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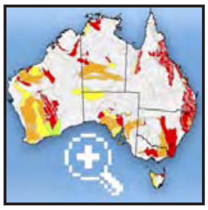

In the 2005-2006 Federal Budget handed down on May10, the Government announced an important new initiative that will have a significant impact on Geoscience Australia.

The initiative is the Australian Tsunami Warning System. It will contribute to an Indian Ocean Tsunami Warning System (IOTWS) and will integrate with the existing Pacific Tsunami Warning Centre to facilitate warning to the South West Pacific region.

The Government is providing funding of $68.9 million over four years for the system, which will be jointly operated around-the-clock by Geoscience Australia and the Bureau of Meteorology, with Emergency Management Australia handling the public awareness and disaster response aspects of the system.

The purpose of the Australian Tsunami Warning System is to:

- reduce loss of life in the event of a tsunami affecting the Australian coast,
- mitigate tsunami risks for operations at sea and in coastal waters, and
- reduce the impact of tsunamis on essential infrastructure in our coastal regions.

One of Geoscience Australia's main roles is the provision of precompetitive geoscientific information to encourage investment in mineral exploration in Australia. A significant part of this work is undertaken with the State and Territory geoscience agencies under the National Geoscience Agreement. The work is augmented through Geoscience Australia's participation in two Cooperative Research Centres—Predictive Mineral Discovery (pmd*CRC) and the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME)

In this issue we report on a number of the recent outputs of our minerals-related studies. One, conducted jointly with the Northern Territory Geological Survey (NTGS), is the recently released NTGS Report 18 "Gold mineral systems of the Tanami region". It is a study of the genesis and geological controls on lode gold deposits in the Tanami region, one of Australia's significant gold producing areas. In another article, again on the Tanami, we report further on how three-dimensional inversion modelling of gravity and magnetic data can be used to construct better 3-dimensional geological models to improve our understanding of Australia's regional geology and its mineral potential.

Also reported in this issue are the results of two studies arising from our participation in the minerals-focussed Cooperative Research Centres. One, from pmd*CRC, presents new geochronological results from the Mt Isa Province, one of Australia's most important mineral-producing areas. The new work further refines our understanding of the province's geological framework and will further focus future mineral exploration models for the area.

Geochemical exploration tools remain important in Australia and new work within CRC LEME is intended to underpin the development of a national baseline geochemical information layer. In a country as large and diverse as Australia, an initial step in developing this layer is the pilot testing of geochemical survey methodologies in representative regions displaying contrasting topographic, drainage and climatic conditions. In this issue of AusGeo News we report on the first of these pilot projects which was conducted in the Riverina area of southern New South Wales and northern Victoria.

The tragic 2004 Boxing Day Sumatran earthquake and tsunami has again reminded us all of the great damage that can be caused by earthquakes and other natural geohazards. Robust earthquake risk assessments depend on a sound knowledge of an area's seismicity, and this is often difficult to obtain because earthquakes are infrequent on the scale of the human life times. The geological record can help overcome this problem and we report in this issue on evidence from southwest Western Australia, gathered using new technologies, which indicates the occurrence of many prehistoric earthquakes that would have been comparable in size to the Magnitude 6.9 Meckering earthquake that shook the region in 1968. The insights gained from these new approaches will help mitigate earthquake risk through the development of better and safer regional building codes.

In closing I'd like to thank all those subscribers who have provided comments on the first two issues of AusGeo News to appear in its new electronic format. Your feedback is very much appreciated and is vital to the ongoing improvement of AusGeo News to better meet your needs.

Comment

NEIL WILLIAMS
CEO Geoscience Australia

GEOSCIENCE AUSTRALIA'S ROLE IN THE *Australian Tsunami Warning System*

Federal government initiative to provide a warning system for future tsunamis.

Phil Cummins

In the 2005-2006 Federal Budget handed down on 10 May the Australian Government announced the creation of the Australian Tsunami Warning System (ATWS). The ATWS will play a major role in the operation of an international tsunami warning system for the Indian Ocean. The system will also serve to warn Australians of tsunamis that may impact our coasts, both east and west, as well as provide leadership for regional tsunami warning in the southwest Pacific.

The Australian Government will provide funding over the next four years for the ATWS which will be jointly operated around the clock by Geoscience Australia and the Bureau of Meteorology, with Emergency Management Australia handling the public awareness and disaster response aspects of the system.

