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.

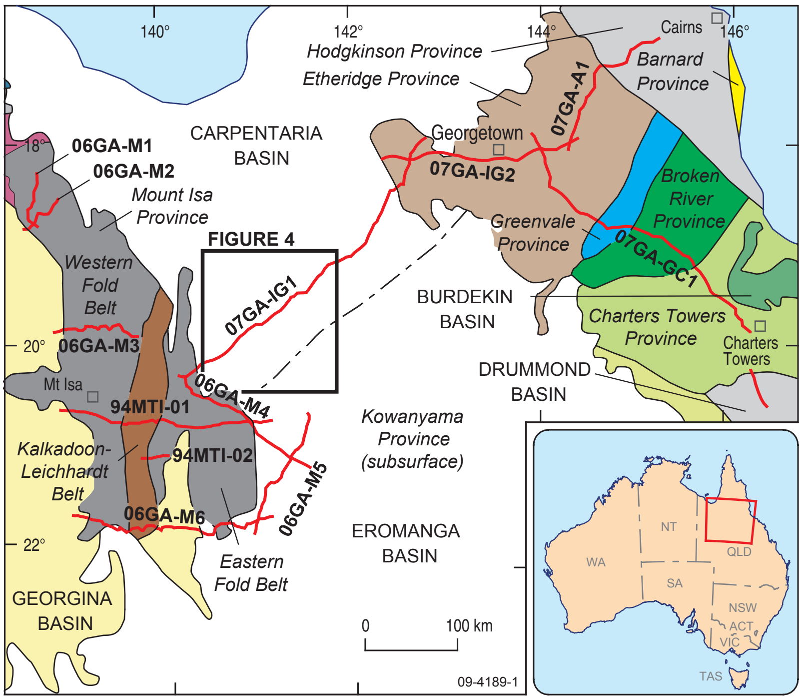

Figure 1. Map of North Queensland showing geological provinces, basins and seismic traverses that form the 2007 Isa–Georgetown–Charters Towers seismic survey. The map also shows the locations of previous seismic surveys acquired in 1994 and 2006.

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,

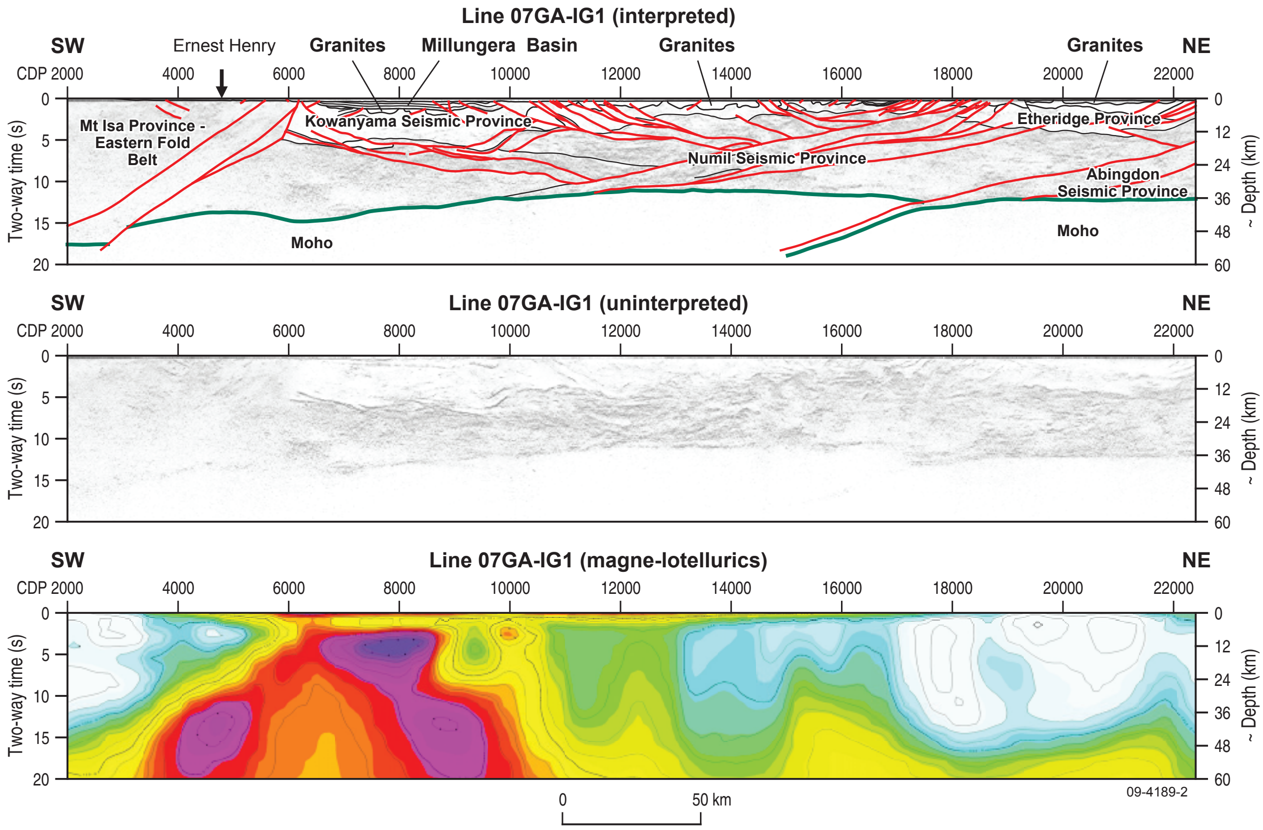

Figure 2. Images of traverse 07GA-IG1 showing (from top to bottom) interpreted seismic section, uninterpreted, migrated seismic section, and electrical resistivity from 2D inversions of magnetotelluric data.

