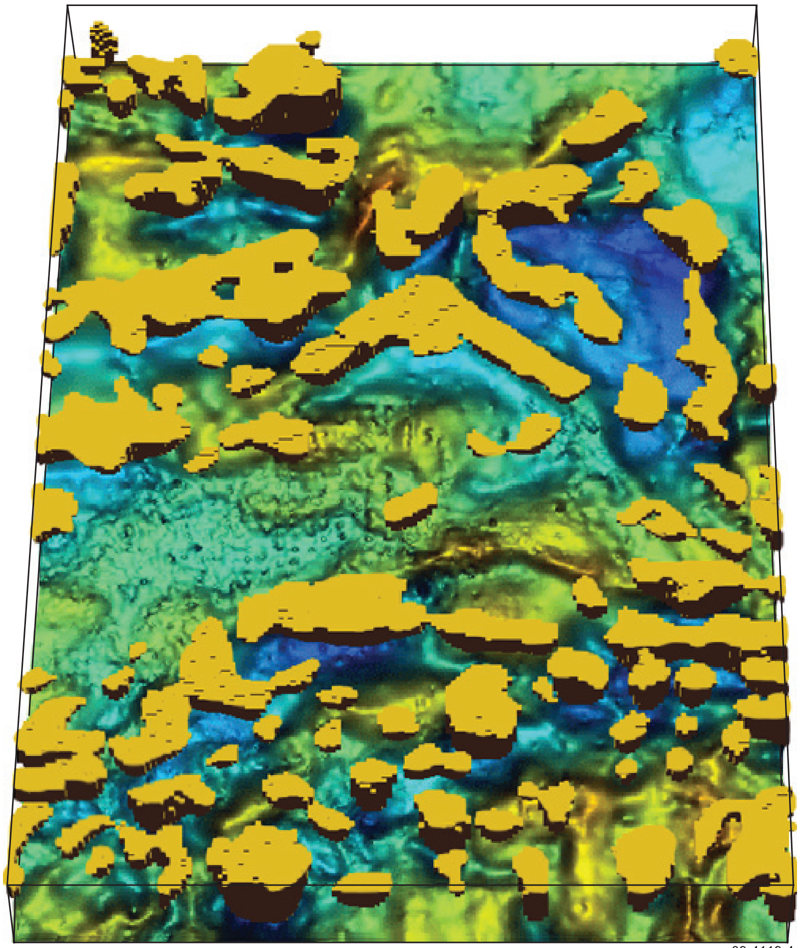


Figure 4. 3D model viewed obliquely from south of inferred sub-sediment granitic bodies overlying an image of gravity data.

For more information

phone Tony Meixner on +61 2 6249 9636
email tony.meixner@ga.gov.au

References

Archibald N, Gow P & Boschetti F. 1999. Multiscale edge analysis of potential field data. Exploration Geophysics 30:38–44.

Chopra P & Holgate FL. 2005. A GIS Analysis of Temperature in the Australian Crust. Proceedings of the World Geothermal Congress 2005, Antalya, Turkey.

Li Y & Oldenburg DW. 1998. 3-D inversion of gravity data. Geophysics 63:109–119.

Primary Industries and Resources South Australia (PIRSA). 2008. PIRSA Petroleum Seismic Data, Cooper Basin 2005-2006 Workstation Dataset. Available at: www.pir.sa.gov.au/petroleum/home/access_to_data/seismic_data

Related website/articles

Geoscience Austtralia's Geothermal Energy Project

www.ga.gov.au/minerals/research/national/geothermal/index.jsp

Cooper Basin region 3D map (Version 1)

www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=68832

The Cooper Basin region 3D map Version 1: A search for Hot Buried Granites (Geoscience Record 2009/15)

www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=68823

Australian Government
Geoscience Australia
AUSGEO news
ISSUE 96 Dec 2009

Australian mineral exploration retreats from record high

Mike Huleatt & Lynton Jaques

Australian and global mineral exploration reached record highs in 2008 but dropped significantly in 2009 as a consequence of the Global Financial Crisis. Australian mineral exploration expenditure fell by 9.7% from a record $2461 million in 2007–08 to $2223 million in 2008–09 according to data from the Australian Bureau of Statistics (ABS). In constant dollar terms this was a fall of 12.4% from the 2007–08 record (figure 1). World-wide mineral exploration fell more sharply. World non-ferrous mineral (including base metals, precious metals, diamonds, uranium but not coal or iron ore) exploration budgets reported by the Metals Economics Group (MEG) fell from a record US$14.4 billion in 2008 to an estimated US$8.4 billion in 2009, a fall of 42%. This directly reflects the impact of the global economic downturn which resulted in reduced demand for most minerals, especially base metals, and consequent substantial price falls for many of those commodities. The fall in exploration in Australia has been less than that experienced globally because demand for Australia's iron ore and coal resources has maintained both high levels of exports and exploration for these commodities.