How Geoscience Australia will contribute

Geoscience Australia's main role will be to provide a monitoring and analysis capability that can rapidly detect earthquakes in the region with the potential to generate tsunamis ('tsunamigenic' earthquakes). When such an event occurs, Geoscience Australia will work with the Bureau of Meteorology to verify that a tsunami has been generated and assess what impact it might have. The Bureau of Meteorology already has in place much of the infrastructure for broadcasting the warnings and so ATWS will make use of this existing infrastructure.

Geoscience Australia will also bring to bear its well-established strength in risk assessment for other hazards such as earthquakes, floods and storm surges in order to improve the overall effectiveness of the ATWS. In addition Geoscience Australia and the Bureau of Meteorology, together with Australian Agency for International Development (AusAID), will have important roles in providing overseas technical assistance and training to build in-country capacity in both the Indian Ocean and the southwest Pacific regions.

International and regional cooperation

For the ATWS to work it is important to integrate with the international effort and with the Pacific Warning Centre.

The international groundwork for ATWS's contribution to an Indian Ocean system has already been laid at meetings of UNESCO's Intergovernmental Oceanographic Commission held in Paris and Mauritius earlier this year, at which representatives of the Department of Foreign Affairs and Trade, the Bureau of Meteorology and Geoscience Australia consulted with their counterparts from other Indian Ocean countries. An international role for ATWS in the southwest Pacific will build on initiatives already planned for this region in consultation with the AusAID and the South Pacific Applied Geoscience Commission.

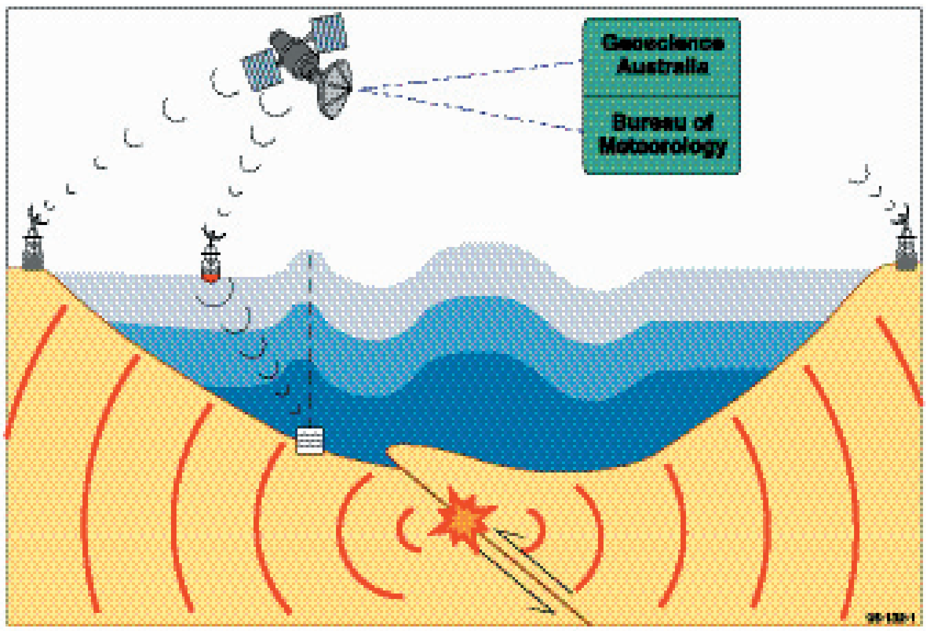

Figure 1. An undersea earthquake causes displacement of both the seafloor and the sea surface, and the spreading out of seismic waves (in red). The disturbance in the sea surface radiates outward as a tsunami, which travels much slower than the seismic waves. Once the seismic waves are detected by distant (usually land-based) seismometers, sea-level data from coastal tide gauges or DART buoys are analysed to determine whether a tsunami has actually been generated.

