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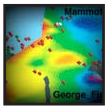

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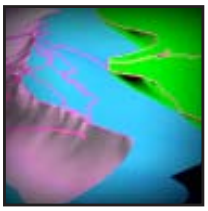


One of Geoscience Australia's main roles is the provision of precompetitive geoscientific information to encourage investment in mineral exploration in Australia. In this issue we report on studies in two of Australia's most important mineral-producing areas, the Yilgarn Craton and the Mt Isa region, arising from our participation in the Predictive Minerals Discovery Cooperative Research Centre (*pmd**CRC).

The Yilgarn Craton in Western Australia is one of Australia's key mineral provinces, producing two-thirds of the gold and more than half the nickel mined in Australia. The main achievement of the project was the building of comprehensive three dimensional maps of the Kalgoorlie-Kambalda and the Norseman-Wiluna region. These maps used solid geology data as a foundation and integrated it with various geophysical, geochemical and geochronological data sets. These new data and the new understanding developed from the project will not only benefit explorers in the Yilgarn Craton but those in other terranes.

Researchers working on the Mt Isa Western Succession project also gave a high priority to building a 3D structural model of the area which incorporated all elements of the mineralising system. The Mount Isa study also used satellite data from a radiometer on board the Terra satellite to map mineralogy on a regional scale with sufficient spatial and spectral detail to be useful for mineral exploration. The resulting new geological framework will provide a new focus for future mineral exploration.

Each year the Australian Government releases new opportunities for offshore petroleum exploration, and permits are at a record high with 184 permits currently in operation. The total offshore area under permit is also at a near record level. Last month another 36 offshore acreage areas in basins around Australia were released for industry bidding and details of these areas are included in this issue.

Also featured are a wide range of articles relating to natural hazards. One article examines how the global infrasound sensor network used to monitor clandestine nuclear detonations could also be utilised to warn of natural disasters such as storms, bolides (meteorites), earthquakes and volcanoes. Another article examines the behaviour of sediments subjected to ground shaking during earthquakes. There is also a report from the Assessment Team sent to recommend assistance measures as part of the Australian Government's response to the Guinsaugon, Philippines, landslide in February this year.

As well, this issue includes reports on Geoscience Australia's contributions to the Australian Government's objective of optimising the accessibility and use of spatial information to assist with government decision making. Our newly released products include the new isotope data uncovering the history of offshore gas accumulations in the North West Shelf and the recently updated version of Australia's maritime boundaries.

As usual we always appreciate your feedback and you may notice that we have included an online rating mechanism with each article allowing you to rate an article with the click of a mouse.

Comment

NEIL WILLIAMS
CEO Geoscience Australia

GOING FOR GOLD in the Eastern Yilgarn

New 3D maps of Australia's premier gold province are now available.

Paul Henson and Richard Blewett

The Late Archaean granite–greenstone terranes of the Eastern Yilgarn Craton host the majority of Australia's world-class gold deposits.

High-resolution gravity, magnetics, geological and geochemical maps make up most of the large amount of data available on the region, augmented by high-quality deep seismic reflection profiles and covered by a range of teleseismic studies. These data have now been integrated into a set of new 3D maps at a range of scales (Blewett & Hitchman 2006).

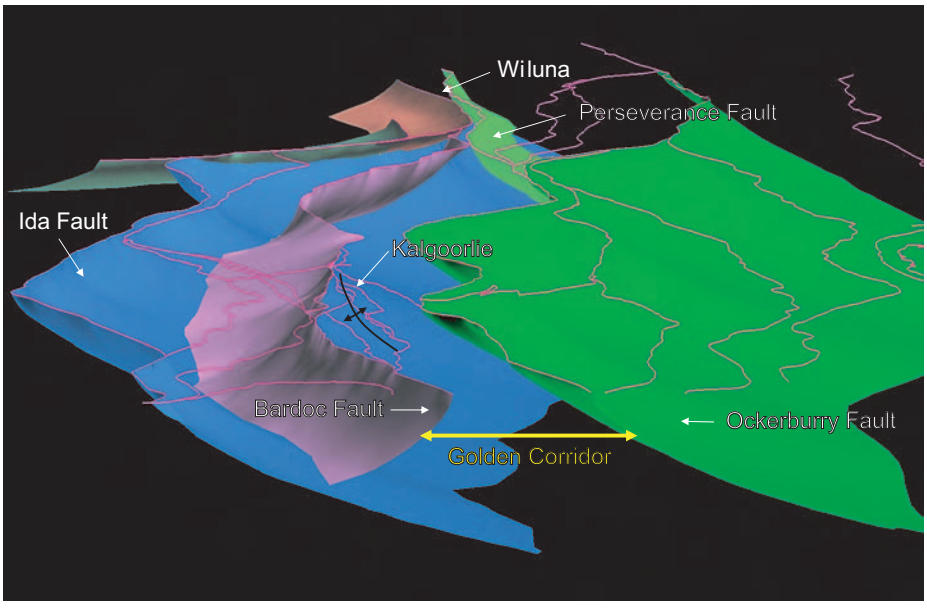
This project was conducted at Geoscience Australia as part of the Predictive Mineral Discovery Cooperative Research Centre's Y2 project. Results from this work are now free of confidentiality protection and are available as Geoscience Australia Record 2006/05.

Imaging the architecture

The philosophy of the Y2 project was to consider mineral systems in terms of five key parameters: geodynamics; architecture; fluid drivers and pathways; sources of fluids and metals; and depositional mechanisms.

Understanding the architecture of a system at a range of scales is essential for effective area selection and targeting. Development of this understanding includes defining and mapping the geometry of pathways for fluid flow, the components involved in fluid focusing, and the ultimate trapping mechanisms. The architecture is best elucidated by 3D maps.

A recurring feature of the Eastern Yilgarn 3D maps at a range of scales is the spatial relationship between domes or anticlinoria and larger gold deposits in the region. As these architectural elements are an essential contributing factor to the endowment of this region, mapping them helps improve predictive discovery.



▲ **Figure 1.** Perspective view looking north from above the 'Golden Corridor' defined by the west-dipping Bardoc Fault and the east-dipping Ockerburry Fault.

Terrane scale

The architecture of the eastern half of the Kalgoorlie Terrane is an elongate anticlinorium from Kambalda to Plutonic, with culminations (below deposits) and intervening depressions. This 'Golden Corridor' is over 700 kilometres long and contains a large proportion of the known gold in the Yilgarn Craton (figure 1). Regional 3D geological maps are therefore likely predictors of favourable tracts of country at the broadest scale.

Semi-regional scale

Domes are defined at several levels within the upper 10 to 15 kilometres of the present crust. The base of the greenstone has been mapped from 0 to 7 kilometres thick, with a dome-and-basin topography to this surface. Coincident with the spacing of the gold deposits at the surface, the wavelength of the dome apices of the greenstone base is typically around 35 kilometres.

Beneath the greenstone base, the felsic upper crust is dominated by sets of strong seismic reflections that are interpreted as shear zones, now altered by fluid flow during orogenesis and mineralisation. These reflections are openly folded into a series of stacked domes of ever decreasing wavelength upwards towards the greenstone base.

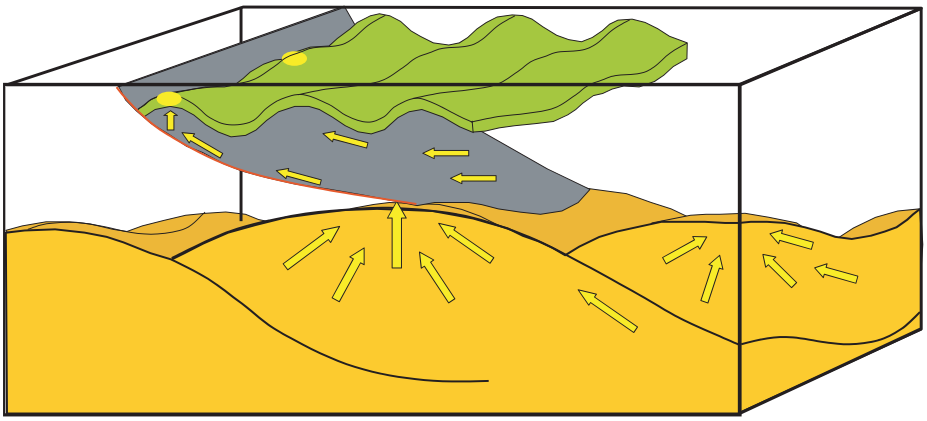
The stacked domes are interpreted to provide an efficient pathway for focusing orogenic fluids into the apex of the domes at higher structural levels (figure 2; yellow surface). 'Breaching' faults (figure 2; grey surface)occur near the apex of many domes, forming pathways for the dome-focused fluid to migrate to progressively higher structural levels for subsequent trapping (mineral deposit formation).

Camp scale

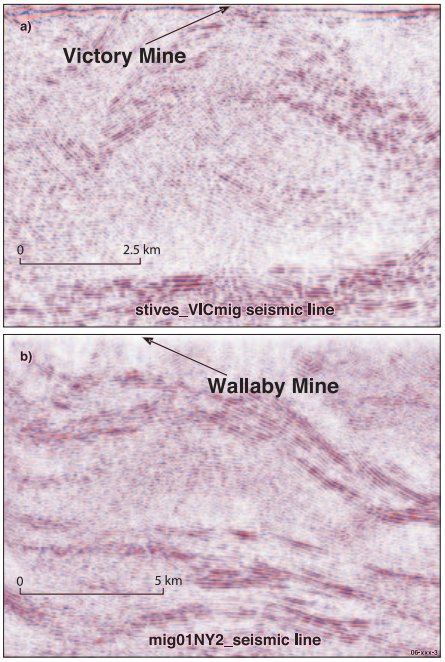
The upper 10 kilometres of the seismic data defines a recurring geometry for many of the gold deposits of the region (e.g. St Ives, Wallaby, Kanowna Belle), with deposits located close to the apices of broad open domes, imaged as high-amplitude reflections that are interpreted as shear zones (figure 2; green surface, figure 3).

These domed reflections are close to, or define, the greenstone base, which is folded over a felsic (granitic) laccolith. At depths between ~6 and ~8 kilometres beneath the domes, there is an equally strong set of planar sub-horizontal reflections. The region between the high-amplitude reflections is interpreted to be occupied by granite, due to its featureless seismic character and gravity modelled low density.

The timing between the folding and doming and granite emplacement is unclear. If the granites are late syn-folding, then magmatic fluids may have contributed to the fluid flux and mineralisation. If they are pre-folding, rheological contrasts may have influenced local stress fields and also explain the local endowment. Both pre- and syn-magmatic factors may be important.



▲ **Figure 2.** Schematic model (from Henson et al 2005) of fluid focusing towards mineral deposits (yellow dots) above a series of stacked domes with decreasing wavelengths (black horizontal lines) upwards.

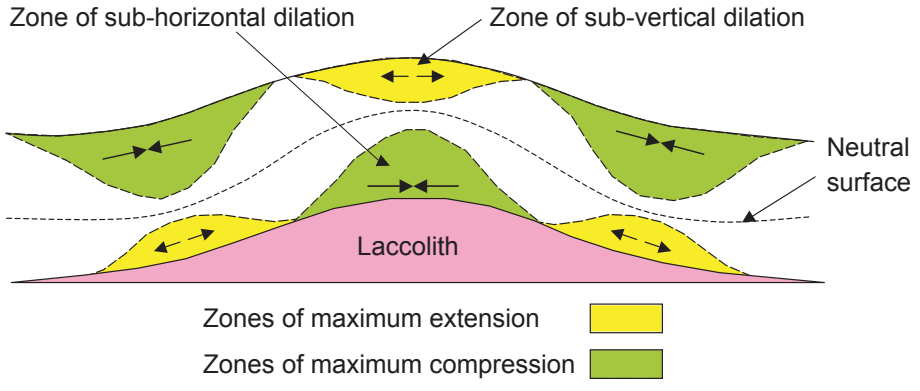


▲ **Figure 3.** Seismic reflection lines (3A, 3B) across the Victory and Wallaby gold deposits showing both located above the apex of domes. The muted regions between the strong reflectivity is interpreted as a granite laccolith. The diffuse zone cross cutting the strong reflectivity at the Victory gold mine (3A) is mapping swarms of porphyry dykes that are likely sourced from the laccolith (dome) at depth.

Deposit scale

The precise location of gold deposits within domes may depend on the local stress mode with respect to the 3D neutral surface of the domes (figure 4). Extension or dilation dominates the outer arc, leading to vertical extension veins and granite or porphyry dykes.

Compression dominates the inner arc, causing flat-lying extension veins and granite or porphyry sills. More space (dilation) occurs in the outer arc, so if the depth of erosion is below the neutral surface of the domes, endowment and prospectivity may be reduced.



◀ **Figure 4.** Variation in local stress field above and below 'a neutral surface' within an anticline/dome. The yellow highlighted zones are areas of maximum dilation (and likely fluid flow) in the outer arc where dykes and steeply dipping veins develop. In the inner arc the green-coloured areas define maximum compression where sills (and sub-horizontal veins) develop. The model suggests that the structural level is important, e.g., if a location is eroded below the neutral surface then the dome apex may be a region of maximum compression not dilation.

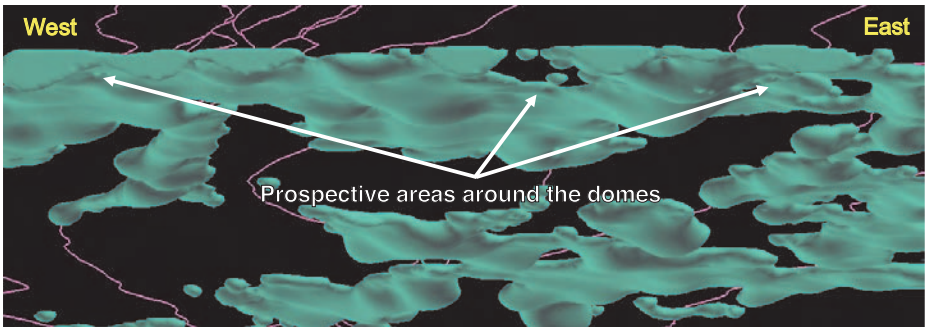


Figure 5. Perspective view looking north from underneath the geologically constrained gravity inversion model (green volume), showing the undulous nature of this surface. Purple lines are the regional fault traces on the Earth's surface.

Gravity tools

Seismic reflection data were used extensively in this project to construct the 3D maps. These data were very effective in defining domes and predicting their occurrence and geometry. However, such data are not available everywhere, so what does the explorer use in the seismic-absent regions?

One of the datasets available over much of Australia is gravity. In a region like the Yilgarn Craton, the greenstones are essentially dense and overlie a less dense felsic (granitic) substrate. The densities of these two main rock types are different enough to be mapped easily by gravity data.

Geologically constrained inversions of the base of the granite–greenstone interface reveal a complex dome-and-basin architecture to this surface. The geometry of the greenstone base established from the gravity inversion matches very closely with the interpretation of this interface in the seismic reflection data (figure 5).

This means that regional inversions of the gravity data effectively map the prospective domes in regions where seismic data are not available. This could be used as a first-pass exploration targeting tool in this province and elsewhere.

Conclusion

Domes occur at a range of scales and are linked in time and space with world-class gold deposits. The 3D mapping of the architecture of these domes is improving area selection, targeting and predictive capacity.

More details and scientific outcomes from the project are available on DVD (Geoscience Australia Record 2006/05).

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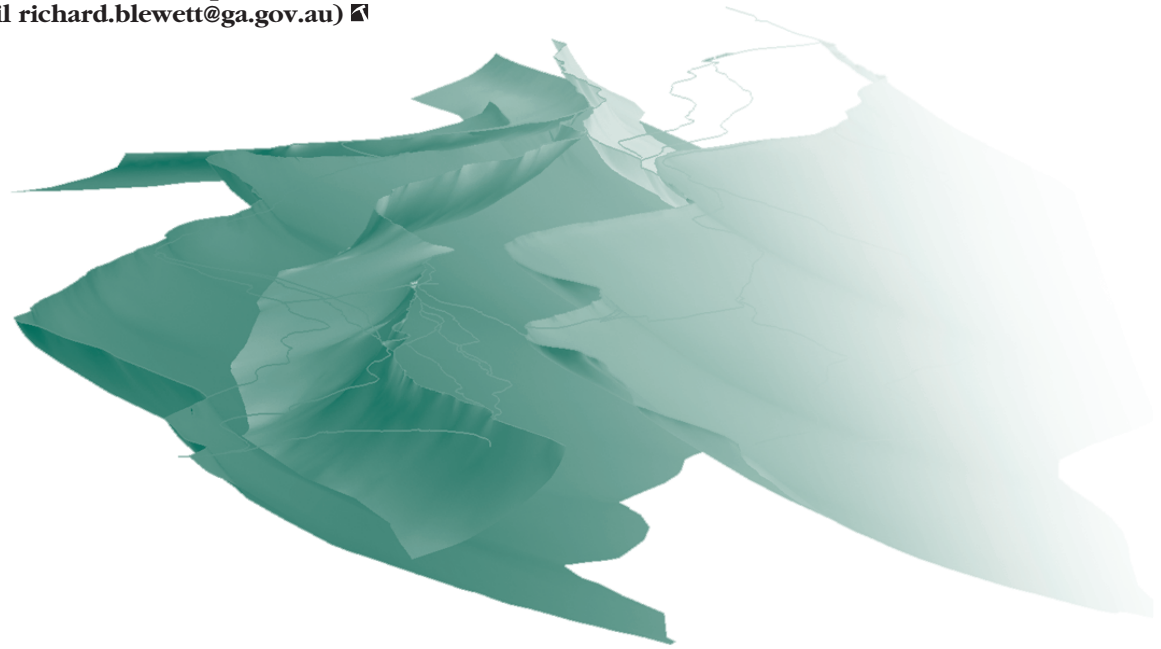


EXPANDING our knowledge of Mt Isa *to a third dimension*

Australian researchers have been working together to interpret the geology and prospectivity of the Mount Isa Western Succession.