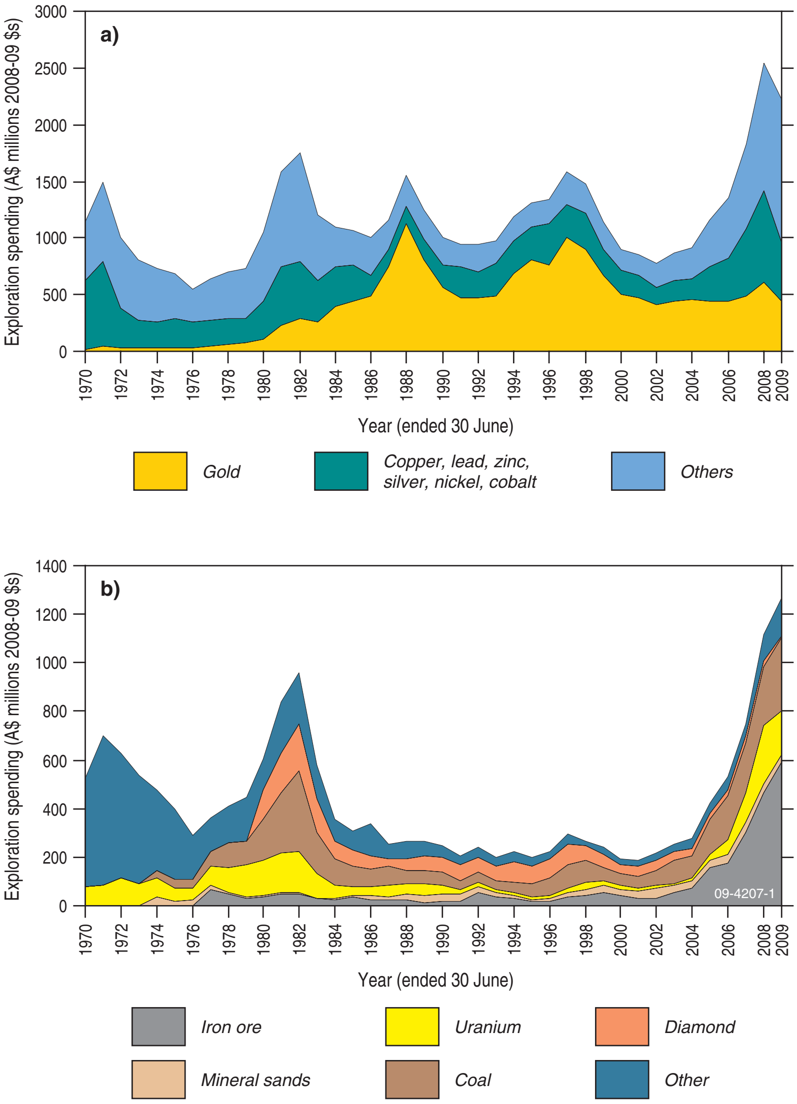


Figure 1. Australian mineral exploration expenditure in constant 2008–09 dollars (Based on Australian Bureau of Statistics data deflated by Consumer Price Index).

Australian mineral exploration dips from peak

Australian mineral exploration (non-petroleum) expenditure in 2008–09 fell by 9.7% to $2223 million from its record high in 2007–08 of $2461.4 million. This was a smaller decline than anticipated as major reductions in expenditure on base metals

($519 million: down 33.8%), gold ($438 million: down 26.1%) and uranium ($185 million: down 20%) were to a large extent offset by spending on exploration for iron ore ($589 million: up 30.9%), coal ($297 million: up 26.6%) and 'Others' which includes commodities such as phosphate, manganese, tungsten and molybdenum ($154 million: up 39.6%).

The Northern Territory was the only Australian jurisdiction which recorded an increase in exploration in 2008–09 with spending rising by 10%. The fall in Western Australia was limited to 1% as iron ore exploration underpinned activity in that jurisdiction. High levels of coal exploration in New South Wales and Queensland limited the overall falls in mineral exploration expenditure in those states to 7.7% and 11.6% respectively. In the other states, with limited or no exploration for iron ore and/or coal, mineral exploration expenditure fell by more than 30%.

World mineral exploration retreats

World non-ferrous mineral exploration budgets (including uranium) in 2009 are estimated to be US$8.4 billion, according to the Canadian-based Metals Economics Group (MEG). This was down some 40 per cent from the US $14.4 billion in 2008. If uranium is excluded, world budgets fell to US$7.7 billion and it was the first reduction after six consecutive years of growth (figure 2). MEG reported that this year's drop represents the largest year-on-year decline in global exploration budgets (in both dollar and percentage terms) since they began their surveys in 1989.

The number of companies in the MEG 2009 survey was down slightly on the number included in the 2008 survey. The 2009 survey is based on the planned non-ferrous exploration spending by 1846 companies (with budgets of at least US$100 000) which MEG estimates covers about 95% of worldwide commercially oriented non-ferrous exploration budgets. MEG reported that, despite the impact of the Global Financial Crisis, the number of junior companies planning active exploration programs fell by only 6% compared with the previous year. The 2009 survey also included a further 319 companies engaged in uranium exploration with exploration budgets of some $664 million. Of these, MEG reports that 152 were exploring solely for uranium.

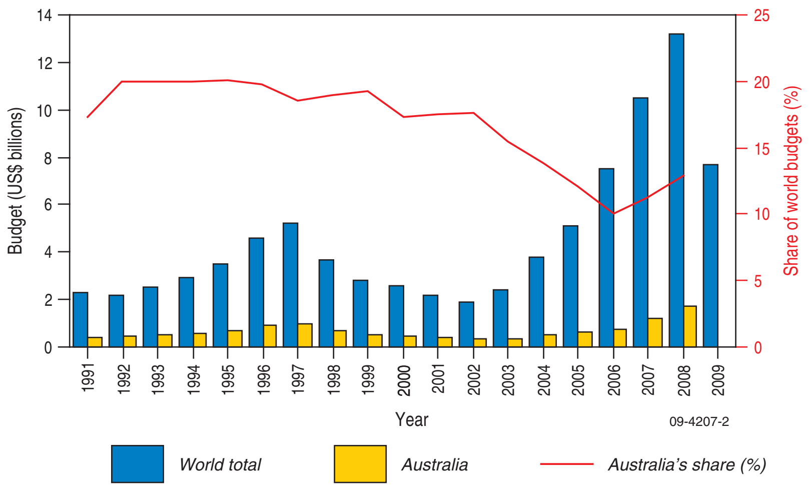


Figure 2. World non-ferrous mineral exploration budgets (excluding uranium) and Australia's estimated share as a percentage (Source: Metals Economics Group).

Australia's share of world non-ferrous mineral exploration has recovered slightly from a low of around 11 to 12% in recent MEG surveys after falling from around 20% in the 1990s (figure 2). Australia has attracted the second highest proportion of non-ferrous mineral exploration budgets after Canada. In addition to the non-ferrous exploration Australia has also experienced high levels of iron ore, coal and uranium exploration over the past five years.

The downturn in mineral exploration in Australia and world-wide is a direct consequence of the Global Financial Crisis which precipitated a fall in metal demand and production cutbacks and closure of a number of base metal mines. The ABS data show that impact of the downturn in mineral exploration expenditure has been greatest in base metals exploration followed by gold.

Focus on brownfields exploration

Both global and Australian data show a continued focus on brownfields exploration at the expense of greenfields in recent years. In their 2008 briefing on world exploration trends MEG noted that the proportion of world non-ferrous mineral exploration budgets allocated to grassroots exploration has fallen progressively from more than 50% in the mid-1990s to 36% in 2008, with the decline in grassroots exploration taken up by increased advanced-stage and, to a lesser extent, mine-site exploration. MEG attributed this trend to a growth in the number of companies engaged in mining combined with increased efforts to prove up reserves and bring them into production during a time of high commodity prices.