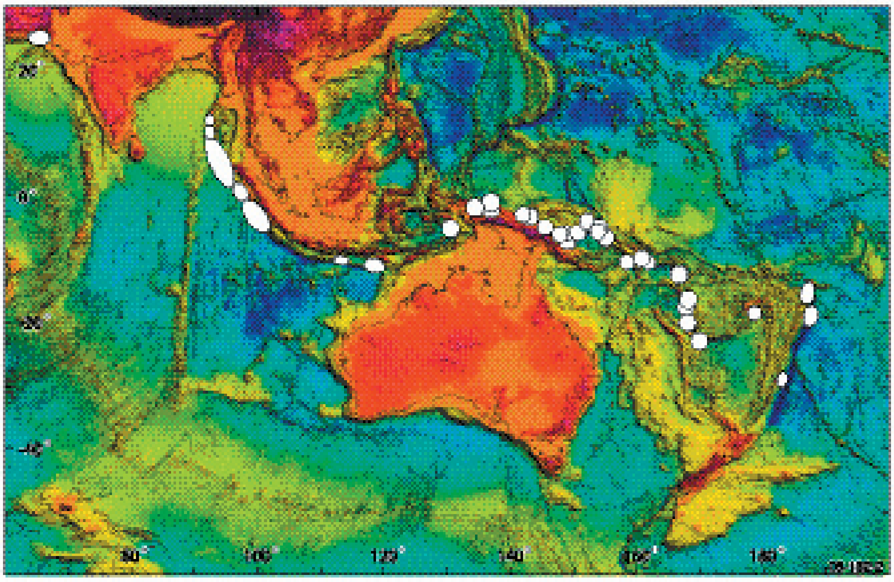

Figure 2. A map of the earth's surface, showing the major tectonic plate boundaries and locations of historic tsunamigenic earthquakes. The tsunami threat to the region originates from the system of subduction zone plate boundaries (also known as ocean trenches) extending through Indonesia, New Guinea, Vanuatu, Fiji and the trench systems to the north and south of New Zealand.

The ATWS proposal involves four major components:

- a monitoring capability
- an analysis capability leading to the ability to issue an alert
- a communication capability to broadcast the alert
- trained emergency response personnel and an educated public.

The science behind the system

All tsunami warning systems are based on the idea that most tsunamis are caused by earthquakes, and since the seismic waves generated by earthquakes travel much faster than the tsunamis, tsunamigenic earthquakes can be detected long before the arrival of the tsunami (figure 1). Most undersea earthquakes do not generate tsunamis, however. If tsunami warnings were based on earthquake occurrence alone, there would be so many false alarms that people would soon lose confidence in the warning system. For this reason, direct monitoring of sea-level data is required after a large earthquake, in order to verify that a tsunami has actually occurred.

The monitoring components of a tsunami warning system therefore consist of a seismographic network for monitoring earthquakes, to be operated by Geoscience Australia, and a network of sea-level monitoring stations, to be operated by the Bureau of Meteorology. The sea-level network will include several 'DART buoys', which are sophisticated systems used to measure tsunami heights in the open ocean. The operations centres of both agencies will receive data from all of these observation platforms, and 'mirrored' analysis systems will be maintained at Geoscience Australia's headquarters in Canberra and the Bureau of Meteorology's operations centre in Melbourne.

The ability to rapidly detect and characterise as potentially tsunamigenic any large earthquake in the Australian region will require a substantial expansion in Geoscience Australia's current earthquake monitoring and analysis capability, which has hitherto been focused on the comparatively small and infrequent earthquakes that occur in Australia.

Warnings in real time

As illustrated in figure 2, earthquakes that cause tsunamis occur near the system of ocean trenches that surrounds Australia from the northwest off Sumatra, eastward along the Indonesian archipelago to New Guinea and the Pacific islands, and then down the Kermadec Trench to south of New Zealand. Tsunamis generated in these trenches can reach Australia within two to four hours, so earthquakes must be detected and characterised within minutes in order to time for a warning to be effective.

Rapid and accurate analysis of earthquakes in these source zones will require a network of seismographic stations that provides adequate coverage of the source zones and transmission of data to Geoscience Australia's analysis centre in real time. The seismographic network envisioned for ATWS is composed of a combination of new and existing stations, some owned and maintained by Geoscience Australia and others shared with international partners in the region.

Coordination critical

The operations centre responsible for analysing this data at Geoscience Australia will require a sophisticated and robust information technology and communications infrastructure, and will be staffed round the clock. Establishing such a facility is a fundamental change in course for Geoscience Australia, and will require some changes from the way Geoscience Australia has operated in the past. Close coordination of our activities with the Bureau of Meteorology and liaison with other tsunami warning systems in the region will be critical to the success of ATWS.