George Gibson, Paul Henson, Avon McIntyre and Narelle Neumann

Since March 2002, a collaborative project to improve our understanding of the 3D crustal architecture and mineral systems of the Mount Isa Western Succession has engaged researchers from Geoscience Australia, universities, industry and other government agencies. The project has been carried out under the auspices of the Predictive Mineral Discovery Cooperative Research Centre (*pmd**CRC).

The project gave high priority to building of a 3D structural model of the Mount Isa region, incorporating stratigraphy, major unconformity surfaces, fault geometries, basin shape and mineral deposit locations. Complementary investigations into the geodynamic setting, origin and timing of events that may have influenced or controlled fluid flow in the region helped the researchers achieve:

- a comprehensive and internally consistent 3D interpretation of basin architecture and regional structure that allows mineral alteration patterns to be better understood in terms of fault geometries, sequence stratigraphy and other potential fluid pathways
- better understanding of the geological and tectonic processes that controlled and influenced basin geometry and fluid flow
- improved temporal constraints on the timing of these processes and the events that gave rise to them.

The project built on previous Geoscience Australia successes with NABRE (North Australian Basins Resource Evaluation) and external partners, such as the AMIRA P552 Fluid Flow Modelling project. It involved collaboration with the Queensland Department of Natural Resources, James Cook University, Melbourne University, the University of Western Australia, CSIRO, and two exploration companies currently active in the region, Xstrata Copper and Zinifex. The University of Newcastle provided further geological input and analytical data on a contractual basis.

Following a 12-month confidentiality period, the results of the project became publicly available from 30 April 2006 and are currently being prepared for publication.

As might be expected of such a richly endowed mineral province, the Mount Isa region in northern Australia (figure 1) has long been the subject of intense geological research and exploration activity. There is a diverse range of opinion about its regional structure, tectonic evolution and metalliferous potential. This makes mineral exploration more difficult and fraught with uncertainty, because there is rarely the time or resources to fully assess the wide range of interpretations.

Despite such uncertainties, tectonic setting and its role in controlling crustal architecture and the pattern of fluid flow are widely perceived to be important factors in the formation of ore bodies and their metallogeny. The difficulty for exploration companies is that the Western Succession, like so many other Proterozoic terranes in northern Australia (including the Eastern Succession), has been substantially modified by later deformation and post-depositional processes. The original tectonic setting and basin architecture are no longer obvious, and there is ongoing uncertainty about the age of mineralisation, its relationship to major structures, and whether these structures first became active before or after mineral deposition.

Marrying basin analysis with regional structural studies was deemed the most effective means of differentiating between pre-, syn- and post-depositional fault movements, although this is seldom enough to narrow the range of potential exploration targets. Details of possible source rocks and traps are also required.

More importantly, the researchers thought it desirable to have all elements of the mineralising system brought together in a single 3D representation, permitting better visualisation of the problem and more effective discrimination between competing geological interpretations. The 3D environment provides a much less forgiving test bed for subsurface geological interpretation than was ever possible from traditional 2D geological maps and cross sections.

Successful exploration now demands a more integrated approach to the problem of target selection, requiring an understanding of the entire mineralising system. This has been the guiding philosophy and visionary goal behind the current research program:

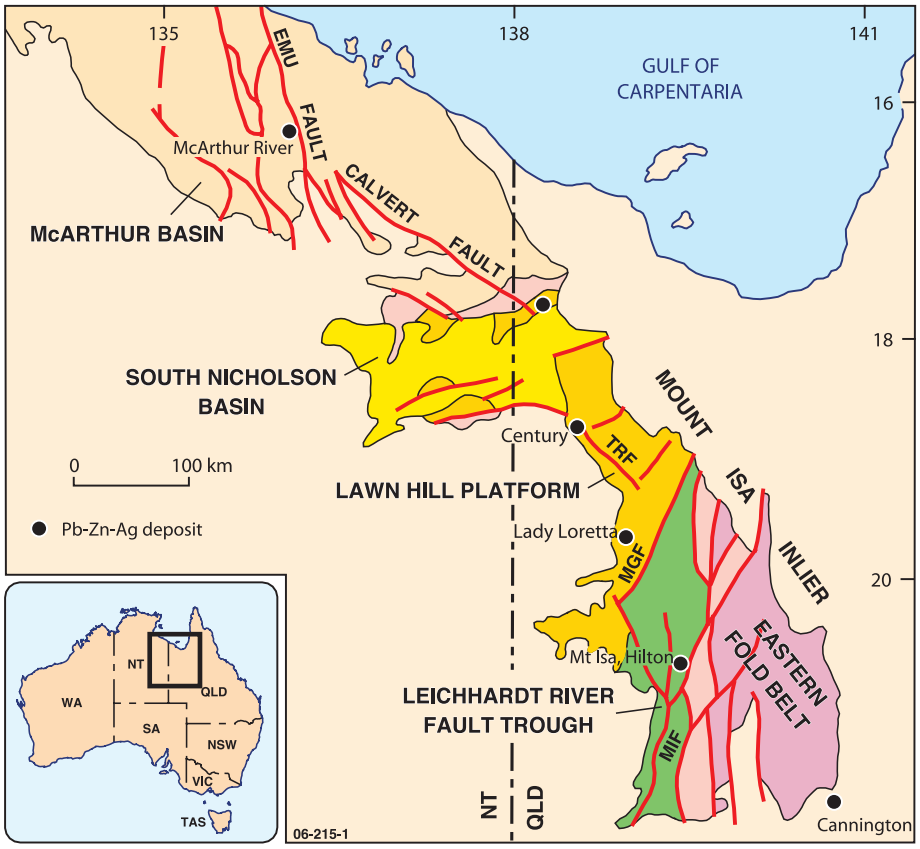
… through a better understanding of the geological controls on existing sediment-hosted Pb–Zn–Cu deposits in the Western Succession derive the key geological parameters that will increase the predictive ability of the exploration industry to locate blind or as yet undiscovered mineral deposits beneath cover elsewhere in northern Australia.

Project scope

The previous Geoscience Australia NABRE study in the Western Succession largely concentrated on elucidation of basin architecture in the Calvert (1730–1670 Ma) and Isa (1670–1595 Ma) superbasins. (See the event chart of Neumann et al for a more detailed geochronology of these two structural entities.)

These studies placed less emphasis on the older underlying Leichhardt Superbasin (1790–1740 Ma) even though it was recognised that major faults dating from that period had the potential to exercise an important control on the geometry and location of future, successor basins. The new study was consequently directed at improved understanding of the architecture of the older Leichhardt Superbasin and how this interacted with younger basins to produce the distribution of sedimentary facies and magmatic rocks preserved in the Western Succession today.

Particularly important in this context was an attempt to recognise rock sequences that may have served as potential source and trap rocks for metals. No less important was a study of fault geometry and distribution, and how these may have influenced fluid flow and the migration of mineralising fluids through the rock pile.



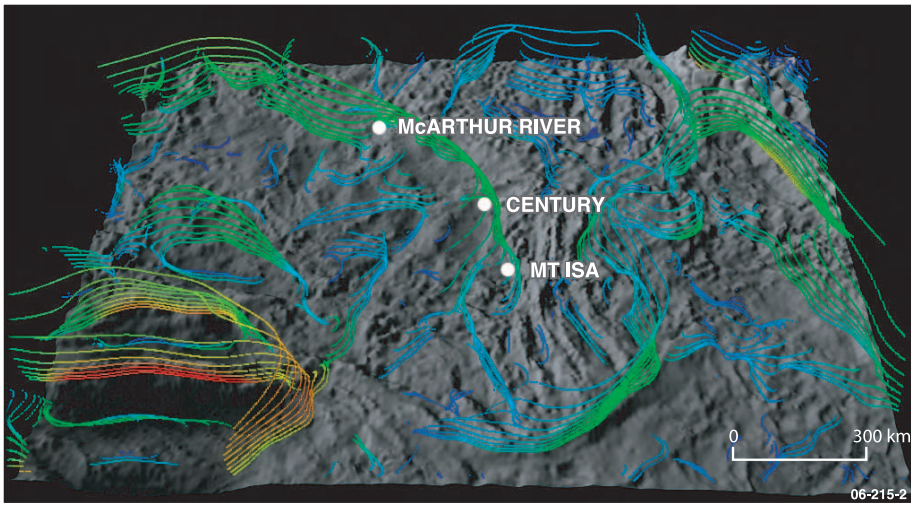
▲ **Figure 1.** Study area in relation to major tectonic elements in the Mount Isa region.

Only part of the Western Succession was investigated in detail, with the bulk of the research being conducted in the northern part of the Leichhardt River Fault Trough and the southern part of the Lawn Hill Platform (figure 1). As such, the study area straddled the Mt Gordon Fault Zone, a prominent geophysical and geological feature (figure 1), as well as a significant length of the 'Barramundi worm' (figure 2). The latter had already been identified in upwardly continued regional gravity datasets (Hobbs et al 2000), and appeared to serve as an important locus for several mineral deposits at Century and Lady Loretta (figure 1). The Century Pb–Zn deposit formed part of a PhD project carried out at James Cook University under the banner of the *pmd**CRC.

Objectives, organisation and deliverables

To achieve its visionary goal, the project was set up to deliver:

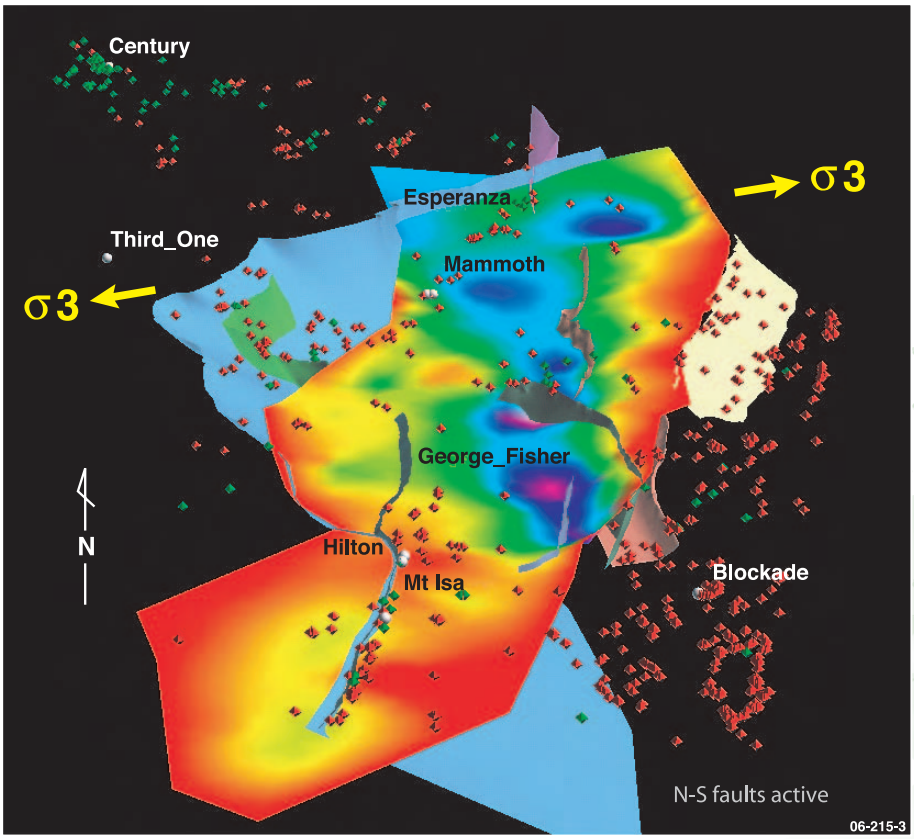
- 3D Gocad model of basin architecture
- improved understanding of the geodynamic setting and crustal architecture
- more tightly constrained space–time plot and event chart
- metamorphic map and improved diagenetic/burial history for region
- timing and age of fault movement with respect to depositional and post-depositional histories and related mineralisation
- pilot study in use of remote sensing as a means of determining the distribution of particular mineral species or parageneses (e.g. muscovite-versus phengite-dominated rocks) or alteration styles (e.g. silicification) associated with mineralisation (see article by Oliver and van der Wielen in this issue of *AusGeo News*).



◀ **Figure 2.** Gravity response upwardly continued from 66 to 220 kilometres to produce the 'Barramundi worm' as determined by Hobbs et al (2000). Note major Pb-Zn mineral deposits located along the trace of this feature which is thought to represent a continent-scale boundary between crustal blocks of contrasting density.

To meet its objectives, the project was managed as a series of modules with specific outcomes and deliverables. These included:

- **3D basin architecture** underpinned by interpretation of the potential field data (gravity and aeromagnetics) and structural analysis undertaken in a number of key localities (e.g. Bull Creek, Barr Hole, Mellish Park, Lake Julius). Construction of the 3D Gocad model (figure 3) is at the core of this module, although it also incorporated a study of faults that may have been active at critical times during basin formation and subsequent inversion and evolution. The geometry and age of these faults were determined through a combination of structural cross-sections, map patterns and field studies. Thermobarometric data (Kubler indices and white mica b dimensions) were employed to constrain the depth of tectonic burial and related metamorphic history of the basin.
- **3D isopach map and identification of sedimentary depocentres** to constrain basin shape and the location of growth faults (figure 3). This module combined mapped sedimentary thicknesses obtained from the 1:100 000 sheets with sequence stratigraphy of detailed measured sections obtained from many of the same key localities used to constrain the deformational history. In view of the detailed work previously undertaken by NABRE (Southgate et al 2000) on the Calvert and Isa supersequences, the focus of this module was on the older underlying units (Myally and Quilalar supersequences) that formed the original rift template.
- **Mineral index maps and numerical modelling** were employed to assess the extent and degree of fluid flow accompanying basin formation and its subsequent inversion. A critical component of this module has been the processing of remotely sensed LANDSAT, ASTER, HYPERION and radiometric data to identify the possible footprints of fossil hydrothermal systems. Large numbers of PIMA analyses were undertaken in support of this module, in order to properly calibrate and ground-truth the remotely sensed data. Cross-referencing with the results of module 1 has been carried out to ascertain whether there is any relationship between the inferred hydrothermal hotspots and regionally significant structures such as faults, stratigraphic boundaries or high-strain corridors. As a test of how basin architecture and fault geometry may have controlled or influenced fluid flow and paleo-temperatures during basin inversion, a number of numerical simulations were run in Flac3D, based on simplified geological models.
- **An extended and revised space–time and event plot** was necessitated by improved chronostratigraphic control on the age of sedimentary deposition (see the article by Neumann in *AusGeo News 78*), as well as a better understanding of the present-day 3D basin architecture and the kinematic framework that gave rise to this architecture. Particularly important in this regard is a large component of U–Pb SHRIMP dating of detrital zircon populations from different parts of the stratigraphy. The results of this work provide important constraints on depositional ages, as well as the provenance of the sediments. Several granites from the Sybella Batholith were also selected for zircon analysis to refine their ages in relation to both the depositional history and the tectonic evolution of the basin.



▲ **Figure 3.** Isopach map for Myally-age sediments (1770-1780 Ma) combined with mineral occurrences (red = Cu; green = Pb-Zn) and major basin-bounding faults in the Mount Isa region.

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Related website/articles

AusGeo News 78
New data on rock ages from Mt Isa Inlier

AusGeo News 82
Mineral mapping with ASTER

Mineral mapping with ASTER

Geoscience Australia has developed a new remote sensing tool that will assist explorers discover Australia's future mineral wealth.