In Australia, the ABS data show growth in brownfields exploration in recent years, with the proportion of exploration expenditure allocated to exploration at existing deposits reaching a peak of 64% in 2006–07. ABS reported that 62% of exploration in 2008–09 was at existing deposits. The growth in brownfields exploration is mirrored by the strong growth in iron ore and coal exploration over the past five years, much of which is focused around known resources.

ABS data for 2008–09 shows that iron ore and coal combined attracted 40% of total Australian mineral exploration spending and gold accounted for a further 20% (figure 3). This differs significantly from the exploration profile in 2003–04 where iron ore and coal accounted for only 18% of Australia's exploration spending while gold accounted for half the total.

The drilling data confirm the continuing dominance of brownfields exploration. The ABS data confirm this focus with 38% of exploration expenditure allocated to the search for new deposits. Exploration drilling fell by 19% to 7.888 million metres in 2008–09. However, greenfields drilling fell by 30.6% to 2.720 million metres whereas brownfields drilling fell by only 11.5% to 6.167 million metres.

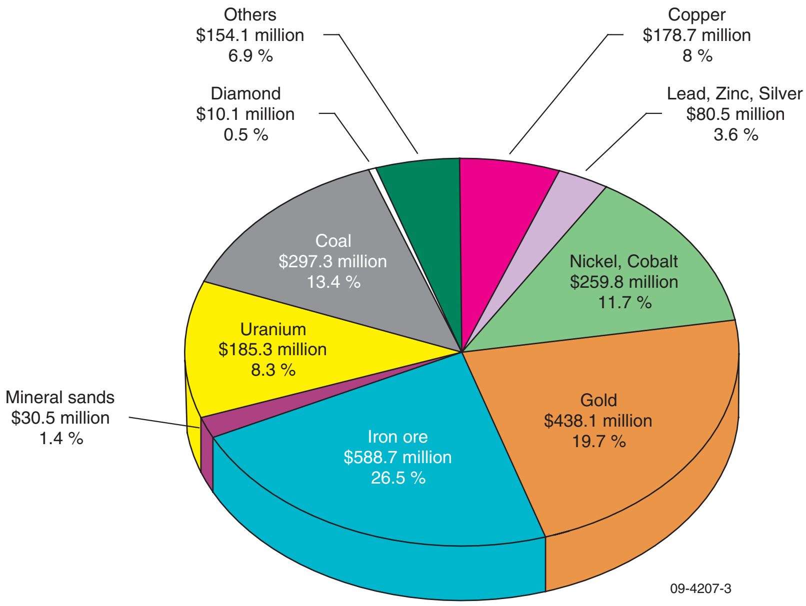


Figure 3. Australian mineral exploration expenditure by commodity (source: ABS).

Exploration outlook

Australia's diverse mineral endowment has helped mitigate the full impact of the adverse world economic conditions on mineral exploration. The collapse in base metal exploration (especially copper and zinc) was offset to a large part by increased iron ore and coal exploration. The overall impact was a reduction in total exploration expenditure of nearly 10% in 2008–09.

Continued strong interest in iron ore and coal has resulted in smaller price falls than for many other commodities. Gold prices have remained very strong and its sustained level above US$1000/oz is likely to encourage increased interest in gold exploration, at least in the short term. The prices of many of the other metals have recovered from the lows reached in late 2008–early 2009 and show further signs of increasing as the world economies recover. Iron ore exploration in particular is likely to remain at high levels in the face of strong demand, especially from China. In contrast base metal exploration generally is unlikely to show strong growth until existing metal stockpiles are reduced and idle production capacity is brought back online as demand increases.

For more information

phone Lynton Jaques on +61 2 6249 9745
email lynton.jaques@ga.gov.au
phone Mike Huleatt on +61 2 6249 9087
email mike.huleatt@ga.gov.au

in brief

Earthquake moves Australia and New Zealand closer

Australia's Tsunami Warning System issued a tsunami warning for sections of Australia's east coast, following a large undersea earthquake at approximately 7.30pm AEST on 15 July 2009. The threat came from the relatively unknown Puysegur subduction zone after a magnitude 7.9 earthquake occurred off the Fjordland region along the southwest coast of the South Island of New Zealand (figure 1). Although it was widely felt throughout the region no major damage was reported.

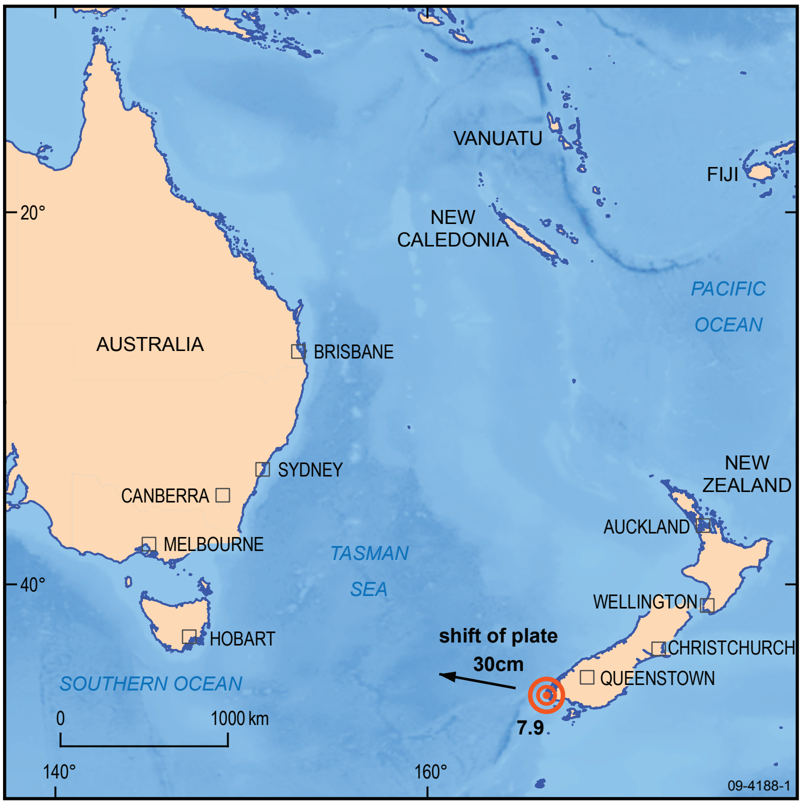


Figure 1. Location map showing the earthquake's proximity to Australia.