The scientific role played by Geoscience Australia and the Bureau of Meteorology will assist Australia's initiative to contribute to the establishment of a durable and effective tsunami warning system in the Indian Ocean and southwest Pacific regions as well as providing a warning system for Australia. It also represents a dramatic expansion in Geoscience Australia's efforts to work with our neighbours in the Indian and Pacific oceans to apply expertise in geoscience to problems of concern to all countries in the region.

It is only through efforts such as these that we will in future be better placed to reduce the terrible loss of life that can be caused by major geologic upheavals, such as the earthquake and tsunami of Boxing Day 2004.

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New results on natural hazards in PERTH

A major assessment of natural hazard risk for Perth has been completed in collaboration with federal, state and local agencies.

Cities Project Perth provides authoritative new knowledge on the risks from the sudden onset of natural disasters in Australia's fourth largest city.

Perth's major hazards

The study area covered greater metropolitan Perth (figure 1). Major natural hazards considered in the project included:

- flood hazard in the Swan River and its tributaries
- severe wind hazard in metropolitan Perth
- earthquake risk in metropolitan Perth and the earthquake hazard in the wheatbelt up to 200 kilometres from Perth
- the susceptibility of the southwest coastline, including Perth beach suburbs, to sea level rise from climate change
- potential tsunami impacts on the coastline

The project also investigated socioeconomic factors that might affect the capacity of Perth citizens to recover from natural disasters, and compared WA with other Australian states.

Work included the preparation of more than a dozen major spatial databases and risk assessment models, including the flood hazard model and comprehensive building and building footprint databases, digital elevation models and GIS hazard maps.

Key findings

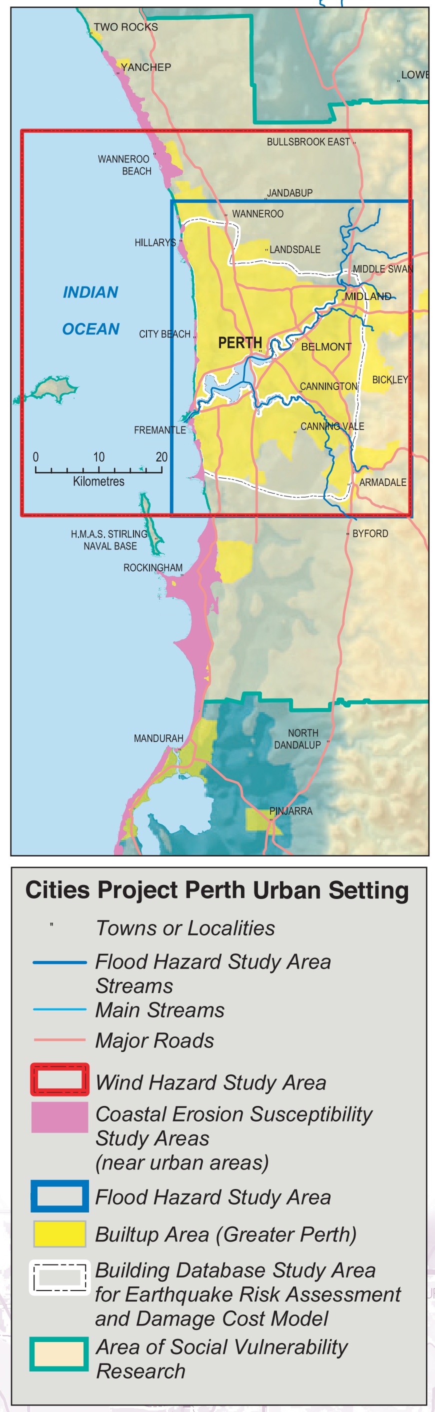
- Cool season storms and tropical cyclones that move southwards, often with associated bushfires, have caused southwest WA's highest natural hazard insurance losses in the past. Cities Project Perth found that communities with high exposure to wind, such as coastal communities, face a measurably higher wind hazard than current building codes describe.
- More wheatbelt communities have been included in an enlarged earthquake source zone east of Perth, rating them at higher hazard than described in the current earthquake loadings standard.
- Potential losses from earthquakes are considerably higher than estimates of historical costs of earthquakes in WA.
- Eight flood scenarios have been modelled for the Swan River, with annual exceedance probabilities ranging from 0.05% to 10%. That is, the most probable scenario event modeled had flood levels with a likelihood of one in ten (or 10%) of being exceeded in any one year. The rarest scenario modeled had flood levels with a likelihood of one in 2 000 (or 0.05%) of being exceeded in any one year.
- As the Perth metropolitan area has a high number of households with relatively high economic resources, a large majority of households in the area would be able to draw on their own economic resources to assist recovery after a natural disaster. However, households in some areas could find the recovery process hard because of limited financial capacity.
- WA's strong community network will be a positive source of support in managing recovery from natural disasters.