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

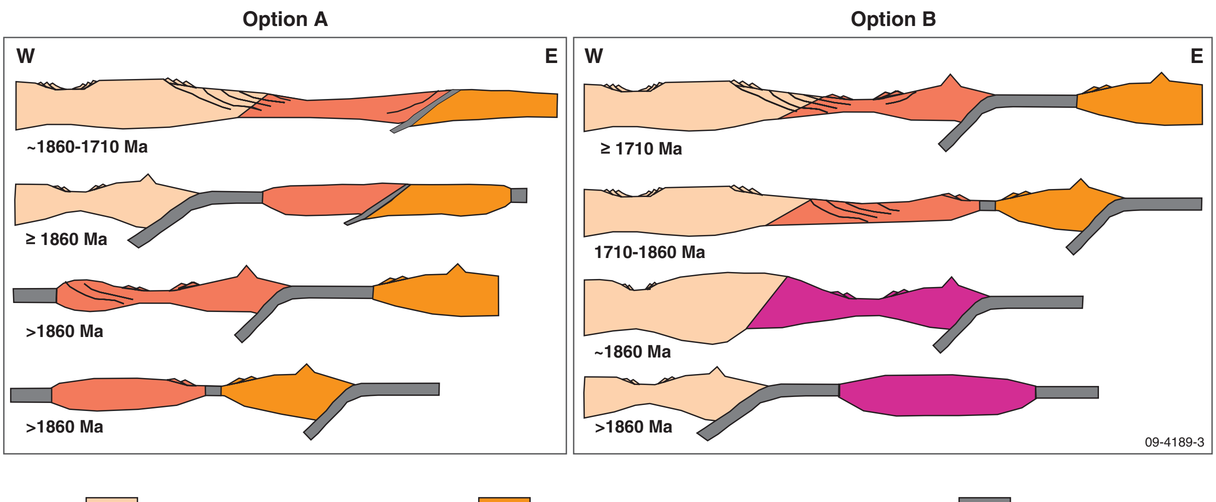

Figure 3a. Preliminary model for the tectonic evolution of North Queensland showing alternative evolutions prior to 1710 Ma.