According to global positioning system (GPS) measurements made after the earthquake, the southwest tip of New Zealand shifted westwards towards Australia by about 30 centimetres during the earthquake, and southwards by about seven centimetres. There was also a shift of approximately two centimetres to the west at Dunedin, on the east coast of New Zealand, which is over 300 kilometres away from the earthquake epicentre.

The displacements associated with the earthquake were determined by the Australian Regional GPS Network (ARGN) and the South Pacific Sea Level Climate Monitoring Project (SPSLCMP) operated by Geoscience Australia and the GPS Active Control Network operated by Land Information New Zealand (LINZ).

The earthquake occurred along the plate boundary between the Australian and Pacific tectonic plates. The Australian plate is being forced under the Pacific plate ('subducted') at a rate of about 40 millimetres a year, resulting in the uplift of the Southern Alps of New Zealand and causing the deep Puysegur trench which runs southwards from southwest New Zealand. The subduction of the Australian plate causes stresses to build up where the plates slide past each other. Periodically, the rocks give way under this stress causing earthquakes, and we observe the effects on land such as ground shaking and displacement of the ground surface.

'When a large, shallow earthquake occurs in the sea off the South Island, such as the event of 15 July 2009, it has the potential to create a tsunami, which propagates towards the eastern seaboard of Australia', according to Clive Collins, a senior seismologist at Geoscience Australia. 'When the upper Pacific plate 'thrusts' up over the downgoing Australian plate, as the boundary between the plates slips during the earthquake, all the water above the seafloor is pushed upwards and creates a tsunami wave'.

A small tsunami was generated during this earthquake and was recorded on tide gauges. A tide gauge at Jackson Bay in New Zealand measured the height of the tsunami wave at 50 centimetres. A tsunami warning was issued for the marine areas of New South Wales, Victoria, Norfolk Island and Tasmania, as well as a land inundation warning for Lord Howe Island. Although no visible effects were reported at any of these locations, tide gauges measured a 15 centimetre wave at Port Kembla in New South Wales and a 12 centimetre wave at Spring Bay in Tasmania.

For more information

phone Clive Collins on +61 2 6249 9544
email clive.collins@ga.gov.au

Planning update on AUSTRALIA 2012—34th International Geological Congress

The 34th International Geological Congress (IGC) was awarded to the Oceania region at the 32nd IGC held in Florence in 2004. It will be held in Brisbane, Queensland, between 2 and 10 August 2012 and known as AUSTRALIA 2012. The venue will be the state-of-the-art Brisbane Convention and Exhibition Centre (BCEC) which can hold more than 7 000 delegates (figure 1).

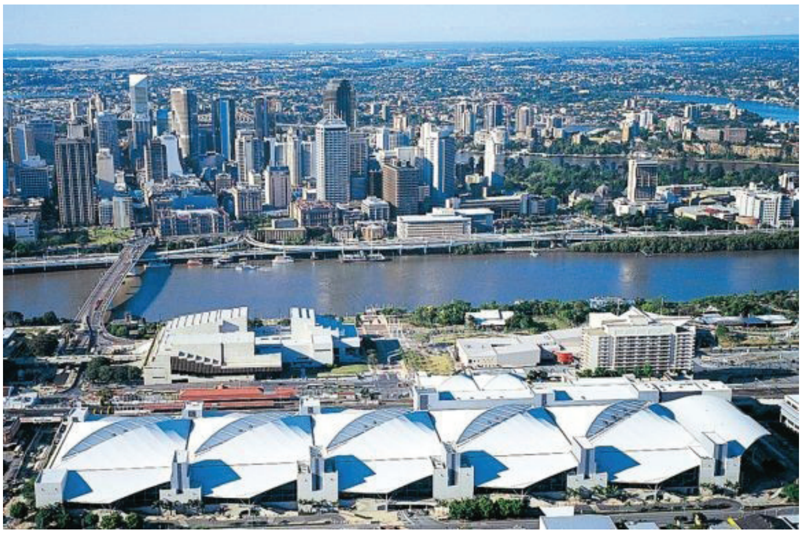


Figure 1. The Brisbane Exhibition and Convention Centre is the venue for AUSTRALIA 2012–34th International Geological Congress.

The IGC, which is usually held every four years, is one of the most prestigious international scientific events, with a tradition dating back to 1878. The event will be of considerable interest to everyone involved in geoscience, whether in industry, government or research, as well as the general public. The scientific sponsor of the IGC is the International Union of Geological Sciences (IUGS).

The AUSTRALIA 2012 Organising Committee is endeavouring to maximise delegate participation by integrating meetings of the major Australian and regional geoscientific societies into the Congress program. Consequently, some Australian geoscience societies have decided not to have their normal scientific business meeting in 2012, but to focus their efforts on the Congress. Other bodies are considering conducting their normal meetings during the IGC to enhance the opportunities for international participation. It is hoped to attract a range of international groups to hold meetings during, or dovetailing with, the Congress.

Organisation of the Congress

By agreement with the IUGS, the Australian Geoscience Council, the peak representative body of eight geoscience-related societies in Australia, is coordinating AUSTRALIA 2012. As the national geoscience and geospatial information agency, Geoscience Australia has made a strong commitment to the Congress. The President and Secretary General of the AUSTRALIA 2012 Organising Committee—Dr Neil Williams and Dr Ian Lambert respectively—are from Geoscience Australia. The agency is also contributing to national and international promotion of the Congress and supporting several of the major activities.

The state and Northern Territory geological surveys and GNS New Zealand are also contributing, particularly in organising many of the field trips. Together with Geoscience Australia, they are also contributing financially to the Congress.

Queensland Events Corporation, an agency of the Queensland Government, is providing financial support. An experienced Brisbane-based Professional Conference Organiser, Carillon Conference Management, has been appointed to work with the Organising Committee.