Participating agencies

Many WA and local government agencies participated in the four-year project. They continue to play a key role as custodians of the project's models and data and by implementing policy and practice based on the results. Our core partners were the WA Fire and Emergency Services Authority, the WA Department for Planning and Infrastructure, the WA Department of Environment, and the Bureau of Meteorology's WA Regional Office.

The Cities Project Perth report will be launched in Perth on 8 June by Parliamentary Secretary Warren Entsch, and a half-day workshop for local and regional emergency managers and other stakeholders will be held to discuss the results and their implications for Perth.

The report can be ordered from www.ga.gov.au/sales. The full report will be also available for download on the Geoscience Australia website.



▲ **Figure 1.** The study areas for Cities Project Perth.

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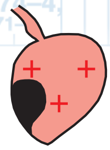
New data on rock ages from Mt Isa Inlier



A new geological event framework has been produced for 1800–1650 million year old rocks from the Western Fold Belt of the Mount Isa Inlier

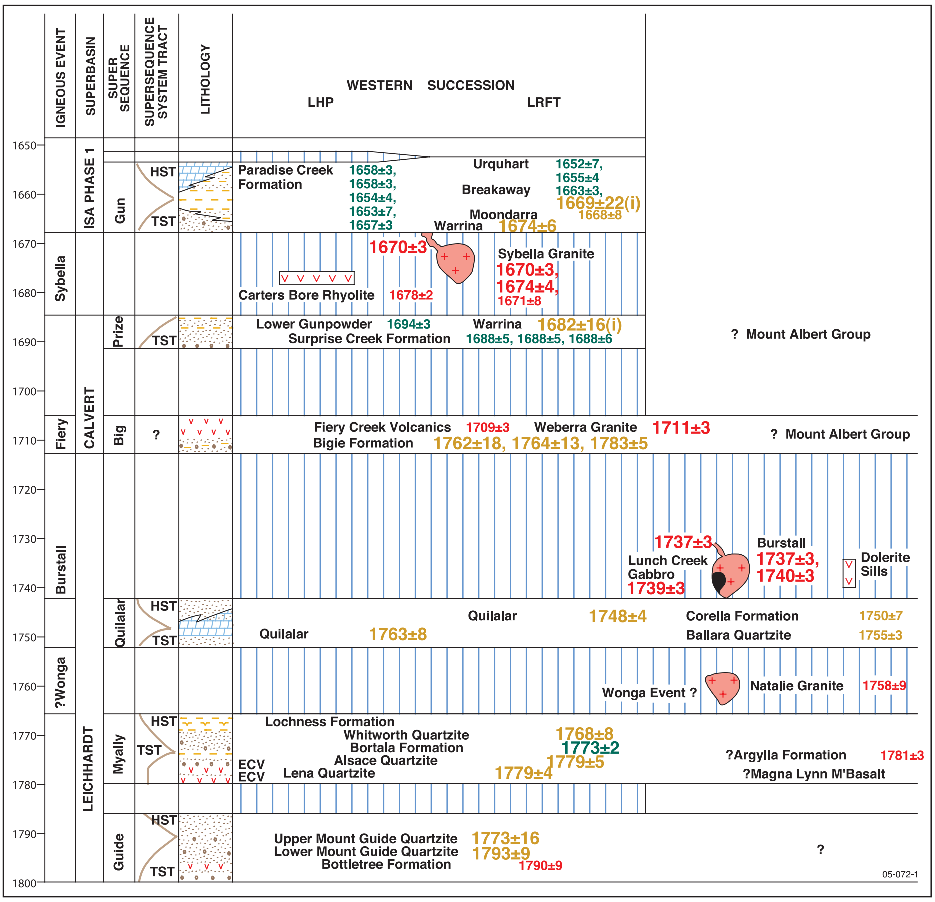
Narelle Neumann, Peter Southgate, Avon McIntyre and George Gibson

The Mount Isa Inlier is one of many Australian Proterozoic terrains with a complex but periodic history of sedimentation, magmatism, tectonism, metamorphism, mineralisation and fluid flow through time.