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

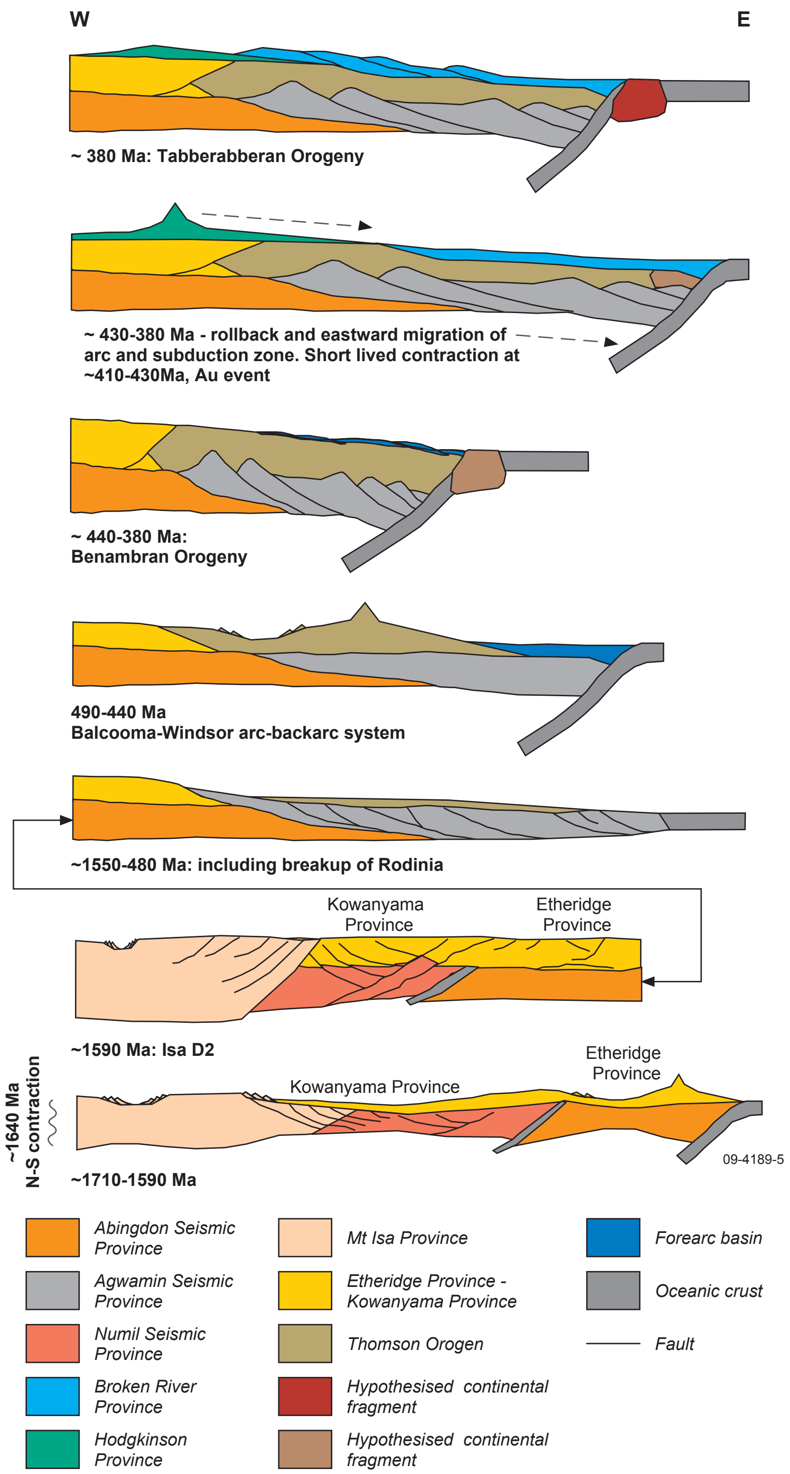

Figure 3b. Preliminary model for the tectonic evolution of North Queensland showing evolution after 1710 ma.

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,

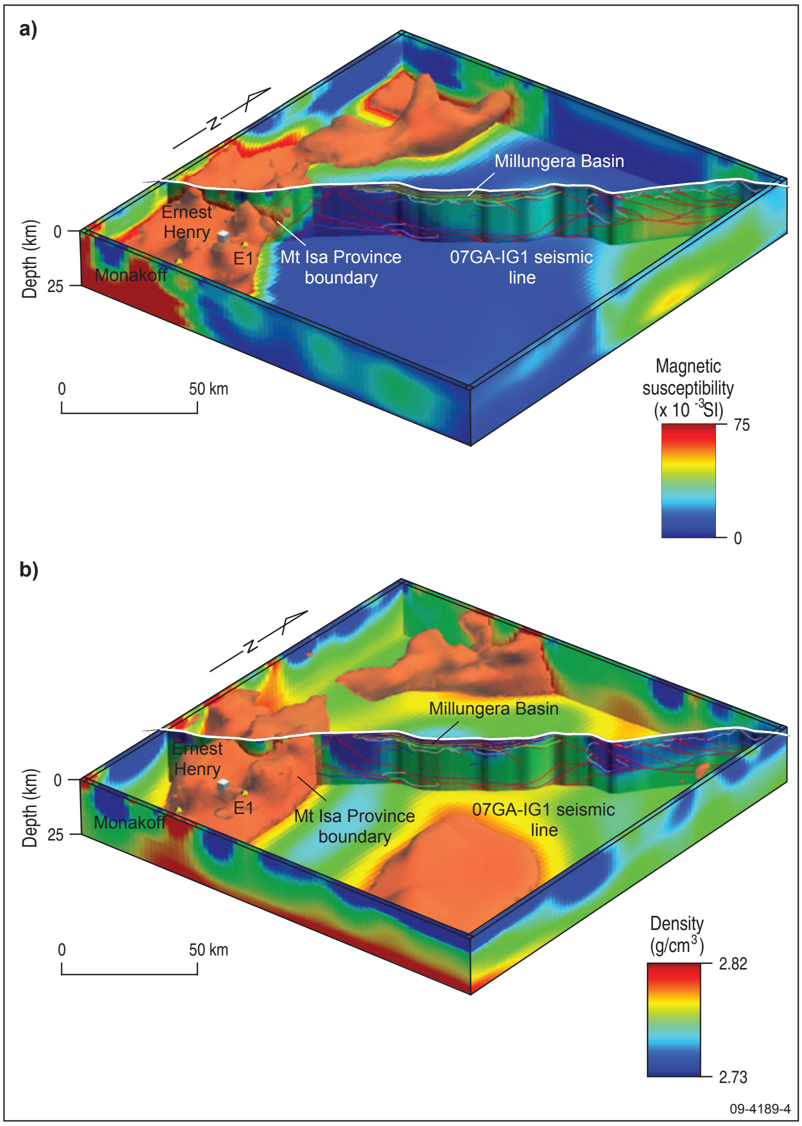

Figure 4. Images showing a) magnetic and b) gravity inversions along the eastern margin of the Mount Isa Province. The top image shows a subset of the 3D magnetic inversion along the eastern margin of the Mount Isa Province. The predicted magnetic susceptibilities are draped on the 07GA-IG1 seismic line 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