There are opportunities for experienced people to assist on the Committee developing the Congress Scientific Program, to either work under this committee as convenors of Symposia, or provide ideas on potential symposia topics. Suggestions are also invited for possible field trips, particularly if leaders are identified.

Scientific Program

The Congress theme will be 'Unearthing our Past and Future', encompassing the crucial contributions of geoscience in meeting societal needs and sustaining planet Earth. A wide-ranging scientific program is being planned by the Scientific Committee, under the leadership of Dr Lynton Jaques.

Each day will comprise a plenary 'theme-of-the-day' session, followed by up to 30 concurrent symposia on a wide range of geoscientific topics. A list of possible topics has been compiled by the Scientific Committee, reflecting the interests of all groups affiliated with the IUGS. It is planned that each symposia will have a local convenor working with an international co-convenor.

Australia's experience in developing a strong and sustainable mineral and energy resources sector will underpin a strong program emphasising future mineral and energy supplies. Other major themes, which reflect major challenges for countries in the Oceania region, will be climate change and its impacts on natural resource management and communities, and understanding and mitigating geohazards. There will also be broad-ranging sessions on geoscience information and standards.

There will be a limit of one oral presentation per delegate, although an individual may co-author several oral presentations. Poster sessions will also be given a high profile in the program. Expert workshops and short courses will reflect Australian and New Zealand international assistance objectives where feasible with the objective of attracting funding to support attendance by delegates from developing countries.

Public lectures, student events and media engagement opportunities will also be organised to ensure the main messages from the Congress reach the general public. A Communications and Outreach Strategy for AUSTRALIA 2012 is available through the IGC website.

Field trips

The 34th ICG is planning approximately 30 pre- and post-Congress field trips which will offer diverse opportunities to experience the fascinating geology of the Oceania region. These field visits will include all Australian states and the Northern Territory and field trips to New Zealand, Malaysia and New Caledonia/Vanuatu are being planned. There will also be a range of one-day tours available during the conference.

Exhibition

A large GeoExpo (trade show) which will occupy two of the exhibition halls is planned. The international exhibitors will include geological surveys, professional/learned societies, scientific publishers, consultants and technical service/product providers. In addition, a major petroleum and minerals industry exhibition is planned in one of the halls during the Congress, to coincide with the high profile minerals and petroleum symposia.

For more information

visit www.34igc.org
phone Paul Kay on +61 2 6249 5829
email paul.kay@ga.gov.au

IUGS AGC Queensland Events

product news

New data supports Ceduna Sub-basin acreage release

The Australian Government's 2009 release of offshore petroleum exploration acreage includes six large areas in the Ceduna Sub-basin of the Bight Basin. Over the last four years, the Bight Basin has been a focus of studies by Geoscience Australia's Southern Frontiers Project aimed at improving understanding of the petroleum prospectivity of the basin. These studies have provided pre-competitive data and information that underpins the 2009 acreage release (figure 1). A key component of the project was the Bight Basin Geological Sampling and Seepage Survey, which used the Marine National Facility vessel RV *Southern Surveyor*. The results of this survey have recently been released as Geoscience Australia Record 2009/24.

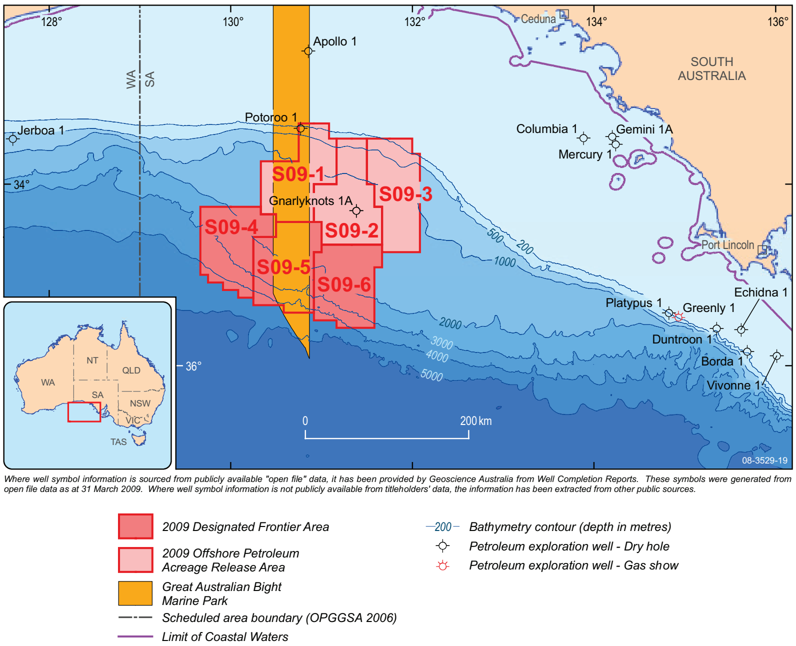


Figure 1. Location of the Bight Basin Release Areas S09-1 to S09-6 included in the Australian Government's 2009 release of offshore petroleum exploration areas.

A highlight of the Bight Basin survey was the collection of Cenomanian-Turonian organic-rich rocks from the northwestern edge of the Ceduna Sub-basin. Geochemical analyses have characterised these marine shales as world-class, oil-prone potential source rocks. These rocks, though predicted to occur, had not been sampled prior to this survey, so previous perceptions about the source rock potential of the basin have changed significantly. Record 2009/24 provides details of the samples collected during the survey and focuses on the organic geochemical and biostratigraphic analysis of these rocks.

To complement Record 2009/24, a presentation summarising the results of 3D petroleum systems modelling in the Ceduna Sub-basin is also available for download. The modelling, undertaken using Schlumberger Petromod® software, utilised new compositional kinetics from organic-rich rocks obtained by the Bight Basin survey to model maturation, generation and expulsion of hydrocarbons from a Cenomanian-Turonian marine source rock. Albian-Cenomanian marine source rocks and Cenomanian coaly source rocks were also modelled. The results of the study suggest that the Ceduna Sub-basin has experienced several phases of hydrocarbon generation, expulsion and accumulation.

To further support the Bight Basin acreage release, Geoscience Australia has also released a report on the seabed environments of the Ceduna Sub-basin, containing information on geomorphology, physical oceanography, sediments, ecology and seascapes for the area (Geoscience Australia Record 2009/09). The report is designed to assist explorers by providing information on a broad range of environmental issues that may impact on hydrocarbon exploration in the Sub-basin.