Geochronological data collected using a sensitive high-resolution ion microprobe (SHRIMP) can be used to determine the age of these rocks and develop an event framework for geological regions. New SHRIMP geochronology undertaken within the Regional Studies and Geochronology group of the Minerals Division of Geoscience Australia, in collaboration with the Predictive Mineral Discovery Cooperative Research Centre's (pmd*CRC) Isa project, has:

- produced a temporal framework for the Leichhardt and Calvert Superbasins
- constrained ages for selected magmatic events in the Western Fold Belt and the Mary Kathleen Zone
- used detrital zircons to test the Gun unconformity at the base of the Isa Superbasin.

The project included collection and interpretation of 29 new U–Pb zircon SHRIMP ages, 20 from sedimentary rocks and nine from igneous rocks. It combined regional sequence stratigraphy and structural analysis with geochronology to produce a new temporal framework for the Leichhardt and Calvert superbasins.



New age constraints

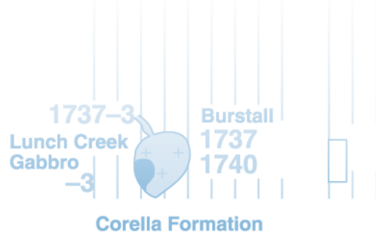
Previously, the only age constraints on the timing of sedimentation for the Leichhardt and Calvert Superbasins were a U–Pb conventional age for the base of the stratigraphy (Bottletree Formation) of 1790 ± 9 Ma (Page 1983), a SHRIMP U–Pb zircon age of 1709 ± 3 Ma for the Fiery Creek Volcanics (Page & Sweet 1998) and several SHRIMP ages from shallow level intrusives in the Surprise Creek Formation at the top of the Calvert Superbasin (Jackson et al 2005).

Although unconformities have previously been identified within the Leichhardt and Calvert sequences, no time constraints have been placed on the time-significance of these intervals of missing rock record.

The new chronostratigraphic event chart for the interval from ~1800 Ma to 1650 Ma (figure 1) recognises three supersequences in the Leichhardt Superbasin:

- The Guide Supersequence spans the interval ~1800–1785 Ma and includes the Bottletree Formation and Lower and Upper Mount Guide quartzites.
- The overlying Myally Supersequence spans the interval ~1780–1765 Ma and includes the Eastern Creek Volcanics, Lena, Alsace and Whitworth quartzites, and Bortala and Lochness formations.
- The Quilalar Supersequence spans the interval ~1755–1740 Ma and includes the Quilalar and Corella formations and the Ballara Quartzite.

◀ **Figure 1.** New event chart for the Leichhardt and Calvert superbasins of the Western Fold Belt and Mary Kathleen Zone, Mount Isa Inlier. Ages in Ma. Colour code for ages: red = magmatic crystallisation age, brown = sedimentary maximum depositional age, green = sedimentary depositional age. Ages in larger font from this study, ages in smaller font summarised in Page et al (2000) and Jackson et al (2005).



Although there are no new depositional age constraints for the younger Bigie Formation, field relationships suggest that it is coeval with the ~1710 Ma Fiery Event. Therefore, we have defined a separate supersequence for the Bigie Formation, the Big Supersequence, even though it may be more genetically related to magmatism of the Fiery Event. The Big Supersequence, together with the ~1690 Ma Prize Sequence, comprises the Calvert Superbasin.

Magmatic event times refined

New SHRIMP data has also refined ages for the Burstall, Fiery and Sybella magmatic events (figure 1). The ~1740–1735 Ma Burstall Event represents a bimodal, dominantly intrusive event following sedimentation of the Quilalar Supersequence in the Mary Kathleen Zone and the Eastern Succession. The refined age for the Weberra Granite is within error of the age for the Fiery Creek Volcanics, and indicates that they are both part of the ~1710 Ma Fiery Event.

The three new SHRIMP ages for the Sybella Granite are all within error of each other and are coeval with the Carters Bore Rhyolite, indicating that magmatism associated with these intrusives is constrained to 1675–1670 Ma. Slightly younger ages from other units of the Sybella Granite may indicate that intrusive sheets associated with the Sybella Event were emplaced over an extended time, or as a series of discrete magmatic 'pulses' between 1675 and 1655 Ma, associated with and followed by deposition of the Gun Supersequence.