Simon Oliver and Simon van der Wielen

Mineral index maps generated using data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) have put Geoscience Australia at the global forefront in the provision of remote sensing products tailored for mineral exploration.

ASTER mineral index maps have improved the way we map alteration mineralogy. While previous studies required many months of detailed mapping and sample collection, ASTER maps enable alteration to be identified before field work is undertaken, maximising the value of time spent in the field.

They are one of the few remote sensing products to map mineralogy on a regional scale with sufficient spatial and spectral detail for mineral exploration, and are highly suited to first-pass reconnaissance and selection of exploration targets in areas of outcrop to moderate surficial cover.

ASTER data

Launched in December 1999 aboard the Terra satellite, ASTER is the result of a cooperative effort between NASA, Japan's Ministry of Economy, Trade and Industry, and the Earth Remote Sensing Data Analysis Centre (ERSDAC).

Terra has an orbital path similar to Landsat 7's. Five instruments on the spacecraft, including ASTER, can be combined to monitor all earth systems (Abrams et al 2002) and generate data in 60 km x 60 km scenes.

ASTER data are used for a range of applications, including land-use studies, mapping, water resources, coastal resources, environmental monitoring, generation of digital elevation models (DEMs), and mapping alteration patterns or specific mineral assemblages known to be associated with mineral systems.

There are two Level 1 ASTER products:

- L1A (Reconstructed Unprocessed Instrument Data) for the production of DEMs
- L1B (Registered Radiance at the Sensor) for spectral studies.

ASTER's eyes

ASTER consists of three separate instrument subsystems:

- Visible and Near Infrared (VNIR)
- Shortwave Infrared (SWIR)
- Thermal Infrared (TIR)

ASTER has 14 bands of information:

Instrument	VNIR	SWIR	TIR
Bands	1–3	4–9	10–14
Spatial resolution	15 m	30 m	90 m
Swath width	60 km	60 km	60 km
Cross track pointing	± 318 km (± 24 deg)	± 116 km (± 8.55 deg)	± 116 km (± 8.55 deg)
Quantisation (bits)	8	8	12

Band 3 has nadir and backward telescopes for stereo pairs from a single orbit. The stereo pair capability of ASTER means that detail DEMs can be produced.

Geoscience Australia's remote sensing unit (ACRES) maintains an extensive archive of ASTER data covering the entire Australian continent, including raw imagery for DEM generation and Level 1B map ready product.

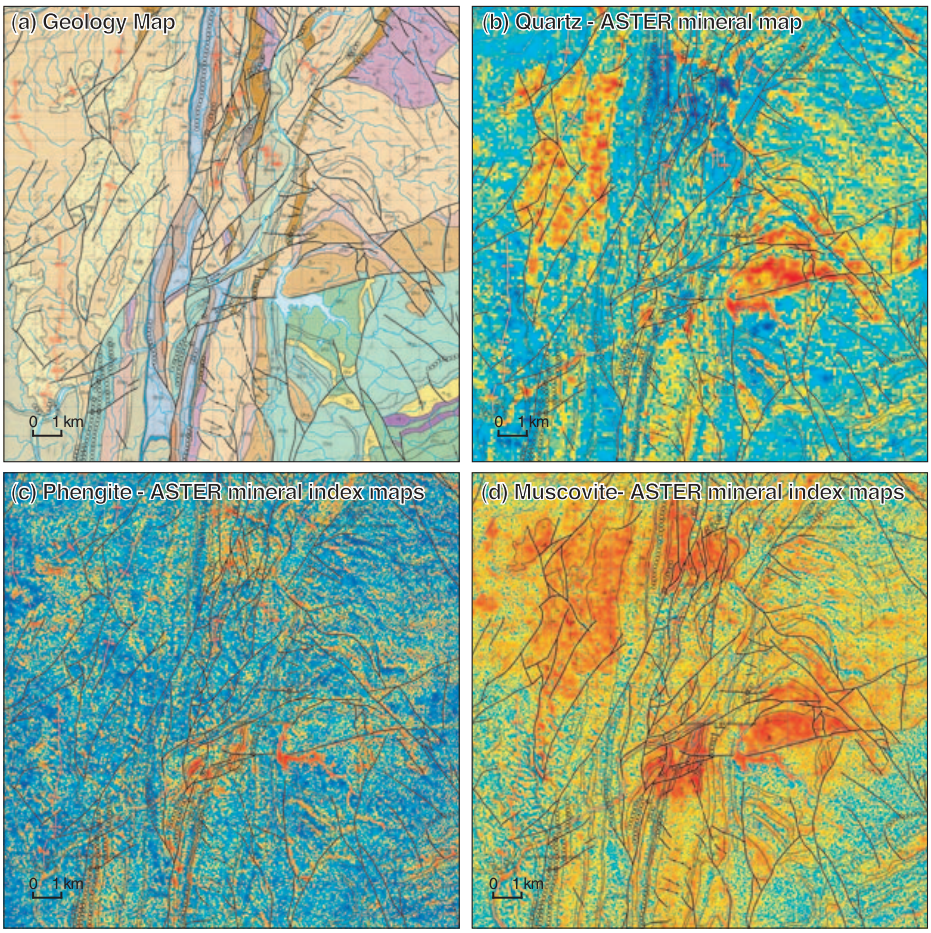
In 2002, ACRES enabled visualisation of its ASTER holdings through the ACRES Digital Catalogue, providing a tool to efficiently retrieve and process data covering entire geological provinces. Under the distribution agreement between Geoscience Australia and ERSDAC, Geoscience Australia provides access to future acquisition requests for Australian users of the data. ERSDAC holds processed products of over 700 000 Level 1A scenes and over 180 000 Level 1B scenes.

ACRES can search this archive, purchase these products on behalf of clients, and organise for ERSDAC to process ASTER data into higher level products.

Development and testing

ASTER can map the distribution of various minerals, including white mica, silicification, carbonates, clays, alunite and iron oxides (Rowan & Mars 2003, Rowan et al 2003; Hewson et al 2005). ASTER-derived mineral index maps are simple band and relative band depth ratios that correspond to absorption features for particular minerals (figure 1).

Geoscience Australia's Remote Sensing Science and Strategy project developed an add-on for ER-Mapper™ (figure 3) that automates the production of ASTER mineral index maps. In addition, the tool provides for automated spatial adjustment using Landsat panchromatic data (www.ga.gov.au/image_cache/GA4050.pdf).

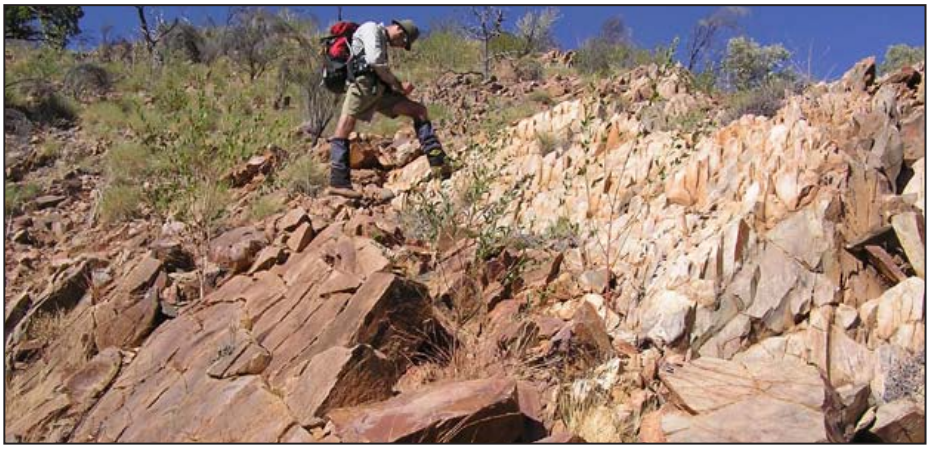


▲ **Figure 1.** Geological map of Mt Gordon Fault Zone, Western Succession, Mt Isa Inlier (Hutton et al 1985) and ASTER-derived mineral index maps of the same area for muscovite, phengite and silicification. The mineral index maps can be interpreted in a similar way to radiometics; that is, red and orange areas contain the mineral of interest, whereas blue and green areas are less likely to contain the mineral.

The effectiveness of ASTER to map minerals has been tested in the Mount Isa region as part of a pilot study within the *pmd**CRC I1 project (Crustal Architecture and Mineral Systems). This involved ground-truthing of the ASTER-derived mineral maps through a portable short-wavelength infrared mineral analyser (PIMA) capable of identifying many of the same mineral species. Individual, cloud-free ASTER L1B scenes were chosen to cover the study area.

ASTER L1B data require several phases of pre-processing (Kalinowski & Oliver 2004) to enable production of mineral index maps. Good correlation (van der Wielen et al 2005) of ASTER mineral index maps for white micas, silica and carbonates was obtained in the Isa region pilot study (figure 2), interpretation of which is complicated by effects of weathering, vegetation growth, fire scars and/or human impact.

Geoscience Australia has an extensive catalogue of ASTER imagery that can be used to produce regional ASTER mosaics to map the distribution of minerals (van der Wielen et al 2004, 2005).



ASTER mineral index maps have been produced for various Geoscience Australia projects, including studies of the Mt Isa Inlier, the Paterson Orogen and the Eastern Goldfields. An interactive online example of ASTER mineral index maps from Mt Isa shows four separate images: a 1:100 000 geology map; silicification and phengite mineral index maps; and a VNIR (pseudo natural colour) image (satmap.ga.gov.au/IWS/images/mtisa/mt_isa_shtml).

Implications for exploration

The real potential for ASTER mineral index maps as an exploration tool lies in their identification of minerals distribution associated with alteration haloes and fluid flow. Walshe et al (2003) noted that large ore deposits lie on chemical gradients such as changes in redox, pH, temperature and pressure. ASTER can identify chemical gradients preserved in the rock record as subtle variations in mineralogy (van der Wielen et al 2005).

Many world-class gold and copper deposits have large, previously unrecognised, white mica haloes. Walshe et al (2003) recognised that deposit location corresponds to changes in white mica composition from muscovite to phengite. The variation in composition appears to reflect chemical changes in ore fluid chemistry resulting in the precipitation of metal. The distribution of both phengite and muscovite can be mapped with ASTER mineral index maps.

Two ASTER mineral index maps from Geoscience Australia projects demonstrate their potential.

Phengite and muscovite mineral index maps over Mt Gordon copper mine in the Mt Isa Inlier (figure 1) show that copper mineralisation occurs where there is mixture of muscovite and phengite.

◀ **Figure 2.** Hydrothermal phengite (pale colour) in the Mt Isa region that was identified using ASTER imagery and verified by ground-based PIMA and field work.

Muscovite and phengite mineral index maps of the Telfer Au–Cu deposit in the Paterson Orogen (figure 4) were combined to reflect areas that contain phengite and muscovite verified by PIMA ground truthing. The combined image was then draped over a single-band grey scale image.

The Telfer example shows a broad zone of phengite (yellow) to the south and muscovite (blue) to the north, with a mixture of phengite and muscovite around the Telfer deposit. The change from phengite to muscovite has been interpreted to represent a chemical gradient associated with mineralisation at Telfer. The image has highlighted several 'look-alike' targets in the vicinity of Telfer.

Conclusion

As the only remote sensing product able to map mineralogy on a regional scale with sufficient spatial and spectral detail for mineral exploration, ASTER mineral index maps from Geoscience Australia are a valuable new tool for Australia's explorers.

Acknowledgments

The authors would like to thank researchers in Geoscience Australia and partner organisations for providing advice and assistance with this work, particularly Anna Potter for her work on ASTER in the Telfer region. Initial pilot studies and some researchers' salaries were funded by the *pmd**CRC.

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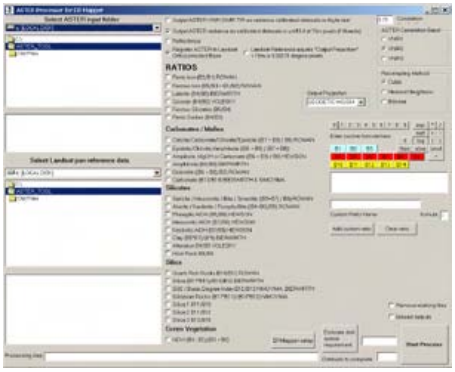


Figure 3. Front end of the ASTER processing tool developed by Geoscience Australia to facilitate production of ASTER mineral index maps.

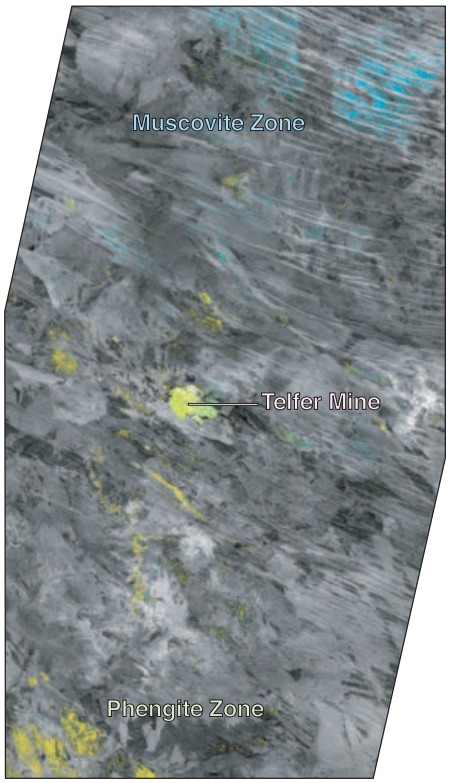


Figure 4. Combined phengite (yellow) and muscovite (blue) mineral maps draped over grey-scale 1 ASTER image. Individual index maps were clipped using a mean plus two standard deviation algorithm, then re-coloured. Phengite forms a broad zone to the south whereas muscovite is restricted to the north. Telfer is located where the white mica changes from phengite to muscovite.

Related websites

An interactive online example of ASTER mineral index maps from Mt Isa: http://satmap.ga.gov.au/IWS/images/mt_isa/mt_isa.shtml

How Geoscience Australia processes ASTER satellite imagery: www.ga.gov.au/image_cache/GA7833.pdf

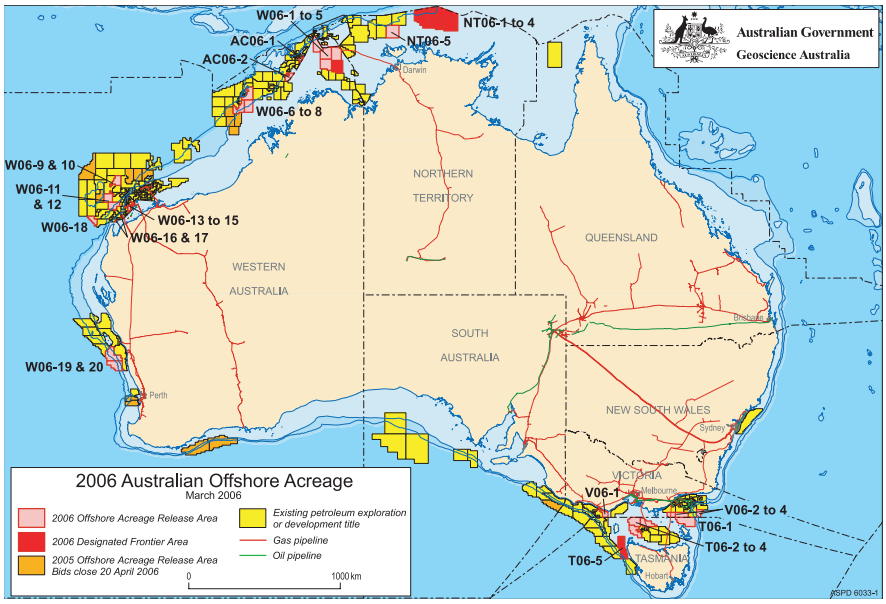
Accuracy assesment of ACRES Landsat Orthocorrected Products: www.ga.gov.au//image_cache/GA4050.pdf

Related article

AusGeo News 77 ASTER satellite data now available

New petroleum acreage open to exploration

Offshore exploration permits at record high.



Jenny Maher

Each year the Australian Government releases new opportunities for offshore petroleum exploration. This annual release of offshore acreage is part of Australia's Offshore Petroleum Strategy, and all areas are available through a work program bidding system.

The 2006 release was announced on 8 May by the Hon. Ian Macfarlane, Minister for Industry, Tourism and Resources, at the annual Australian Petroleum Production and Exploration Association (APPEA) conference. Thirty-six new exploration areas, located in nine of Australian's offshore sedimentary basins, were released (figure 1).

Figure 1. Overview of Australia's offshore petroleum exploration areas, showing the 2006 release areas.