A major goal of the Southern Frontiers Project was to improve the understanding of the evolution and geology of the southern Australian margin as a whole. The southern margin includes the well-explored, hydrocarbon-producing Otway and Bass basins, as well as the frontier, but highly prospective, Bight Basin. Taking a margin-scale approach—examining regional and plate-scale controls and drivers—has provided insights into basin evolution. This work has involved collaborations with university researchers and consultants in a range of studies focusing on the big picture.

Two major products that document the results are:

- *Australian Southern Margin Synthesis.* This study entailed a tectonostratigraphic compilation and synthesis of Australia's southern margin basins. The report was prepared by FrOG Tech Pty Ltd and utilised the results of Geoscience Australia's southern margin basin studies over the past 10 years. It includes analysis of the tectonic and stratigraphic development of the Bight Basin (including the Bremer Sub-basin) as well as the Otway, Gippsland, Sorell and Bass basins.
- *South Australia-Antarctica Conjugate Rifted Margins report.* This study, undertaken by Nick Kusznir (University of Liverpool), involved 3D inversion of satellite gravity data incorporating a lithosphere thermal gravity anomaly correction. This technique was used to determine total crustal thickness, the thickness of residual continental crust, and the degree of continental lithospheric thinning for the southern Australian and Antarctic conjugate rifted margins and adjacent oceanic regions.

These reports and set of grids for the Rifted Margins report can be downloaded through the Geoscience Australia website.

For more information

phone Jennie Totterdell on +61 2 6249 9407
email jennifer.totterdell@ga.gov.au

Related websites/articles

Bight Basin Geological Sampling and Seepage Survey (Geoscience Australia Record 2009/24)
www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=68689

Results of 3D petroleum systems modelling in the Ceduna Sub-basin
www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=69485

Ceduna Sub-Basin: Environmental Summary (Geoscience Australia Record 2009/09)
www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=65838

Australian Southern Margin Synthesis
www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=68892

South Australia - Antarctica Conjugate Rifted Margins report
www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=68655

South Australia - Antarctica Conjugate Rifted Margins grids
www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=68656

Regional Petroleum Geology of Australia - Southern Australia
www.ga.gov.au/oceans/rpg_SthrnAust.jsp

2009 offshore petroleum exploration areas (Department of Resources, Energy and Tourism)
www.ret.gov.au/resources/upstream_petroleum/offshore_petroleum_exploration_in_australia/2009/Pages/default.aspx

AusGeo News 87: Promising results from Bight Basin survey
www.ga.gov.au/ausgeonews/ausgeonews200709/bight.jsp

Revealing Archean mafic-ultramafic magmatism and mineral prospectivity across Australia

Geoscience Australia has recently released two web-based map sheets that show the continental extent and age relationships of Archean mafic and ultramafic rocks, and associated mineral deposits. These maps will be of interest to explorers searching for nickel, platinum-group elements, chromium, titanium, vanadium, and cobalt.

The Archean Eon (~4000 to 2500 million years ago or Ma) represents a part of the Earth's history that is noteworthy for the widespread occurrence of unusual olivine-rich ultramafic rocks called komatiites, which contain world-class deposits of nickel sulphides.

In Australia, Archean mafic and ultramafic igneous rocks with reliable crystallisation ages are confined to the older crustal components in Western Australia and South Australia. During compilation of the map, twenty-six Archean Magmatic Events (AME) ranging in age from the

Eoarchean (~3730 Ma: AME 1) to the late Neoarchean (~2520 Ma: AME 26) were identified. This mafic-ultramafic magmatic event series is based on several hundred published age measurements, of which over 95 per cent are derived from recent uranium-lead dating of zircon and baddeleyite.

The Archean mafic-ultramafic magmatism event series commenced in the northwest Yilgarn Craton, with 3730 ± 6 Ma Eoarchean gabbroic rocks from the Manfred layered complex. These are the oldest dated rocks in Australia with the next oldest mafic-ultramafic rocks from the Pilbara Craton.

Mafic-ultramafic magmatic events became more widespread in the early Neoarchean with several samples of similar ages from the Yilgarn and Pilbara cratons, Hamersley Basin, and Sylvania Inlier. The national Archean mafic-ultramafic magmatic record concludes in the late Neoarchean with two isolated magmatic events (AME 25–2560 Ma and AME 26–2520 Ma) in the Gawler Craton.

The colour-coding of mafic and ultramafic rock units by their age of magmatism on Sheet 1 provides a visual cue to the spatial and temporal correlations of magmatic units at province and continental scales. A Time–Space–Event Chart highlights three significant periods of mineralisation associated with mafic-ultramafic magmatism.

They are:

- ~2925 Ma—platinum-group elements+nickel+copper (Munni Munni Intrusion: AME 8) and nickel+copper+platinum-group elements (Radio Hill Intrusion: AME 8)
- ~2800 Ma—titanium+vanadium (Windimurra Intrusion: AME 11)
- ~2705 Ma—nickel+copper±platinum-group elements associated with komatiitic rocks (Kambalda-Wiluna region: AME 19).

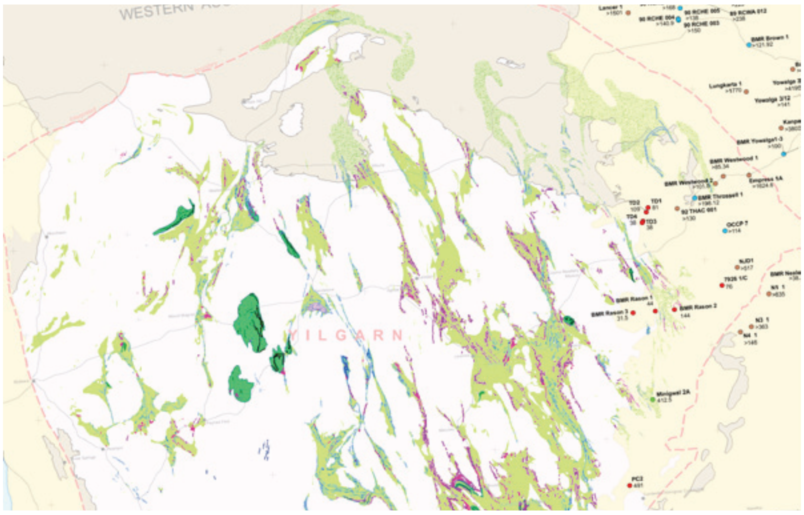


Figure 1. A section of the new 1:3 000 000 scale map of Australian Archean Mafic-Ultramafic Magmatic Events: Yilgarn Craton, Western Australia (Sheet 2 of 2). The Archean greenstone sequences containing potentially mineralised komatiitic rocks are depicted by a green screen for outcrop and stipple for undercover. Based on interpretations of aeromagnetic data, these rocks occur under shallow cover and younger sedimentary basins near the northeastern margin of the Yilgarn Craton.