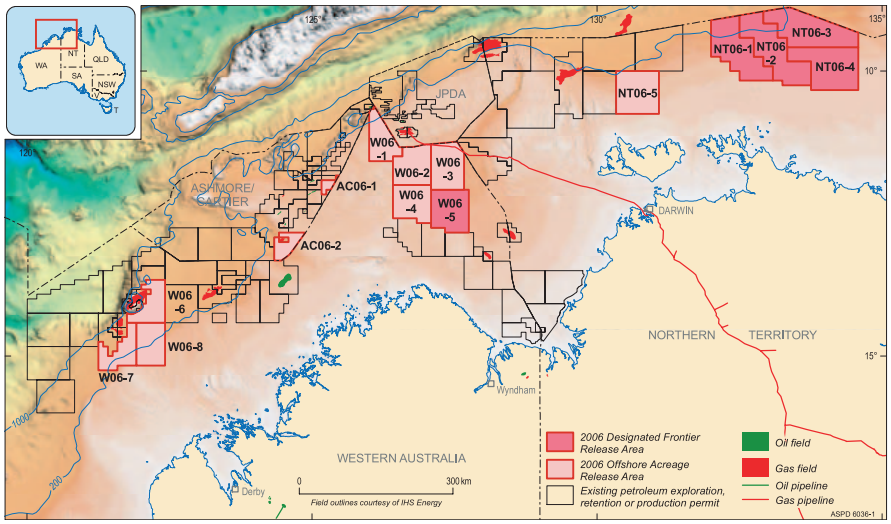


Figure 2. 2006 offshore release areas in northern Australia.

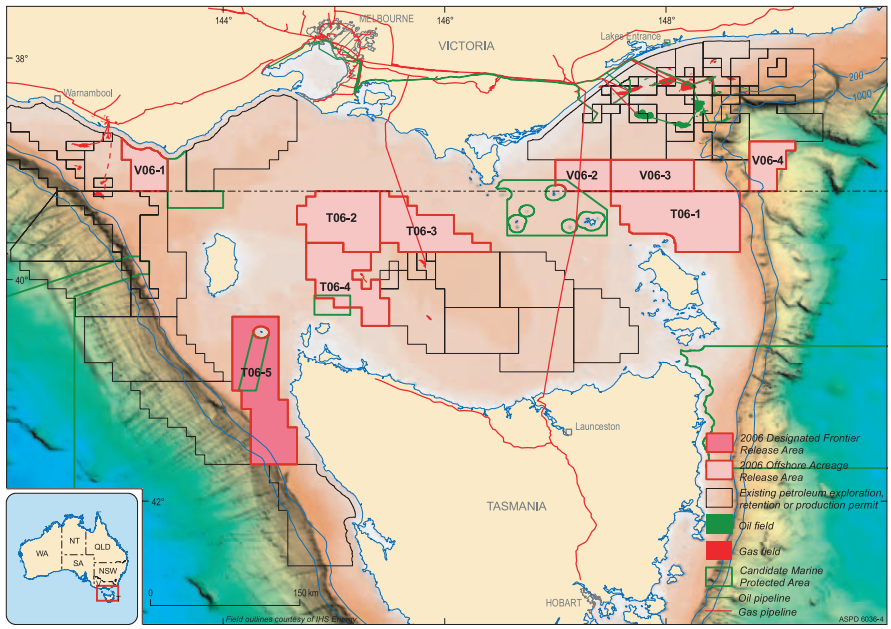
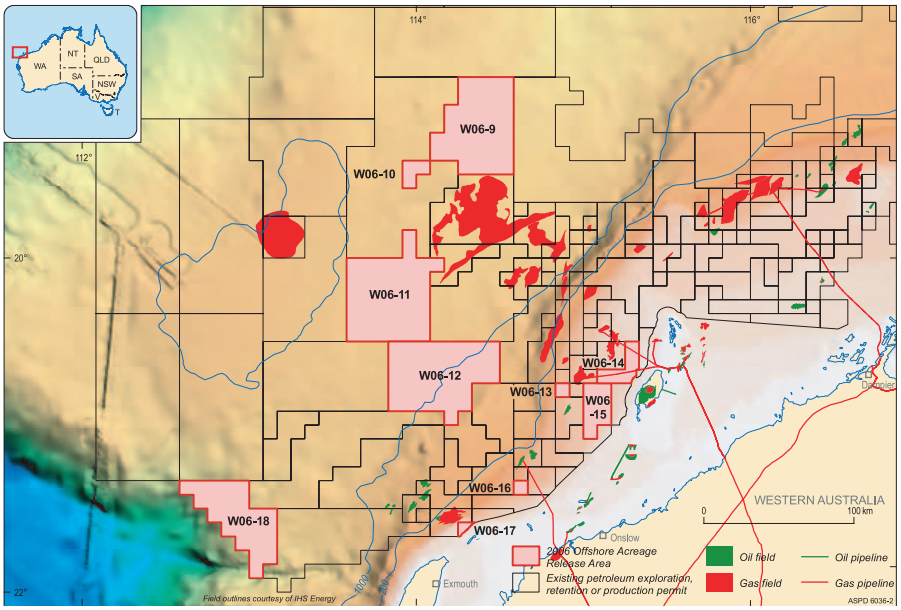
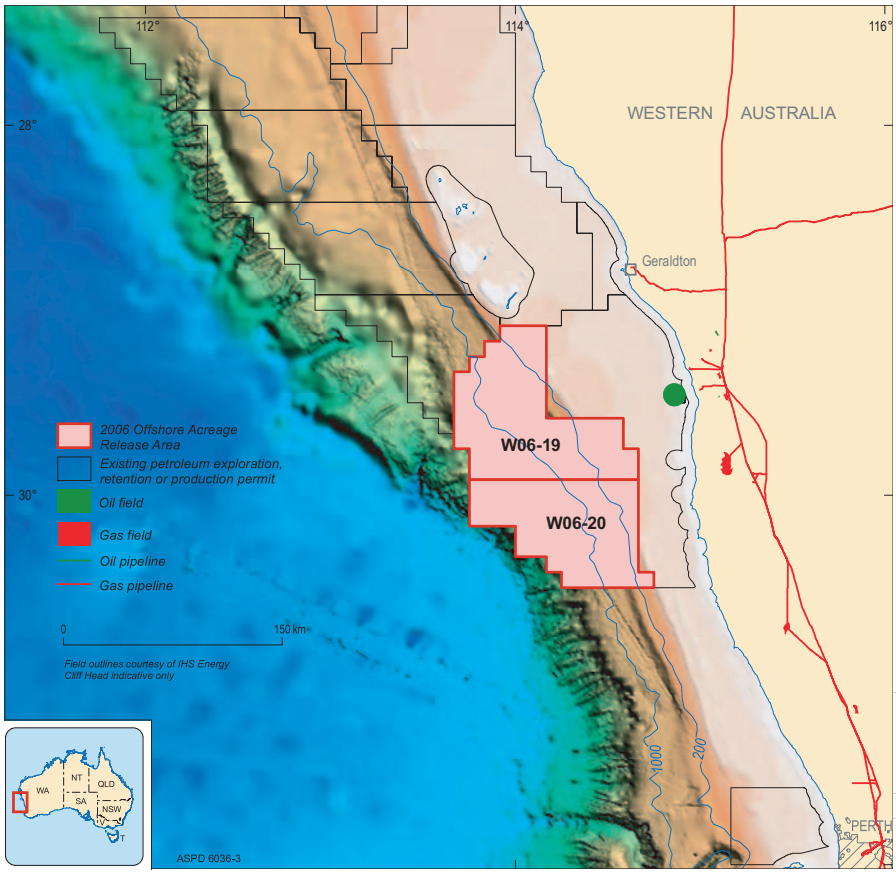


Figure 3. 2006 offshore release areas in southeastern Australia.



▲ **Figure 4.** 2006 offshore release areas in the Carnarvon Basin.



▲ **Figure 5.** 2006 offshore release areas in the Perth Basin.

The areas on offer include:

- large shallow water frontier areas in the Northern Arafura Basin (figure2)
- large deepwater frontier areas in the South Eastern Terrace of the Gippsland Basin and in the Northern Sorell Basin (figure 3)
- moderate sized to smaller blocks in the midst of large gas accumulations in the Browse and Carnarvon basins (figures 2 and 4)
- moderate sized blocks under various water depths in the immature to sub-mature basins of the Southern Carnarvon and Perth basins (figures 4 and 5)
- small blocks in the mature oil-rich Barrow and Exmouth sub-basins of the Carnarvon Basin (figure 4) and
- shallow water blocks over the Bonaparte Basin (figure 2) and the Eastern Otway, Gippsland and Bass basins (figure 3).

All areas are available for bidding through a work program bidding system. Closing dates for the release areas are 9 November 2006 and 10 May 2007, depending on the size and relative exploration maturity of the areas.

Geoscience Australia has a number of products that could help explorers review potential acreage. For more information about these products or about the release, phone Jenny Maher on +61 2 6249 9111 (email jenny.maher@ga.gov.au) or visit the Geoscience Australia website.

Information on the 2006 release can also be obtained from the Department of Industry, Tourism and Resources website

Related websites

Current release areas:
www.industry.gov.au/petexp

Data supporting the 2006 release areas:
www.ga.gov.au/oceans/ss_Acreage.jsp

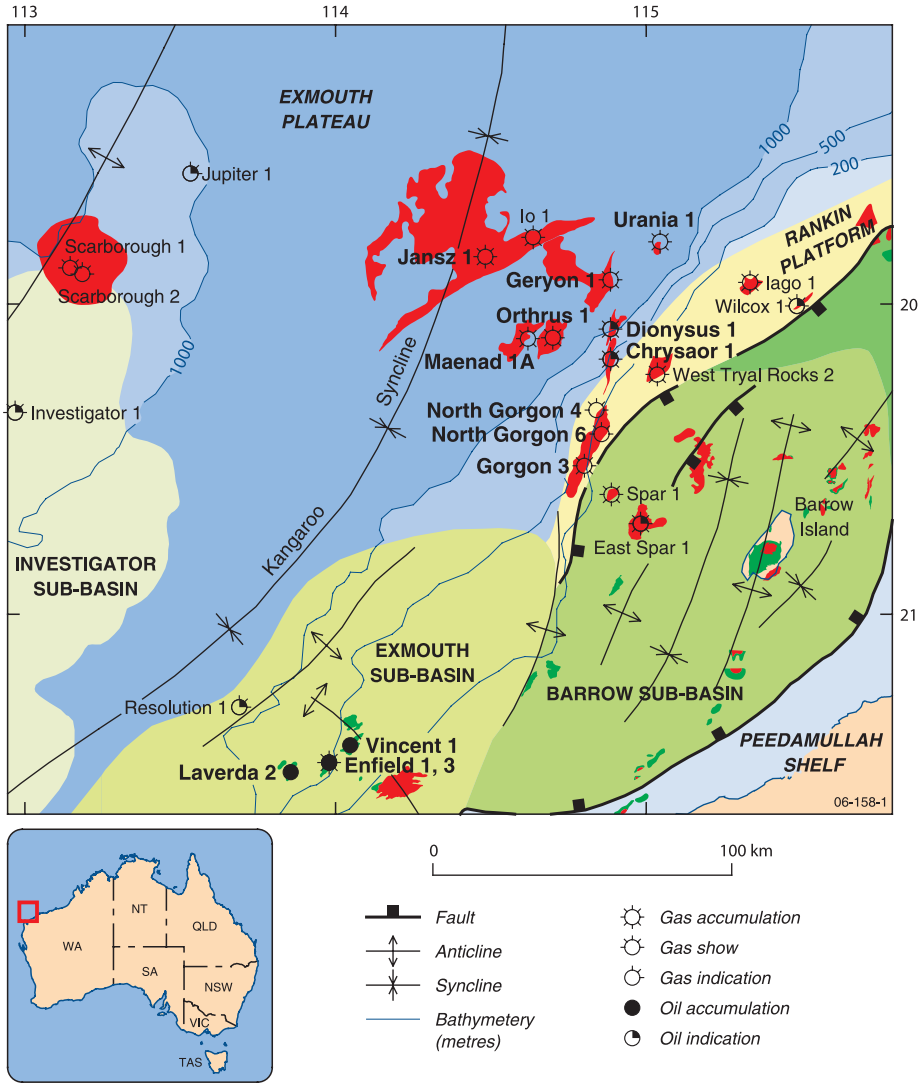
Sourcing WA's offshore natural gases

New isotope data uncover the history of North West Shelf accumulations

Dianne Edwards, Chris Boreham, Janet Hope, Ziqing Hong, Steve LePoidevin and Tamara Buckler

Molecular and stable isotopic (carbon and hydrogen) analyses of fluid samples from Australia's offshore natural gas accumulations are being undertaken as part of a Geoscience Australia initiative to understand the origin, thermal maturity and degree of preservation of these economic resources.

Isotopic signatures of the natural gases from the Exmouth Plateau and Exmouth Sub-basin (figure 1) show that many accumulations have complex fill histories. Natural gas accumulations on the Exmouth Plateau comprise mixtures of non-combustible and combustible gases derived from numerous sources. The combustible hydrocarbon gases have a thermogenic origin, with the non-combustible carbon dioxide and nitrogen gases originating from both organic and inorganic sources. With the exception of Scarborough, the Exmouth Plateau natural gas accumulations have not been biodegraded. The natural gases from the majority of the Exmouth Sub-basin accumulations show differing degrees of biodegradation.



Gas isotopes

The use of hydrogen isotopes to understand petroleum systems has gained prominence through the recent availability of compound-specific isotopic analysis (CSIA) using continuous flow gas chromatography – stable isotope-ratio mass spectrometry (GC-IRMS).

Reported here are the initial results of a study using stable hydrogen (deuterium) isotopes ($^2H/^1H$ ratio or δD) applied to natural gases on the North West Shelf. These data complement and expand on a decade of experience in the geological application of CSIA for stable carbon isotopes ($^{13}C/^{12}C$ ratio or $\delta^{13}C$; Boreham et al 2001, Geoscience Australia & GeoMark 2006).

Exmouth Plateau

The Exmouth Plateau region contains Australia's largest undeveloped gas resources. The primary reservoirs are the Middle–Late Triassic Mungaroo Formation (Chrysaor, Dionysus, Geryon, Maenad, Orthrus and Urania), the Late Jurassic (Oxfordian–Tithonian) sands of the Dingo Claystone at Geryon and Io/Jansz, and the Early Cretaceous Barrow Group at Scarborough.

Geryon, Io/Jansz, Maenad, Orthrus and Urania (Mungaroo C sand reservoir) are dry gas accumulations with a condensate to gas ratio (CGR) of about 3 bbls/MMscf, although they contain low proportions of wet gases (average $\%C_1/\%C_1–C_5$ = 93.4%; >97% is considered to be a dry gas).

The Urania 1 gas in the shallower Mungaroo AA sand is wetter ($\%C_1/\%C_1–C_5$ = 86.8%) than the gas reservoired in the deeper Mungaroo C sand. All of these Exmouth Plateau gases have low concentrations of nitrogen (N_2 = 3.1%) and carbon dioxide (CO_2 = 1.2%).

Figure 1. Location map of the hydrocarbon accumulations on the Exmouth Plateau and in the Exmouth Sub-basin. Gas samples analysed in this study are shown in bold.

Interestingly, although the Late Jurassic reservoir at Io/Jansz (Oxfordian Jansz sandstone) is in pressure communication with the Late Jurassic (Tithonian) reservoir and Brigadier Formation reservoir at Geryon (Jenkins et al 2003), the $\delta^{13}C$ CO_2 values differ, implying that the gases are not in chemical equilibrium.

Gas–gas correlations based on the carbon and hydrogen isotopic compositions of individual hydrocarbons from methane to *n*-pentane (C_1–C_5) are shown in figure 2. The Geryon 1, Jansz 1, Maenad 1A, Orthrus 1 and Urania 1 gases have similarly shaped $\delta^{13}C$ isotopic profiles that show very little isotopic differentiation between ethane, propane and butane (figure 2a).

Such a flat isotopic profile in these wet gases is typical of a terrigenous gas source and may indicate either a different source for the wet gases and methane or a land-plant component to the marine Type II kerogen, as interpreted from the cross plot of $\delta^{13}C$ ethane versus $\delta^{13}C$ methane (figure 3).

The Urania 1 gas recovered from the Mungaroo C sand was generated at lower thermal maturity than the Geryon 1, Jansz 1, Maenad 1A and Orthrus 1 gases (figure 3), all of which were generated at vitrinite reflectances (Ro) between 1.3% and 1.5%.

Since the Maenad 1A, Orthrus 1 and Urania 1 gases are in reservoirs within the Mungaroo Formation, and offset from the main Mesozoic rift system, the most likely source of these gases is the regressive fluvial–deltaic Middle–Late Triassic sediments of the Mungaroo Formation.