Significant high-grade nickel sulphide deposits (such as Spotted Quoll, Flying Fox, Maggie Hays) in the Southern Cross Domain in the Yilgarn Craton are hosted by poorly dated komatiitic sequences that are most likely older (~3000 Ma to ~2800 Ma) than those identified in AME 19. The nickel deposits in the Kambalda-Wiluna region (AME 19) are very similar to nickel sulphide deposits (~2700 Ma) in the Abitibi Belt of Canada, but Australia appears to lack analogues of similar age to the ~2585 Ma Great Dyke of Zimbabwe that hosts economic platinum-group elements-bearing chromitites.

Sheet 2 focuses on the interpreted distribution and characterisation of economically important Archean mafic-ultramafic rocks in the Yilgarn Craton. In particular, it shows potential new areas of komatiitic rocks, indicated under shallow alluvial cover and younger sedimentary basins (figure 1). Elsewhere in the craton these rocks host significant resources of nickel, copper, and the platinum-group elements. The komatiitic rocks have been assigned to seven broad groups on the basis of their interpreted range of emplacement ages and Al_2O_3/TiO_2 ratios. This sheet also shows nickel resource endowment and the crustal neodymium (a rare-earth element) model ages of the Yilgarn Craton.

The new map sheets, when used in association with the *Australian Proterozoic Mafic-Ultramafic Magmatic Events* map published in 2008 (Geoscience Australia Record 2008/15), summarise the temporal and spatial evolution of Precambrian mafic-ultramafic magmatism in Australia. Together these maps provide a national framework for investigating under-explored and potentially mineralised environments, and assessing the role of mafic-ultramafic magmatism in the dynamic evolution of the Australian continent.

For more information

phone Dean Hoatson on +61 2 6249 9593
email dean.hoatson@ga.gov.au

Related websites/articles

Australian Archean Mafic-Ultramafic Magmatic Events Map (Sheets 1 and 2)
www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=69347

Australian Proterozoic Mafic-Ultramafic Magmatic Events in Australia (Sheets 1 and 2)
www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=66114

AusGeo News 91: Revealing Proterozoic mafic-ultramafic magmatism in Australia
www.ga.gov.au/image_cache/GA11649.pdf

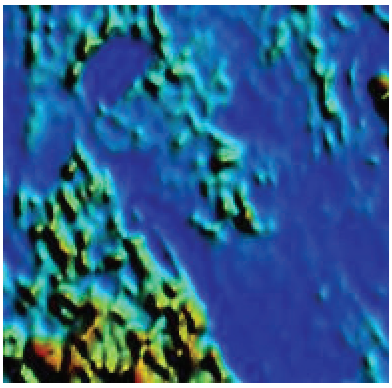
Guide to using the 1:5 000 000 map of Australian Proterozoic mafic-ultramafic magmatic events (Geoscience Australia Record 2008/15).
www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=66624

New geophysical datasets released

Datasets from two geophysical surveys, which will be a valuable tool in assessing the mineral potential of the Pine Creek–Rum Jungle area in the Northern Territory and the Cunderdin area in Western Australia, were released in September 2009.

The Pine Creek–Rum Jungle airborne electromagnetic survey covers the Pine Creek Orogen. The survey covers much of the Pine Creek 1:250 000 sheet area and surrounds to the west and south. It was conducted under Geoscience Australia's Onshore Energy Security Program. The survey data can be obtained free online through the Geoscience Australia website or can be purchased on DVD from the Geoscience Australia Sales Centre.

The Cunderdin regional gravity survey covers the Perth, Kellerberrin, Pinjarra and Corrigin 1:250 000 sheet areas. The survey was managed by Geoscience Australia on behalf of the Geological Survey of Western Australia. The Cunderdin data have been incorporated into the national gravity database. The point-located and gridded data for this survey can be obtained free online using the Australian government's Geophysical Archive Data Download System (GADDS).



For more information

phone Murray Richardson on +61 2 6249 9229
e-mail murray.richardson@ga.gov.au

Table 1. Details of the Pine Creek-Rum Jungle airborne electromagnetic survey.

Survey	Date	1:250 000 map sheets	Line spacing/ terrain clearance/ orientation	Line km	Contractor
Pine Creek – Rum Jungle (TEMPEST®)	October 2008 – May 2009	Cape Scott (part), Pine Creek (part), Mount Evelyn (part), Port Keats (part), Fergusson River (part), Katherine (part)	1600 m and 5000 m, 120 m (aircraft), 90 m (sensor), east - west	20 825	Fugro Airborne Surveys Pty Ltd

product news

Table 2. Details of the Cunderdin gravity survey.

Survey	Date	1:250 000 map sheets	Station spacing/ orientation	Stations	Contractor
Cunderdin (WA)	February – April 2009	Perth (part), Kellerberrin (part), Pinjarra (part), Corrigin (part).	500 m and 2000 m east – west	7 100	Daishsat Pty Ltd

Related websites

Pine Creek-Rum Jungle TEMPEST AEM Survey, NT, 2009
www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=69229

Geophysical Archive Data Delivery System (GADDS)
www.geoscience.gov.au/gadds

Geological Survey of WA
www.dmp.wa.gov.au

Geoscience Australia – Onshore Energy Security Program
www.ga.gov.au/minerals/research/oesp/index.jsp

Shark Bay World Heritage Area features in new map

The remote Shark Bay World Heritage Area in Western Australia is ideal for visitors interested in discovering unique and diverse wildlife and observing nature at its best. There are 34 species of mammals, 120 species of reptiles and more than 245 species of land-based, wading and migratory birds that live along the shoreline. It is also an important area for the reintroduction of threatened species.