The isotopic profile of the wet gases in the Jansz 1 sample is similar to those of the Geryon 1, Maenad 1A and Orthrus 1 gases (figure 2); however, both the carbon and hydrogen isotopes of methane in the Jansz 1 gas show a relative depletion of about –1.8‰ in $\delta^{13}C$ (–38.3‰) and –7.8‰ in δD (–164.8‰) that cannot be attributed to maturity differences.

This depletion is thought to be source-related, possibly indicating a second source of dry gas, rather than the result of biodegradation, since there is no isotopic enrichment of propane—the compound most susceptible to biodegradation.

Gorgon area

The gas accumulations from the Gorgon area (Gorgon, Central Gorgon, North Gorgon, Chrysaor and Dionysus) are primarily reservoired within the Mungaroo Formation.

These gases are slightly wetter (CGR = 9–12 bbls/MMscf) and contain higher carbon dioxide contents (CO_2 = 5.0–22.8%) than those on the adjacent Exmouth Plateau at Geryon, Io/Jansz, Maenad, Orthrus and Urania.

The Gorgon 3, North Gorgon 6 and Chrysaor 1 hydrocarbon gases display an almost linear $\delta^{13}C$ *n*-alkane profile (figure 2c).

Isotopically, the hydrocarbon gases from Dionysus 1 seem to be more similar to the gases from Maenad 1A and Jansz 1 (figure 2a, 2b) than to those from Chrysaor 1 and Gorgon 3 (figure 2c, 2d). However, the Dionysus 1 gas contains a high concentration (8.7 %) of isotopically enriched carbon dioxide ($\delta^{13}C$ CO_2 = –5.5 ‰) that is isotopically most similar to the gas from Chrysaor 1 ($\delta^{13}C$ CO_2 = –5.2 ‰). These data imply that the Dionysus gas accumulation has a different charge history from the adjacent gas accumulations and is derived from multiple sources.

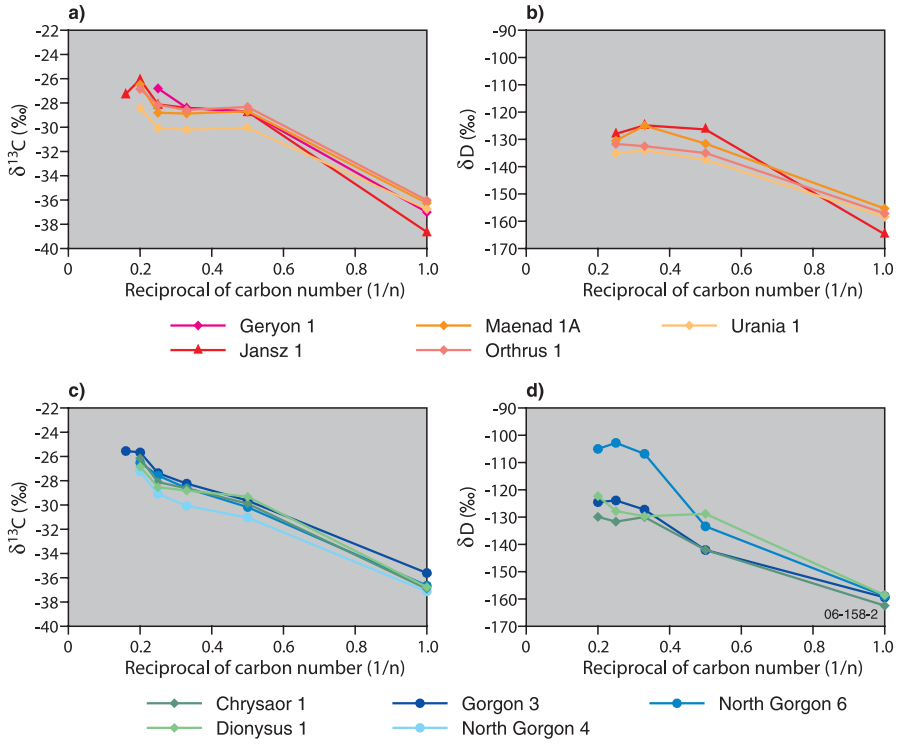


Figure 2. Carbon and hydrogen isotopic values for individual gas components from the Exmouth Plateau and Gorgon area, highlighting source differences.

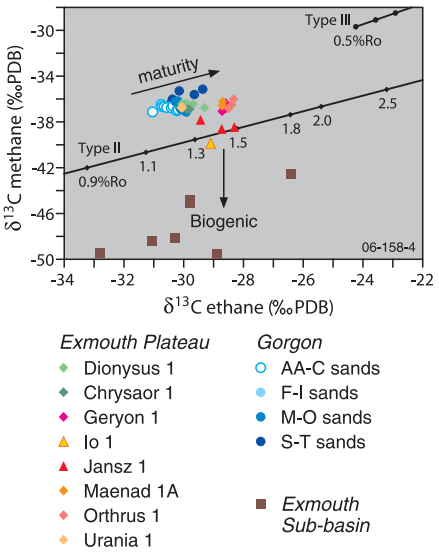


Figure 3. Plot of $\delta^{13}C$ ethane versus $\delta^{13}C$ methane showing kerogen type and maturity trends for the Exmouth Plateau and Rankin Platform gases, and the effect of biodegradation on gases from the Exmouth Sub-basin.

Biodegradation

Methane depleted in ^{13}C (range $\delta^{13}C$ = –41.5 to –48.4‰) is recorded in the gases from the Exmouth Sub-basin at Enfield 1, 3, Laverda 2 and Vincent 1 (figure 4).

As well as the addition of secondary biogenic methane to these accumulations, the remaining wet gases (propane in particular) show increasing enrichment in their $\delta^{13}C$ and δD values as a result of increasing levels of biodegradation. These accumulations show a range of gas wetness ($\%C_1/\%C_1–C_5$ = 96.5–99.9%) corresponding to the differing degrees of biodegradation.

Extremely dry gas is encountered at Scarborough 1 and 2 (mean 95.6 mol % methane; 0.1 mol % ethane; 4.3 mol % nitrogen; 0.04 mol % carbon dioxide). The $\delta^{13}C$ isotopic value of –42.3‰ for the Scarborough 1 gas, when compared with the biodegraded gases in the Exmouth Sub-basin (figure 4), indicates incorporation of isotopically light secondary biogenic methane into this accumulation.

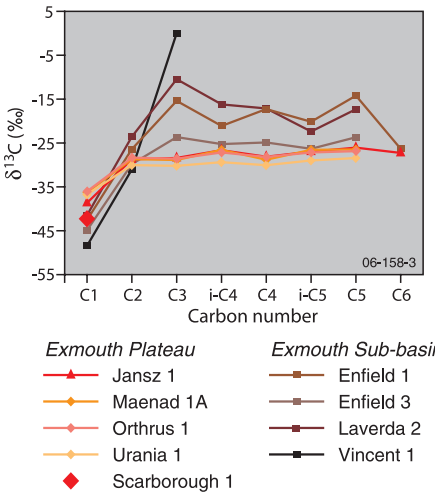


Figure 4. Carbon isotopic values for individual gas components from the Exmouth Sub-basin, emphasising the effects of biodegradation.

Summary

Molecular and isotopic data for natural gases in the Exmouth Plateau and Gorgon areas indicate several source provinces for the thermogenic hydrocarbon gases with carbon dioxide and nitrogen originating from both organic and inorganic sources.

Within the Exmouth Plateau gas accumulations, biodegradation is only apparent at Scarborough. However, biodegradation is widespread within the Exmouth Sub-basin accumulations, resulting in the overprinting of their isotopic signatures and destruction of source information.

Gas–source correlation studies are proposed to determine the origin and level of thermal maturity required for gas generation in offshore Australian basins, and to understand the factors that control gas wetness.

This article is based on a paper presented at the Combined National Conference of the Australian Organic Geochemists and the Natural Organic Matter Interest Group, Rottnest Island, Perth, WA, February 2006 (Edwards et al 2006).

Gas chromatography – stable isotope mass spectrometer used in hydrocarbon isotope analysis.

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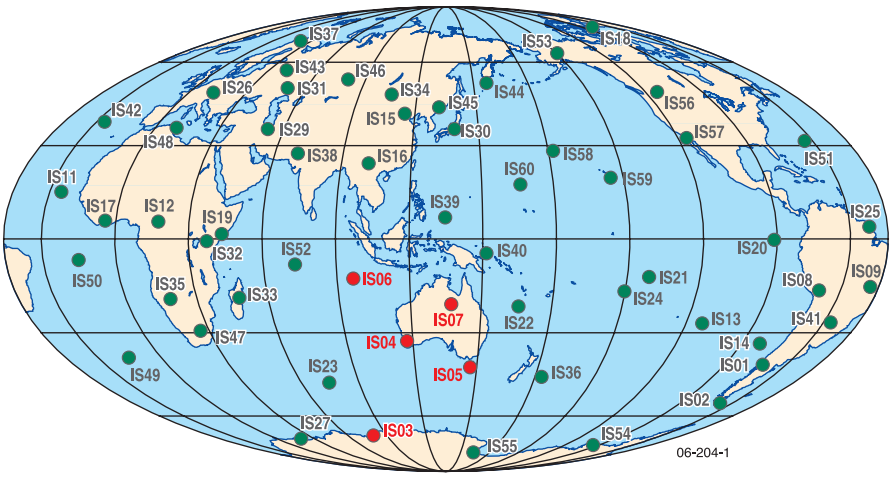
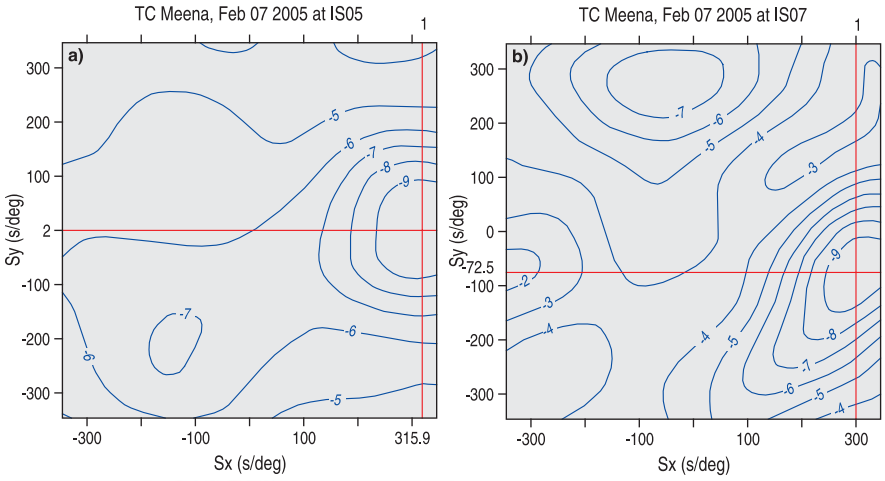
Listening to the EARTH

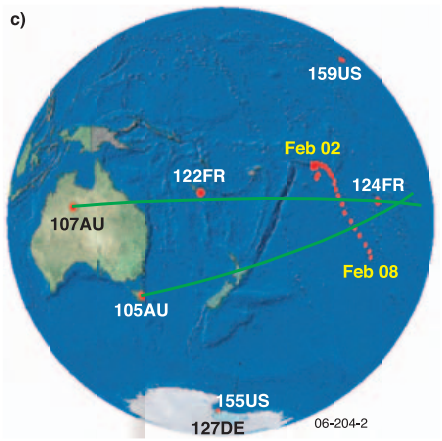
A system to monitor H-bombs warns of other disasters.

David Brown



▲ **Figure 1.** The 60-station IMS infrasound network, with the Australian-operated stations shown in red.





▲ **Figure 2.** Contours of signal power as a function of slowness for the microbarom signals generated by tropical cyclone Meena recorded at (a) IS07 and (b) IS05. (c) The path of TC Meena superimposed with great-circle paths from IS05 and IS07 with azimuths determined by (a) and (b).

For humans, sound is ubiquitous. We are constantly bathed in a spectrum of acoustic radiation from human and natural sources, from very high ultrasonic signals of submillimetre wavelength to very low infrasonic acoustic-gravity waves with wavelengths of 10 kilometres or more.

The distance to which acoustic signals propagate is governed by how rapidly the energy is absorbed by the atmosphere. Absorption of acoustic energy varies roughly according to frequency. Lower frequency signals tend to travel further—one reason why low-frequency ship horns can be heard over several kilometres and high-frequency sirens become inaudible within a kilometre.

Explosions provide a good broadband source of sound. High-frequency components in the hundreds to thousands of Hz range dissipate within a kilometre or so, but longer-lived infrasound components, if they are generated, can travel thousands of kilometres.

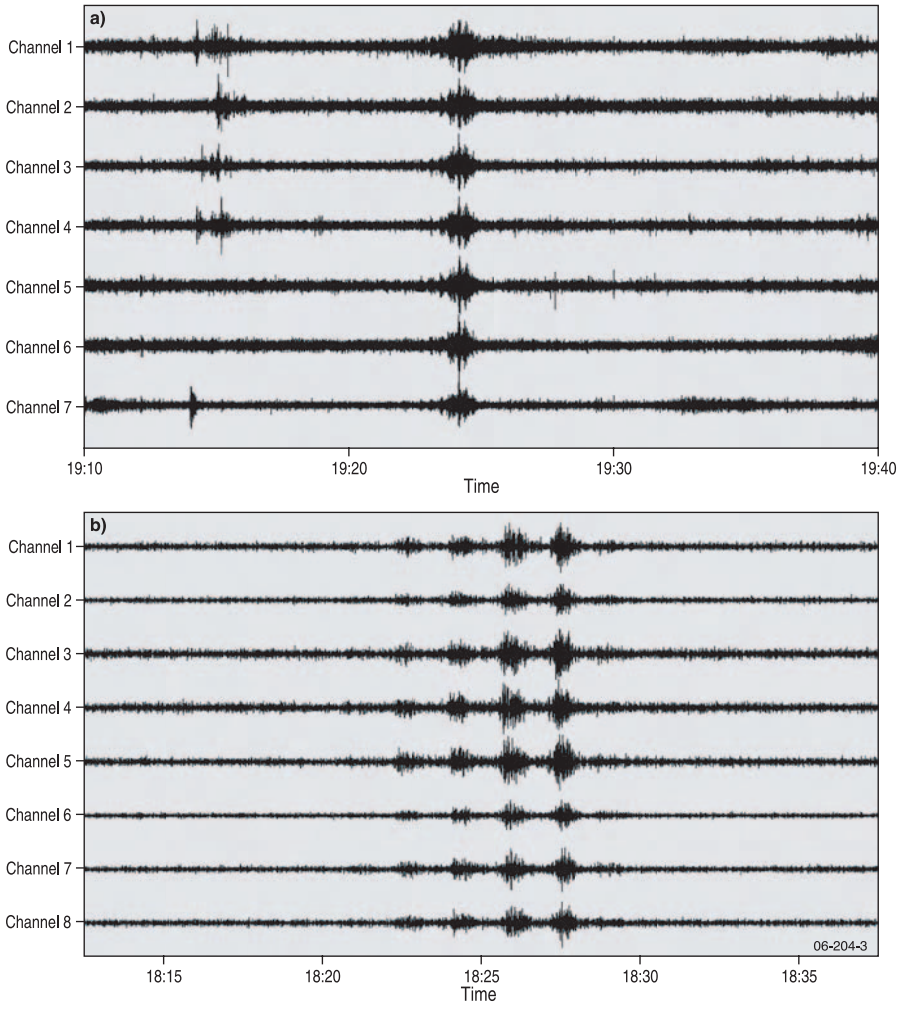
The long-lived infrasonic core generated by large atmospheric explosions is the focus of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) in its efforts to monitor the environment for clandestine nuclear detonations. A global 60-station infrasound sensor network, a component of the International Monitoring System (IMS) of the CTBT, is being established to monitor compliance with the treaty when it enters into force (figure 1).

Detecting infrasound

Geoscience Australia and the Australian National University will operate five IMS infrasound stations as part of the Australian Government's commitment to monitoring the test ban treaty.

Each station consists of between four and eight low-frequency microphones placed on the surface, separated by between 0.2 and 3 kilometres.

The main goal of the IMS is to detect explosions of one kiloton yield or higher. It also has the potential to contribute in other areas, in particular by detecting volcanic activity that might be the source of ash clouds, which jeopardise the safety of aircraft.



▲ **Figure 3.** Acoustic signals recorded from the terminating explosion of a bolide striking the atmosphere near the northern NSW coast: (a) IS07; (b) IS05.

Storms at sea

The biggest radiator of natural infrasound is the surface of the sea. The 3–8 second period acoustic radiation coming off the sea, known as microbarom radiation, is the precise atmospheric analogue of microseismic radiation.

It is important to note that isolated travelling ocean waves don't radiate acoustically. Microbarom radiation requires standing wave conditions, which, according to the Ponomaryov wake generation model (Ponomaryov 1988), are most strongly generated in the wake region of moving storm systems.

A good example of storm-generated microbarom radiation is the acoustic signal generated by tropical cyclone Meena, which wreaked havoc in the Cook Islands in February 2005. Figure 2 shows contours of signal power as a function of slowness for acoustic signals recorded on IMS stations IS05 and IS07 for microbarom radiation generated by Meena. The signals in figures 2a and 2b can be used to infer the approximate location of the storm system, as shown in figure 2c.

Bolides

A second source of naturally occurring infrasound is the entry of bolides (meteorites) into the atmosphere. Bolides hit the atmosphere at speeds ranging from 10 to 70 kilometres per second, and generate acoustic signals in two ways.

In the first, supersonic motion through the atmosphere generates a line source that's recorded as a shock wave in the near field, or as a linear acoustic wave in the far field.

The second mechanism, a larger source of sound, is the terminating explosion as the kinetic energy of the bolide converts into thermal energy. An example of this is shown in figure 3, which shows signals recorded on IS05 and IS07 from a bolide that struck the atmosphere, waking residents along the northern coast of New South Wales.

Based on the extracted signal parameters, triangulation places the source near Taree. This information may be useful in locating debris for meteorite analysis.

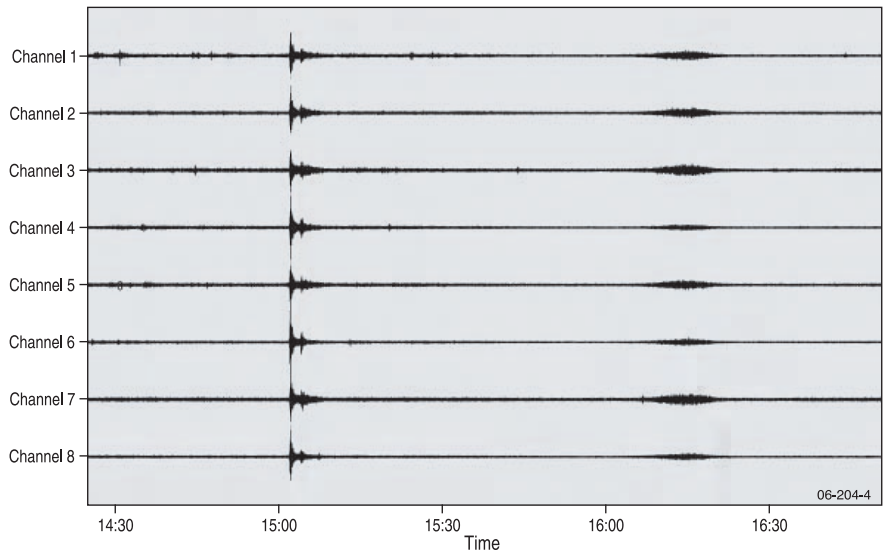


Figure 4. Macquarie Ridge magnitude 8.1 earthquake signal recorded on the IS05 infrasound station. The earliest arrival is the P phase, followed by S, and some time later by the airborne acoustic signal.

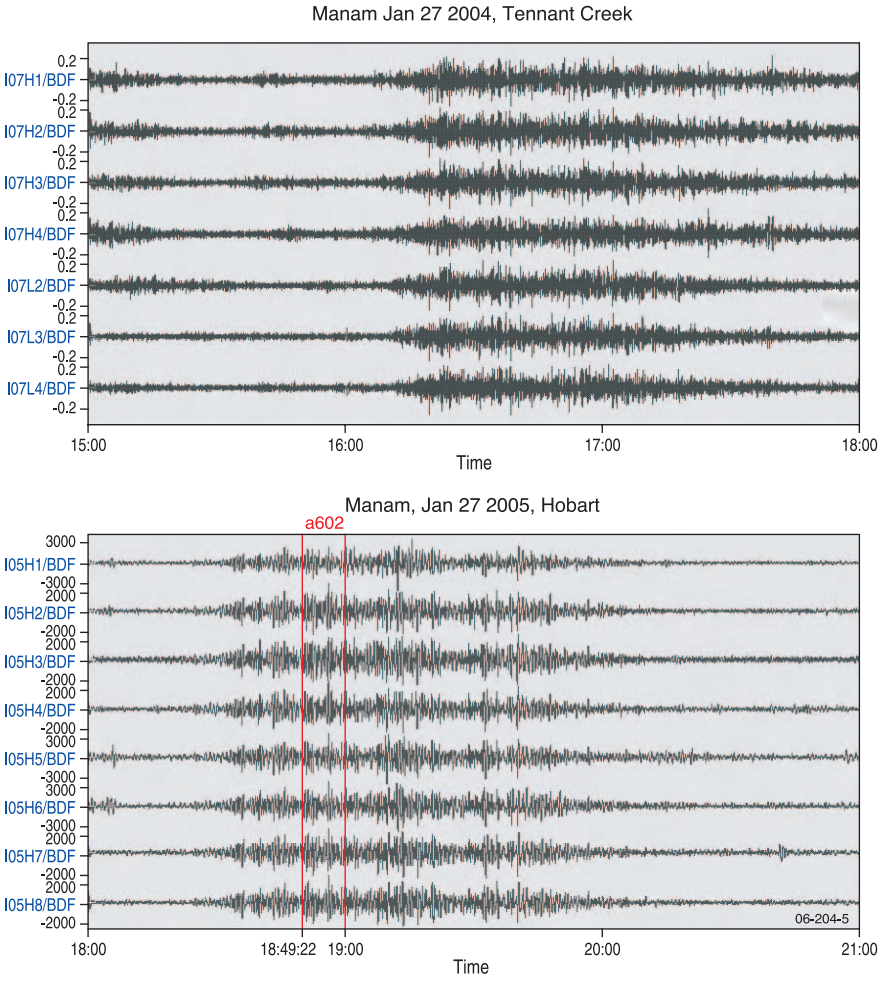


Figure 5. Acoustic signals from the eruption of Manam volcano of 27 January 2005, recorded on (a) IS07, filtered between 0.4 and 1.6 Hz, and (b) IS05, filtered between 0.03 and 0.1 Hz.

Earthquakes

Large-scale earthquake activity often registers on IMS infrasound stations. Several signals are usually recorded. The earliest arriving signals are seismic phase P, followed by S, some time later by the converted hydroacoustic T phase, and last by the acoustic phase that propagates through the air from source to receiver. The Macquarie Ridge earthquake of 24 December 2004 is a prime example. Station IS05 at Buckland, Tasmania, 1300 kilometres from the source region, recorded strong seismic and infrasonic signals. Figure 4 shows the P, S and Is phases recorded at Buckland.

In this case, the precise mechanism of the airborne acoustic signal is not well understood, as the signal would have travelled through a significant depth of water.

Volcanoes

An arc of volcanic activity borders Australia, from New Zealand in the east to Indonesia in the west. The Indonesia–PNG area alone contains 165 active volcanoes, and significant volcanic events in that area often register on the Australian IMS infrasound stations. The eruption of Manam volcano in PNG in January 2005 is a good example and highlights the potential contribution the IMS network can make to a multitechnology ash warning system for aircraft.

On 27 January, after several months of low-level volcanic activity, Manam erupted violently—with devastating consequences. The Manam seismic observatory, operated by Rabaul Volcanological Observatory, was destroyed, with at least one death.

Thick cloud cover made satellite analysis of the main eruption difficult, and an ash warning for aircraft was not issued until 14 hours after the event (Tupper et al 2005). However, acoustic signals from the main eruption registered strongly on the two Australian IMS infrasound stations then operating (figure 5).

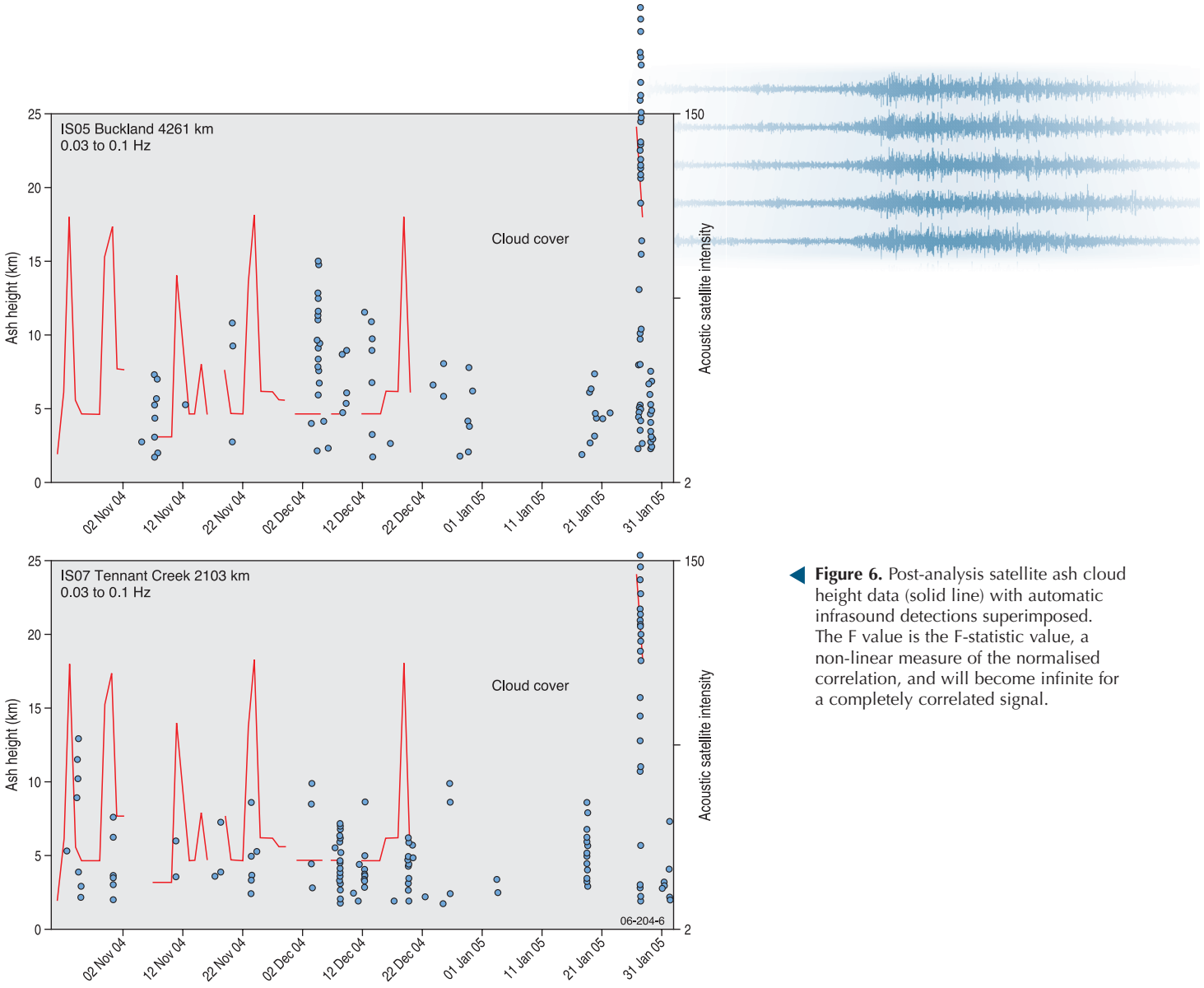


Figure 6. Post-analysis satellite ash cloud height data (solid line) with automatic infrasound detections superimposed. The F value is the F-statistic value, a non-linear measure of the normalised correlation, and will become infinite for a completely correlated signal.

Post-analysis satellite data for several months leading up to the main Manam eruption were provided by Andrew Tupper of the Darwin Volcano Ash Advisory Centre. Comparison with infrasound detections made by the automatic processing system at both stations for the same period (figure 6) shows that:

a) for IS07, the closest station, fair-to-good correlation exists between the known ash cloud events and infrasound detections

b) correlation exists between the detections at IS05 and IS07 for some of the ash cloud events—there also seems to be some indication that volcanic activity occurred without an observed ash event, perhaps due to heavy cloud cover.

There is clearly a potential role for the IMS network in a multitechnology ash monitoring system for aircraft.

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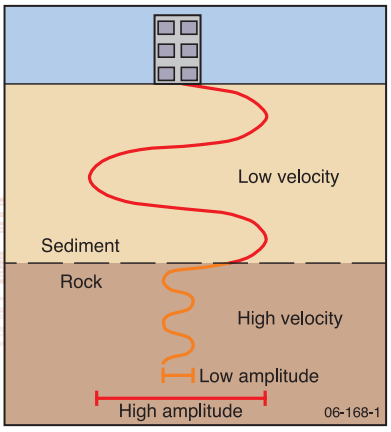
ESTIMATING the influence of *sediments on ground shaking*

Predictive shear-wave velocity models for the Los Angeles Basin show limited relevance to Australian conditions.

Andrew McPherson

Many of Australia's major population centres are built on alluvial plains or coastal margins characterised by significant thicknesses of unconsolidated sediment. Such soils and sediments near the surface can modify ground shaking during earthquakes by reducing the velocity of earthquake waves and increasing their amplitude. This amplification can increase the risk of earthquake damage in Australian cities and other areas underlain by significant quantities of unconsolidated sediment.



▲ **Figure 1.** Sediments near the Earth's surface can amplify earthquake energy waves by reducing their velocity and increasing their amplitude.

Understanding the geophysical behaviour of sediments

Predicting the potential impact of earthquakes on built structures requires an understanding of the behaviour of sediments when they are subjected to ground shaking. One of the best methods is direct measurement of variables such as shear-wave velocity (V_s), a measure of the speed of the large-amplitude waves that damage structures (figure 1). Unfortunately, such data do not exist or are not readily available for much of Australia—so how else can we estimate shear-wave velocity?

A collaborative project to develop models for predicting shear-wave velocity in near-surface sediments using geological data has recently been completed by Geoscience Australia staff in conjunction with colleagues in the United States Geological Survey's (USGS) Earthquake Hazards Team.

A key outcome of the successful development of these models would be better earthquake site response prediction, for input into Australian earthquake hazard and risk models.

The USGS has acquired a number of detailed datasets in the Long Beach area of California (figure 2) as part of a combined groundwater and seismic hazard assessment project in the Los Angeles Basin.

These datasets are unique in that they provide both measured geophysical data (such as V_s) and corresponding geological variables (such as sediment grain size, lithology, age, roundness and sorting). Data from six reference core sites were analysed to develop models for predicting Vs based on geological variables.

The models are intended to be applied in areas where geophysical data are sparse or absent, but where 3D geological data are available (for example, from drilling logs). They thus provide a potential mechanism for predicting shear-wave velocity at Australian sites for which sufficient geological data are available.

▲ **Figure 2.** Long Beach study area, Los Angeles Basin, California. Reference profiles are marked. (Image: D Ponti, USGS).

Developing the predictive model

One of the key variables influencing V_s is sediment grain size, so to enable prediction of V_s from geological data it is necessary to establish a relationship between grain size and lithology. This relationship then permits reclassification of geological data from drilling logs and the application of the predictive model. This is particularly important in the Australian context, because most of our available geological data are only in the form of lithologic information, with little or no grain size information.

Two classification systems were developed to characterise and group grain size data, one with four classes and one with twelve. The four-class system—gravel, sand, silt, clay—provides the strongest relationship between average grain size and lithology.

Multiple regression analyses were run to develop a series of equations for predicting V_s. These models were tested against subsets of the Los Angeles data to determine their applicability, and were found to give a reasonable predictive capability against the original data (figure 3). However, problems remain, particularly with the ability to correctly account for V_s amplitude shifts relating to grain size.

Several variables were expected to be useful in modelling V_s. Depth, grain size and geological age, of which the latter is essentially depth dependent, were found to be the most useful predictors. In contrast, variables such as grain sorting and roundness, which would be expected to be significant due to their influence on the physical structure of sediments, were shown to be very poor predictors using the available data.