The Shark Bay region is the focus of a new 1:250 00 scale topographic map recently released by Geoscience Australia. The map includes Francois Peron National Park, Shark Bay Marine Park and the coastal zone from Carnarvon in the north to about 35 kilometres south of Hamelin Pool. The reverse side of the map depicts the same area using a satellite image with an overlay of major roads as well as insets featuring the towns of Carnarvon and Denham.

Shark Bay has the largest area of seagrass (over 4000 square kilometres) and twelve seagrass species – the most recorded in any one place in the world. Hamelin Pool contains the most diverse and abundant examples of stromatolites in the world. Stromatolites, which are evidence of one of the oldest life forms on Earth, first appeared some 3 500 million years ago.

Francois Peron National Park covers approximately 52 500 hectares in the northern part of the Peron Peninsula. The National Park, which has become one of the most important natural areas in Australia, and is home to many rare and endangered species, is under the care of the Western Australian Department of Environment and Conservation.

The Department of Environment and Conservation contributed information during the compilation of the map. Information was also supplied by Australian Government agencies, including the Department of the Environment, Water, Heritage and the Arts.

The maps are available from the Geoscience Australia Sales Centre and map retailers.

For more information or to order a copy visit

www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=68756

events

Earth Science Week 2009 celebrations

The 12th International Earth Science Week was celebrated from 11 to 17 October 2009 based on the theme 'Understanding Climate'. Events were held around Australia to celebrate and raise awareness of the Earth sciences in the community, and to recognise the contributions of people working in these fields.

A highlight of Earth Science Week 2009 was the official screening of the winning entries and the presentation of awards for the third national *Geologi* Short Film Competition at Geoscience Australia's headquarters in Canberra on 12 October.

Over 400 students across Australia produced and submitted short films for the competition, which was hosted by Geoscience Australia and the Australian Science Teachers Association. The films were judged on their science content, creativity and promotion of the theme 'Earth science in everyday life'. Film topics included natural hazards, geological time and Australia's natural resources.

The senior gold *Geologi* was won by 'Movements of the Earth' produced by a Year 12 student from Tully State High School in Queensland. The junior gold *Geologi* was presented to students from Presbyterian Ladies' College, Perth, Western Australia, for their short film 'Oil'. This year's *Geologi* included a primary school category for the first time, with students from St Therese Primary School, Mascot, New South Wales, taking the gold *Geologi* for their film 'Volcanooo!'.

The Earth Science Week celebrations concluded with Geoscience Australia's annual Open Day on Sunday 18 October. Open Day saw around 1300 visitors participate in a variety of displays, activities and tours highlighting how geoscience is being applied to some of Australia's most important challenges. Among the visitors to Open Day was the Minister for Resources and Energy, The Hon. Martin Ferguson AM, MP.

For more information

phone Fiona Slater on +61 2 6249 9859
email education@ga.gov.au

Figure 1. Winners of the 2009 *Geologi* Short Film Competition with Dr James Johnson, Chief of Geoscience Australia's Onshore Energy and Minerals Division, following the presentation of awards.

Related websites

Earth Science Week-Geoscience Australia
www.ga.gov.au/education/events/science-week/index.jsp

Earth Science Week-International
www.earthsciweek.org

Geologi
www.ga.gov.au/education/events/geologi-short-film/index.jsp

events calendar

NAPE Expo 2010	11 & 12 February
American Association of Professional Landmen GBR Convention Center, Houston, Texas, USA Contact: NAPE, 4100 Fossil Creek Boulevard, Fort Worth, Texas 76137 USA	p +1 817 306 7171 f +1 817 847 7703 e info@napeexpo.com www.napeonline.com
PDAC 2010 International Convention & Trade Show	**7 to 10 March**
Prospectors and Developers Association of Canada Metro Toronto Convention Centre, Toronto, Canada Contact: PDAC, 135 King Street East, Toronto, Ontario M5C IG6	p +1 416 362 1969 f +1 416 362 0101 e info@pdac.ca www.pdac.ca
AGES-Annual Geoscience Exploration Seminar	**22 to 24 March**
Northern Territory Geological Survey Alice Springs Convention Centre Contact: Northern Territory Geological Survey, GPO Box 3000, Darwin NT 0800	p +61 8 8999 5313 e ages@nt.gov.au www.nt.gov.au/d/Minerals_Energy
XXIV FIG International Congress 2010	**11 to 16 April**
International Federation of Surveyors Sydney Convention & Exhibition Centre Contact: arinex Pty Ltd GPO Box 128, Sydney NSW 2001	p +61 2 9265 0700 f +61 2 9267 5443 e fig2010@arinex.com.au www.fig2010.com
World Geothermal Congress 2010	**25 to 30 April**
International Geothermal Association Bali International Convention Centre Contact: Organising Committee WGC 2010, Grha Bimasena, JI Dharmawangsa Raya 39, Jakarta Selatan, Indonesia	p +62 21 725 8668 f +62 21 7236 193 e secr@wgc2010.org www.wgc2010.org/working/index.php
GEOHAB 2010	**4 to 7 May**
Wellington Town Hall, Wellington, New Zealand Contact: Conference Manager, GEOHAB Meeting, PO Box 38 951, Wellington Mail Centre 5045, New Zealand	f +64 4 587 0181 e janet.simes@conferences.co.nz www.geohab2010.com
2010 APPEA Conference and Exhibition	**16 to 19 May**
Australian Petroleum Production and Exploration Association Brisbane Convention & Exhibition Centre Contact: Moira Lawler, APPEA Limited, GPO Box 2201, Canberra ACT 2601	p +61 2 6267 0906 e mlawler@appea.com.au www.appeaconference.com.au
AMEC National Mining Congress	**1 & 2 June**
Association of Mining and Exploration Companies Inc Perth Convention Exhibition Centre Contact: AMEC, PO Box 6337, East Perth, WA 6892	p +61 8 9225 4399 or 1300 738 184 (Within Australia) f +61 8 9221 9377 or 1300 738 185 (Within Australia) e events@amec.org.au www.amec.org.au

For more information on Geoscience Australia's involvement in the above events phone Suzy Domitrovic on +61 2 6249 9571 (email suzy.domitrovic@ga.gov.au)