Testing against Australian data

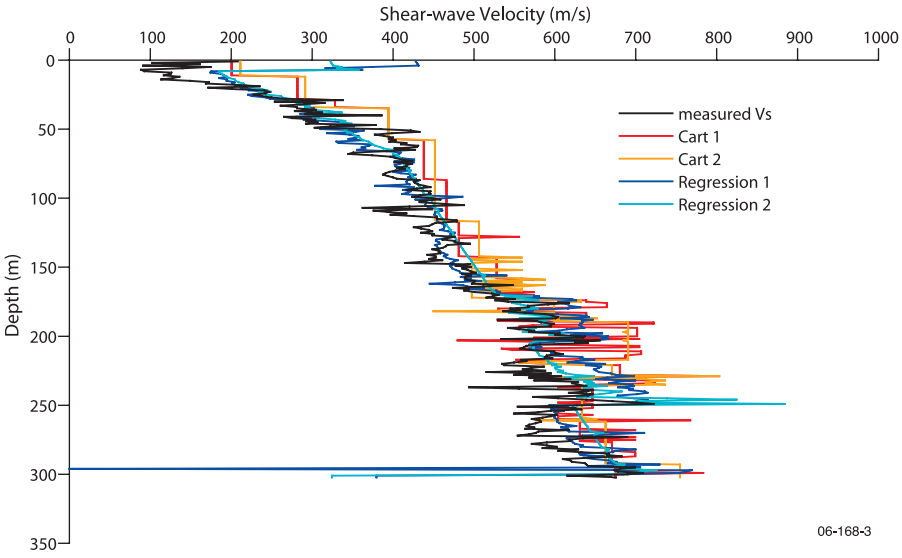
When the developed models were tested against data from sites in Newcastle, Australia, the results were disappointing. In figure 4, the highly linear predicted V_s results demonstrate the significant influence exerted by the depth variable. They also demonstrate the inability of the various models to capture any medium-to-fine scale variation in V_s.

Lessons learned

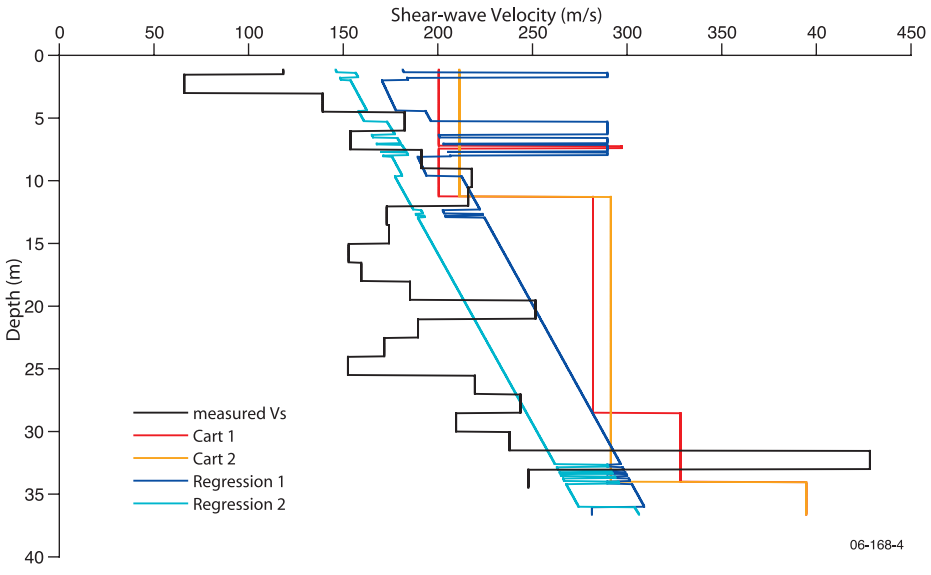
The properties of unconsolidated sediments clearly influence the behaviour of earthquake energy, as represented by measured shear-wave velocity. The predictive models developed for materials in the Los Angeles Basin may be suitable for approximate shear-wave velocity prediction in that region.

Unfortunately, these models appear to be unsuitable for application to sedimentary environments such as those in Newcastle. The variability in observed and predicted shear-wave velocities, and the large discrepancies between them, can potentially be attributed to a number of factors, including:

- **Sampling resolution of the geological data underpinning the lithology classification.** This may be insufficient to accurately differentiate the geological materials. In the case of the Long Beach data, grain size is recorded as a median value for each logged lithological interval, reducing the ability to detect any relationship between small-scale grain-size and V_s variations. This can be significant if you have, for example, a gravel bed within a thick sand sequence.



▲ **Figure 3.** Comparison of predicted shear-wave velocity for various models against measured V_s from a reference site from Long Beach, California.



▲ **Figure 4.** Comparison of predicted shear-wave velocity for various models against measured V_s from a reference site from Newcastle, Australia.

- **Sampling resolution of the geophysical data used to generate the predictive equations.** The V_s data in Newcastle were collected at 0.05 metre intervals. The V_s data in Long Beach were collected at a minimum interval of 0.5 metres, a 10-fold difference in spatial resolution that may have effectively 'smoothed' the LA data compared to that from Newcastle. Resampling of the Newcastle data at a coarser resolution does little to change the result.
- **The analytical techniques applied to the data.** The methods employed in the data analysis assume a linear relationship between the variables. The observed non-linear change in V_s with depth—in association with other geological variables—suggests that non-linear analysis may be necessary.
- **Differences in geological evolution.** The LA Basin is actively subsiding and has several kilometres of essentially unconsolidated sediment, whereas the Newcastle area is characterised by tens of metres of sediment overlying bedrock. The pronounced linear trend in the Long Beach data may suggest a diagenetic trend (explaining the significance of the depth and age variables), while the profile in Newcastle would be too shallow and potentially too young to have developed such features.

Conclusion

To gain a more accurate picture of earthquake site response in any given area it is desirable to measure the geophysical properties of the sediments directly. If this is not practical, the minimum requirement for predictive capability would be the acquisition of detailed geological data calibrated by limited direct geophysical measurements.

Where such detailed calibration of site response models using direct measurement is not feasible, indirect measurement using techniques such as spatial autocorrelation or microtremor methods may need to be considered. The geological environment in which any of these methods is applied also requires careful consideration.

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Australian Government
Geoscience Australia

In Brief

Geoscience Australia contributes TO PHILIPPINES LANDSLIDE RESPONSE

A major landslide struck the village of Guinsaugon, Southern Leyte Province, Philippines on Friday 17 February. The Philippines National Disaster Coordinating Council (NDCC) reported on 28 February that there were 140 people dead with 973 missing, 19 injured and 415 survivors.

The NDCC estimated that the landslide caused approximately AUD$2.5 million in damage to infrastructure and AUD$0.6 million in damage to the area's agriculture. Between 350 and 400 hectares were buried by the landslide, with thicknesses of debris estimated to be 20 to 40 metres at the base of the mountain where the village was located (figure 1).

As part of the Australian Government's response an AusAID Landslide Assessment Team, which included Andrew McPherson, a natural hazard geoscientist from Geoscience Australia, was mobilised. The Assessment Team worked from 22 to 28 February and the aim of their mission was to:

- assist the Philippines authorities in assessing slope stability in the vicinity of the landslide site and the potential for further landslides in the province
- provide technical advice on water and sanitation to the Philippines National Red Cross (PNRC) and local government agencies supporting evacuees
- make recommendations for future Australian assistance—for both short and medium term relief and rehabilitation assistance for landslide survivors and evacuees, as well as longer-term disaster management assistance.

▲ **Figure 1.** View of the landslide from the nearby search and rescue base camp (photo: A McPherson).

As a result of the mission the Landslide Assessment Team put forward a series of recommendations, including:

- Support for a United Nations Development Program proposal to provide both long and short term assistance in:
  - geohazard mapping for natural disaster assessment
  - development and implementation of community-based early warning systems
  - community and government disaster education initiatives
  - incorporation of disaster risk reduction into local development planning.
- Support for a Philippine National Red Cross community-based disaster preparedness programme focused on the establishment of village disaster action teams in four prioritised provinces, along with the implementation of small-scale disaster mitigation activities in the provinces.
- Potential provision of technical support to Philippine Government agencies responsible for geohazard mapping and risk assessment. This would be scoped through AusAID in consultation with Geoscience Australia and other key Australian agencies. If practicable the need for technical assistance would be gauged through visiting delegations from relevant Philippine agencies, which would identify specific skills and expertise required from Australia.

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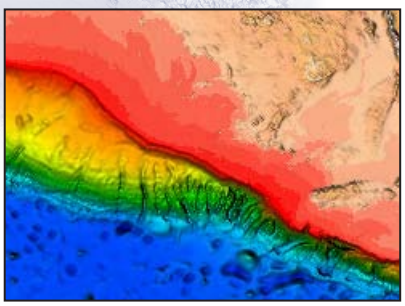
In Brief

NEW BATHYMETRIC DATA *from the continental slope*

New swath and sub-bottom profile data acquired during the transit of the French ship RV *Marion Dufresne* from Sydney to Albany is contributing to several Geoscience Australia projects. Data from the base of the continental slope across the Great Australian Bight is being used to help plan an upcoming Big New Oil marine survey while data collected along the south coast of New South Wales will assist in regional marine planning. The 'voyage of opportunity' was undertaken after completion of the AUSFAIR survey – a joint French-Australian geological sampling and geophysical acquisition survey which collected data from the Fairway and Capel basins.

The swath acquisition system onboard the RV *Marion Dufresne* is a Thomson-Marconi TSM 5265 multi-beam sonar, which produces high-resolution bathymetric and backscatter images of the seafloor across a swath 20 kilometres wide in deep water. In conjunction with this equipment, a digital sediment sounder (3.5 kHz) gives an acoustic record with a penetration through 100 metres of sediments. This system is capable of acquiring data in deeper water than the system onboard the Australian marine research facility, the RV *Southern Surveyor*.

The acquisition track along the foot of the Ceduna and Eyre terraces in the Great Australian Bight was at water depths between 2000 and 5000 metres. It was designed to complement existing bathymetric datasets and acquire data beyond the limits of the RV *Southern Surveyor*. The updated bathymetry grid is now being used to help identify potential geological sampling sites in the Bight Basin. Although few rocks older than Maastrichtian (latest Cretaceous) have been recovered from the distal, deeper water parts of the Bight Basin, geological studies undertaken by Geoscience Australia identified this area of the basin as the region most likely to contain potential source rocks. A geological sampling survey targeting rocks of Albian-Santonian (Early-Late Cretaceous) age, which are exposed at places along the continental slope, is currently being planned. The new bathymetric data will also assist in the accurate siting of dredge localities.



The bathymetric data acquired from the New South Wales continental slope will be used to study the seabed character of the deeper part of the margin. There have been very few systematic surveys of the New South Wales margin over the last 50 years, so the new data should considerably assist in natural resource management of the area.

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Related article
AusGeo News 65
Ancient deltas key to Bight's oil potential: www.ga.gov.au/pdf/Corp0090.pdf

Enhancing the protection of AUSTRALIA'S CRITICAL INFRASTRUCTURE

The launch of the Critical Infrastructure Protection Modelling and Analysis (CIPMA) Program, at Geoscience Australia in February, marked the formal beginning of a national initiative that will put Australia at the forefront of critical infrastructure assessment.

CIPMA is a collaborative project between Geoscience Australia, the Attorney-General's Department and CSIRO. It will examine the inter relationships and dependencies between critical infrastructure systems, and will demonstrate how a failure in one sector can greatly affect the operations of other sectors.

Using detailed data and knowledge provided by industry, CIPMA will help business and government better understand critical infrastructure complexities. It will enable contributors to identify the most important and vulnerable components of their critical infrastructure networks, and assess the flow-on effects if they are compromised.

The CIPMA program is a logical extension of Geoscience Australia's Risk Research Group's work program. CIPMA's strategic approach to critical infrastructure assessment applies the Group's expertise in all hazard research, geospatial mapping and hazard assessment, and draws on existing relationships with key stakeholders.

The Program will initially focus on the communications, energy, and banking and finance sectors. It will support critical infrastructure protection, counter terrorism and emergency management prevention, preparedness, planning, and recovery.

CIPMA has already gained strong support from the owners and operators of critical infrastructure, state and territory governments, and Australian Government agencies. The CIPMA development team will continue to engage stakeholders across sectors to ensure access to critical data and industry knowledge for the ongoing development of the capability.

Ultimately, CIPMA will provide the detailed analysis needed to make informed decisions. It will help government develop more targeted and cost effective national security and CIP policies to better protect assets vital to Australia's security and prosperity.

▲ **Figure 1.** Attorney-General Phillip Ruddock launching the CIPMA Program with Infrastructure Assurance Advisory Group Chairs, Keith Orchison (Energy), Bill Davey (Communication) and John Geurts (Banking and Finance).

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Related article
AusGeo News 79,
Protecting the nation: www.ga.gov.au/ausgeonews/ausgeonews200509/cip.jsp.

Geoscience Australia contributes TO SENTINEL ASIA

Geoscience Australia's Sentinel bushfire monitoring system, through its Web Mapping Service (WMS) and Web Feature Service (WFS), will become a data node of *Sentinel Asia* providing access to Australian hotspot information. *Sentinel Asia* will initially disseminate information about forest fires and then will expand its services in the future to provide data on other natural disasters such as floods, earthquakes and landslides.

Sentinel Asia is an initiative of the Japan Aerospace eXploration Agency (JAXA) and the Asia-Pacific Regional Space Agency Forum to provide a disaster management support system in the Asia-Pacific region. A meeting held in Hanoi in February to discuss disaster management in the Asia-Pacific region was attended by 70 participants, representing 34 different organisations across 18 countries. Australia was represented by Shanti Reddy of Geoscience Australia, Alex Held of CSIRO and Agnes Apostolou of the Bureau of Meteorology.

Sentinel Asia is modelled on the Australian Sentinel hotspot system and is a network of distributed web mapping systems consisting of three types of nodes:

- Data provider nodes–agencies that collect and distribute satellite data
- User nodes or local service providers–government departments and Non-Government Organisations
- Research and Training nodes–universities and research and development institutes.

As well as Geoscience Australia, other nodes will include the Singapore Centre for Remote Sensing and Tokyo University, which are also ready to commence operations.

JAXA is keen to demonstrate the capabilities of the Advanced Land Observing Satellite (ALOS) to mitigate damage in disaster-affected areas. The ALOS Rapid Response System developed for the Asian Disaster Reduction Centre (ADRC) of Japan will become part of *Sentinel Asia*. Plans are underway within JAXA to create a new specialist group to oversee disaster management applications and promote international use of its data. JAXA will also fund a few nodes each year to set up the necessary infrastructure in the developing countries in Asia.

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Supporting Indigenous policy WITH SPATIAL INFORMATION

Geoscience Australia's Spatial Information Industry Advice and Facilitation (SIIAF) Branch is responsible for providing advice to Government on geospatial industry matters and facilitating the uptake of spatial information and technology by government agencies.

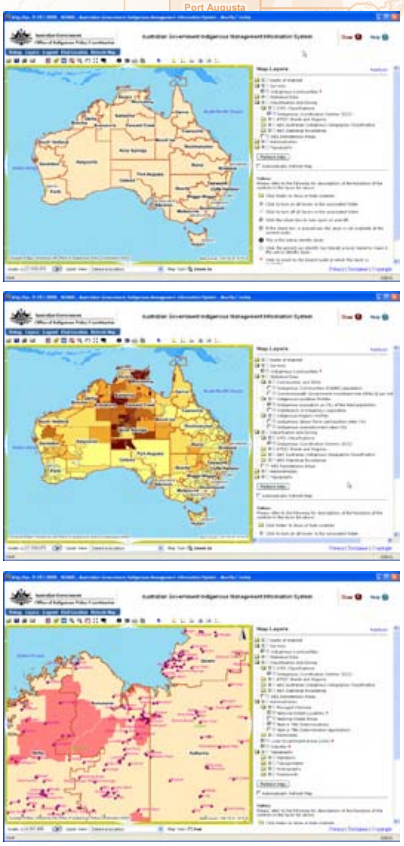
SIIAF recently concluded a successful pilot project for the Office of Indigenous Policy Coordination (OIPC). The OIPC is an agency within the Department of Families, Community Services and Indigenous Affairs (FaCSIA) which coordinates a whole-of-government approach to programs and services for Indigenous Australians across Australian Government agencies.

The aim of the pilot project was to demonstrate potential uses of geospatial technologies and spatial data that can be used by a policy maker in the OIPC main office to assist coordinators in the field in the Indigenous Coordination Centres (ICCs).

In the first stage, a database of publicly available spatial datasets relevant to OIPC's business was compiled. At stage two, a web mapping application was developed using a blend of open source and proprietary technologies. The map interface enables users to browse and query a large amount of contextual information. At stage three, a level of integration was achieved with existing agency databases which hold Australian Bureau of Statistics (ABS) Census data so that reports containing tables and figures can be generated by clicking on a geographic area of interest. In addition to these reports, a select portion of otherwise tabular census material can be portrayed spatially.

The pilot project was well-received and has contributed to generating a momentum for examining a broader uptake of spatial information and technology by the OIPC. Geoscience Australia is continuing to provide specialist advice to the OIPC in drafting the spatial capability strategy and will continue to be involved during implementation of the strategy.

For more information phone Dmitar Butrovski +61 2 6249 9825 (email dmitar.butrovski@ga.gov.au)



AUSGEO news
ISSUE 82 June 2006

SPATIALLY ENABLING GOVERNMENT

During the 30 March launch of "Responsive Government – A New Service Agenda" the 2006 e-Government Strategy by the Special Minister of State, The Hon. Gary Nairn MP, special mention was made of the importance of spatially enabling the Australian Government. But what exactly does spatially enabling mean and why is it important?

The business of government agencies lies principally in policy development and program implementation. These activities depend upon quality information, analysis and decision-making. Spatial (or geographic) information is one of the many types of information used in analysis and decision-making. It helps answer the *where* question in government policy development and program implementation.

Historically, the widespread use of spatial information (and its associated technologies and knowledge) in government has been impeded by restricted accessibility, complexity, unknown quality and high cost. That situation is now changing. Web-based solutions, using sophisticated analytical tools and accessing large volumes of data from remote sites, are now becoming readily available on standard desktop computer systems.

In simple terms spatially enabling government means optimising the accessibility and use of spatial information in government decision-making.

Why is it important?

The potential benefits of spatially enabling government include:

- improved decision-making by better understanding of the geographic impact of policies and programs, and more reliable and accurate source information used in decisions
- Possible reduction in administrative costs by automation of low-level tasks such as validation of client data and completion of forms
- better whole-of-government outcomes through use of common and authoritative reference data, and commonly deployed IT&T infrastructure
- enhanced industry development opportunities through procurement of products and services from the private sector.

Current developments

Spatial enablement is occurring today in many government agencies, at both federal and state/territory level. Geoscience Australia, for example, is involved in a number of spatial enablement projects, including:

- Helping the Office of Indigenous Policy Coordination evaluate web-based desktop technology that will add a geographic dimension to its whole-of-government reporting through the Australian Government Indigenous Management Information System (see previous article)
- Working with the Department of Industry, Tourism and Resources to establish a GIS capability to better understand energy infrastructure, ownership and management
- Implementing the Australian Marine Spatial Information System to allow users to visualise vast amounts of information on the Australian marine jurisdiction from their desktop (AMSIS to be launched by The Hon. Bob Baldwin MP, Parliamentry Secretary to the Minister for Industry, Tourisim and Resources)
- Educating potential users on relevant standards (e.g. metadata, web services and interoperability) and technologies (e.g. Spatial Smart Tag, Geocoded National Address File and Spatial Meshblocks) in conjunction with the Office of Spatial Data Management.

Geoscience Australia is able to assist agencies in spatial enablement by drawing upon its capabilities in delivering geoscience outputs to Government. These include knowledge of private sector spatial information service providers. Specific support includes:

- Provision of advice on the use of spatial information and applications in government business
- Facilitation of implementation of specific government business solutions
- Providing access to authoritative geospatial datasets and geospatial web services
- Maintenance of a community of interest in spatial enablement in Australian Government
- Advising on the use of appropriate geospatial standards across government.

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Product News

NEW YILGARN SYNTHESIS

A recently released Geoscience Australia Record uncovers one of Australia's key mineral provinces, the eastern Yilgarn Craton in Western Australia. The Yilgarn produces two-thirds of the gold and more than half the nickel mined in Australia.

The Record reports on research conducted at Geoscience Australia as part of the predictive mineral discovery Cooperative Research Centre's Y2 Project. The principal goal of the project was to determine the 3D architecture of the eastern Yilgarn Craton (EYC) and its evolution through time "to enable prediction of where within the terrane the location of major gold deposits is likely to occur". It is envisaged that the new datasets and new understanding developed by the Y2 project not only benefit explorers in the Yilgarn, but those in other terranes as well.

The main achievement of the Y2 project was the building of comprehensive 3D maps of Kalgoorlie-Kambalda and the Norseman-Wiluna region. The maps were built on a foundation of 2D solid geology maps from government agencies, universities and industry. These data were integrated with various geophysical data sets (seismic reflection, refraction, broadband recording, receiver function, gravity and magnetic data, plus various derivatives such as "worms"), geochemical data sets (e.g., from AMIRA P624), and geochronological data sets (from AMIRA P624 and earlier projects as well as published data). The result of this integration is a more holistic understanding of the Eastern Yilgarn Craton.

Record 2006/05 is structured around the six key outputs delivered by the project:

- An integrated geological and geophysical 3D map (model) for three specific regions within the EYC. These regions were the Kalgoorlie-Ora Banda region, the Leonora-Laverton region, and the Norseman-Wiluna region, the first two being nested within the later model
- Interpreted seismic sections for the 2001 seismic data recorded in the Leonora-Laverton region
- Tomographic model of the Kalgoorlie-Ora Banda region which links the region's velocity structure from the surface, through the base of the crust to the base of lithosphere with the integrated geological and geophysical 3D geological models
- Map of chalcophile elements across selected portions of the EYC
- Assessment of the utility of the new 3D data versus the 2D data at a regional scale
- Prospectivity analysis of the derived 3D models.

Extensive appendices follow each chapter, including all pertinent publications and deliverables. Acknowledgements as well as an outline of all data sources and intellectual property, and references complete the report.

The Y2 project was a predictive mineral discovery Cooperative Research Centre (*pmd**CRC) collaborative project between Geoscience Australia, the Geological Survey of Western Australia and the University of Western Australia. It also involved significant collaboration with the Australian National University's Research School of Earth Sciences, AngloGold Ashanti, Goldfields St Ives, and the former companies WMC Resources, and Placer Dome Asia Pacific.

For more information phone Richard Blewett +61 2 6249 9713 (email Richard.Blewett@ga.gov.au)

Related articles
AusGeo News 82
The Eastern Yilgarn in 3D

Improved access to petroleum exploration well data

Originally launched in 2003 the National Petroleum Wells Database has become an extremely useful tool, giving petroleum explorers access to scientific and well header data for Australian petroleum exploration wells.

The web page provides users with access to a number of comprehensive databases, representing about 100 person-years of data entry completed by geologists, geochemists, biostratigraphers and technical staff.

Database information includes well header data, biostratigraphic picks, reservoir and facies data (porosities, permeabilities, hydrocarbon shows and depositional environments), organic geochemistry data (Rock-Eval pyrolysis, molecular and isotopic analyses), and organic petrological data (vitrinite reflectance, maceral analyses).

A major revision of the web page was released at the Australian Petroleum Production & Exploration Association (APPEA) conference in May. The updated web page includes many new and improved features to meet current government and industry needs including:

- easy retrieval of Acreage Release data
- an improved map for spatial searching and display of data
- ability to retrieve age restricted and isopach data for many data types in the database
- query and produce multiple summary reports (including graphs) for wells
- generation of multiple oil and gas reports for wells
- links to scanned documentation
- improved graphical displays of data.

For more information phone David Rowland +61 2 6249 9253 (email david.rowland@ga.gov.au)

Related articles/websites
AusGeo News 82
Sourcing WA's offshore natural gases
National Petroleum Wells database
dbforms.ga.gov.au/www/npm.well.search

Australia's maritime boundaries *updated*

Geoscience Australia has recently released an updated version of Australia's maritime boundaries (AMB) in digital format. The boundaries include the outer limits of the coastal waters, territorial sea, contiguous zone, exclusive economic zone (EEZ) and continental shelf. They were determined in accordance with the provisions of the United Nations Convention on the Law of the Sea (UNCLOS) and a variety of domestic legislation, in particular, the *Seas and Submerged Lands Act 1973*. The delineation of these boundaries has strategic, economic and environmental implications for Australia.

Extensive work has been carried out to validate and where necessary to update the territorial sea baseline from which the outer limits are derived. As well, the straight baseline components of the territorial sea baseline have been amended with the new locations re-defined by proclamation under the *Seas and Submerged Lands Act 1973* dated 15 February 2006. For the first time, the data also includes boundaries adjacent to the Australian Antarctic Territory and areas of continental shelf beyond 200 nautical miles from the baseline. These continental shelf boundaries were submitted by Australia to the United Nations Commission on the Limits of the Continental Shelf in November 2004. Also included are Australia's territorial sea baseline, relevant basepoints and relevant maritime treaties.

All the AMB data are clearly attributed, providing information about the source material used to determine the baseline and linking the baseline with the various limits. The data are available in geographical coordinates related to the WGS84 datum which is used on maritime charts and by mariners generally.

Maritime boundary data continues to be used by a range of agencies and for a variety of uses which include: coastal surveillance, the management of fisheries and fishing permits, the management of petroleum leases and distribution of royalties, management of the marine environment, and the enforcement of various legislation.

Geoscience Australia has updated the determination of these maritime boundaries for Australia in cooperation with the relevant Commonwealth and State government agencies. This information is made available as digital data suitable for a geographic information system (GIS) and is known as Australia's Maritime Boundaries (AMB Version 2.0). This data replaces the Australian Maritime Boundaries Information System (AMBIS) 2001 Version 1.1 data which was previously released in October 2001.

The AMB data are available in the following common industry formats:

- ESRI ArcInfo export format (.e00 files)
- ESRI Shape Files (.shp, .shx, .dbf files)
- Map Info tables (.mid, .mif files).

The data can be downloaded free of charge from Geoscience Australia's web site (www.ga.gov.au) or purchased on CD ROM from the Geoscience Australia Sales Centre.

To order the CD ROM phone Freecall 1800 800 173 (in Australia) or +61 2 6249 9966 (email sales@ga.gov.au)

New Riverine Flood Hazard & Risk Studies Database *available*

Geoscience Australia has developed a Database of Australian Riverine Flood Hazard and Risk Studies (www.ga.gov.au/oracle/flood) which is now available online. The database offers information on over a thousand national flood studies.

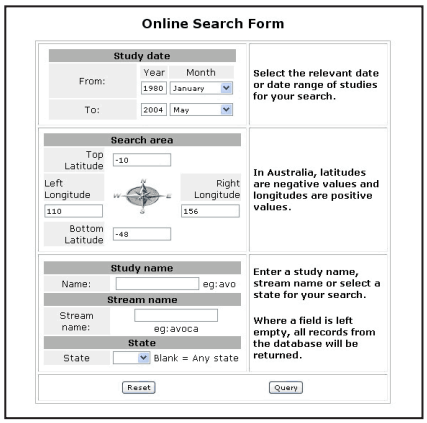
It contains comprehensive information on flood studies undertaken between 1980 and 2004. This database will be beneficial to independent consultants, all levels of government and anyone interested in floodplain management.

The database can be searched by study date, name, stream name, state, and longitude or latitude. Studies can also be viewed by category, including damage assessment, hydrology or hydraulic scenarios, hazard or inundation mapsets, terrain or floor level survey, historical floods, post flood information and related studies.

This new resource provides the foundation for users to identify and prioritise areas for future flood studies. It also gives users access to previous studies of a particular area as well as information on the techniques and data used as well as the current custodian. This means that agencies wanting to commission a flood study (particularly small local government bodies) can learn from flood risk assessments undertaken in other areas.

The database is a useful tool at both the national and regional level helping to determine areas of high flood hazard and risk, and assisting in comparisons of relative risk between urban centres. The information can also be used to identify areas where further research is needed and where studies should have an increased focus on risk assessment.

The development of this database was made possible by funding provided by the Department of Transport and Regional Services and is the culmination of two years work. The cooperation of the many agencies who contributed data, is greatly appreciated.



For more information phone Miriam Middelmann +61 2 6249 9240 (email miriam.middelmann@ga.gov.au)

Related website
Database of Australian Riverine Flood Hazard and Risk Studies
www.ga.gov.au/oracle/flood

Events

PDAC 2006–the world's premier MINERAL EXPLORATION CONVENTION

The 74th Prospectors and Developers Association of Canada Annual International Convention, Trade Show and Investors Exchange, (PDAC 2006), was held in Toronto, Canada, between 5 and 8 March. A record 14 500 delegates, exhibitors and visitors from an estimated 100 countries attended this year's event. Among the attendees were national delegations from some 40 countries including one from Argentina which numbered 100 people. The Trade Show attracted 280 exhibitors including government agencies from 26 countries. In the Investors Exchange 430 companies exhibited and attracted an additional 3400 investors as well as convention traffic.

The mood of the Convention was buoyant reflecting the continuing optimistic outlook being enjoyed by the mineral exploration industry at a time when most commodity prices are at or near 25-year highs.

Australia mounted a high-profile promotion by combined industry and government exhibitors. All the state and the Northern Territory governments as well as the Australian Government (Geoscience Australia) were represented under the "Team Australia" banner. In addition to the Australian governments, the Australian Pavilion attracted five industry exhibitors whose participation was coordinated by GeoJAG Australia. Industry participants were Encom Technology Pty Ltd, Intrepid Geophysics, Intellection Pty Ltd, Gekko Systems Pty Ltd and AME Mineral Economics.

The governments' displays highlighted Australia's premier exploration provinces, undiscovered mineral potential and scientific and technical expertise in relation to mineral exploration. Australia's profile was boosted by the attendance of the NT Minister for Mines and Energy, the Hon Kon Vatskalis who led a delegation from the Northern Territory. Australia's High Commissioner to Canada, Mr Bill Fisher, again added his support to the Australian promotion. The Australian exhibitors received valuable support from the Austrade office in Toronto.

In addition to the Trade Show promotion, a well attended (up to 140 delegates) half-day seminar, 'Exploration Down Under', featuring eight mining and mineral exploration companies active in Australia, was opened by Minister Vatskalis. Presentations were made by: Teck Cominco Ltd, Iluka Resources Ltd, Avoca Resources Ltd, Arafura Resources NL, Western Areas NL, Allegiance Mining NL, Compass Resources and Ivernia Inc.

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Delegation from INNER MONGOLIA *visits Geoscience Australia*

On 28 March eight delegates from the Inner Mongolia Autonomous Region (IMAR), People's Repubilc of China, visited Geoscience Australia as part of an eleven day AusAID-sponsored study tour of Australia.

The delegates included officials from government departments of the Alxa League, an arid mountainous region in the western-most IMAR roughly the size of Australia's Nullarbor Plain. The group included economists and engineers who were particularly interested in learning about Australian agricultural and environmental management practices, together with the roles played by governments, research institutions, industry and the community.

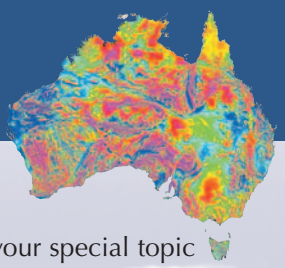
During their visit to Geoscience Australia, the delegation enjoyed a tour of the organisation's world-class, energy-efficient premises and learnt about geoscience applications utilising 3D data. The delegates also learnt about research currently being conducted by the Risk Research Group within the Geospatial and Earth Monitoring Division. The presentations provided the delegation with information on the Australian Government's approach to natural hazard risk assessment and geoscience in general.

The delegation was keen to learn about natural hazard risks in Australia and presentations included information on earthquakes, severe winds and the tsunami risk posed to the Australian community. They were also given an insight into national flood risk, floodplain management in Australia and the development and implementation of flood vulnerability curves. They concluded that while most of the natural hazards facing IMAR and Australia are different there are some common hazards such as floods and earthquakes

▲ Geoscience Australia scientists Adrian Hitchman and Miriam Middlemann (centre) with the visting Mongolian delegation.

For more information phone Adrian Hitchman +61 2 6249 9800 (email adrian.hitchman@ga.gov.au)

AusGeoRef
Australian Geoscience References



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Australian Earth Sciences Convention 2006
18th Australian Geological Convention & Australian Society of Exploration Geophysicists 18th Geophysical Conference and Exhibition
2 to 6 July
Melbourne Exhibition and Convention Centre
Contact: The Meeting Planners, 91-97 Islington Street Collingwood Vic 3066
phone +61 3 9417 0888
fax +61 3 9417 0899
email earth2006@meetingplanners.com.au
www.earth2006.org.au/

Catchment to Coast
Australian Marine Sciences Association
9 to 13 July
Cairns Convention Centre
Contact: AMSA2006 Conference, PO Box 8, Kilikivan, Qld 4600
phone +61 7 5484 1179
fax +61 7 5484 1456
email amsa2006@amsa.asn.au
www.amsa.asn.au

Diggers and Dealers Forum 2006
7 to 9 August
Goldfields Arts Centre
Contact: Suzanne Christie, Diggers and Dealers Mining Forum, PO Box 979, West Perth, WA 6872
phone +61 8 9481 6440
fax +61 8 9481 6446
email admin@diggersndealers.com.au
www.diggersndealers.com.au/

16th Annual V M Goldschmidt Conference 2006
European Association for Geochemistry, Geochemical Society and Geological Society of Australia
27 August to 1 September
Melbourne Exhibition and Convention Centre
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Mining 2006
1 to 3 November
Hilton Brisbane
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AAPG International Conference and Exhibition
American Association of Petroleum Geologists
5 to 8 November
Perth Convention and Exhibition Centre
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13 ARSPC
13th Australasian Remote Sensing and Photogrammetry Conference
20 to 24 November
National Convention Centre, Canberra
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