Testing depositional ages from detrital zircons in sedimentary rocks

Detrital zircons have also been used to characterise the Gun unconformity at four locations in the Leichhardt River Fault Trough. Detrital zircons in sedimentary units overlying the Gun unconformity at the Oxide Creek and Bull Creek sections provide maximum depositional ages of 1674 ± 6 Ma and 1672 ± 15 Ma, consistent with the age constraints of ~1660 Ma provided by peperites for deposition of the basal Gun Supersequence highstand.

These examples suggest that samples taken directly above regional unconformity surfaces can be used to constrain depositional ages for supersequences. However, in the other two sections the small numbers of young grains, or absence of younger populations, may mean that the maximum depositional ages calculated from detrital zircons are substantially older than the actual age of deposition.

Therefore, it is crucial that maximum depositional ages calculated from sedimentary units be integrated with sequence stratigraphy and basin analysis in Proterozoic basins to construct detailed chronostratigraphic event charts.

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~1800 Ma

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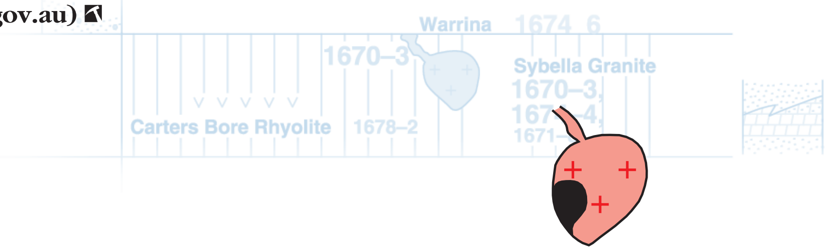

WA rocked IN THE OLD DAYS

South and central west Western Australia experienced major earthquakes in prehistoric times

Dan Clark

New technology used to identify earthquake hotspots so that safer regional building codes can be developed has found evidence that many earthquakes comparable to the 1968 M6.8 Meckering event—the second largest onshore quake recorded in Australia—affected southwest Western Australia in prehistoric times.

Finding fault scarps in a wide open land

Since European settlement, most areas of Australia have not experienced the largest possible earthquake because large quakes occur in cycles of 20 to 40 thousand years or more on a given 'active' Australian fault. Our 100–200 year historic record of seismicity is therefore poorly suited to inform assessments of seismic hazard.

Finding active faults and trenching them is the only viable way to obtain data on the locations and recurrence intervals of large, destructive earthquakes. However, fault scarps are subtly delineated and difficult to recognise in the landscape, and the vastness of the Australian continent has limited the effectiveness of traditional methods to identify these features.

High-resolution digital elevation models (DEM) have recently emerged as an important tool for finding fault scarps. DEMs are well suited to reconnaissance over large or remote areas, and are also useful for defining and mapping areas of probable elevated earthquake hazard.

Thirty-three new Quaternary fault scarps

Examination of a 10-metre resolution DEM supplied by the Western Australian Department of Land Information (http://www.landmonitor.wa.gov.au) and selected Shuttle Radar Tomography Mission 3 arc-second DEM tiles (http://www2.jpl.nasa.gov/srtm/) has identified 33 previously unrecognised fault scarps of probable Quaternary age in the southwest and central west of Western Australia.

This more than doubles, to 60, the number of Quaternary scarps known from this area (figure 1). The veracity of 17 of the scarps has been validated by ground truthing.

The new features are from about 15 kilometres to over 45 kilometres long, and from about 1.5 metres to 20 metres high. As the 1968 M6.8 Meckering scarp is 28 kilometres long and up to 2 metres high, some of the newly discovered features may have been associated with significantly larger earthquakes, or multiple earthquakes.

Evidence that at least the most recent events occurred during the Quaternary is typically provided by diversion of modern drainage, limited stream incision into a scarp, or disruption of Quaternary sediments.

Most of the scarps where a dip direction has been established by the DEMs show reverse displacement (compression) on the underlying fault (for example, figure 2). This, and the dominant northerly trend of the scarps, is consistent with our knowledge of the crustal stress field, which is thought to be oriented generally east–west and to be compressive.

The roughly uniform spatial distribution of the scarps (figure 1) is also consistent with uniformly distributed deformation across the Yilgarn Craton, which is an important constraint for crustal deformation models. Most of the newly discovered scarps are not associated with historic earthquakes (figure 3), suggesting that the focus for earthquake activity (i.e. crustal deformation) migrates over time and that large earthquakes are episodic within any given area.

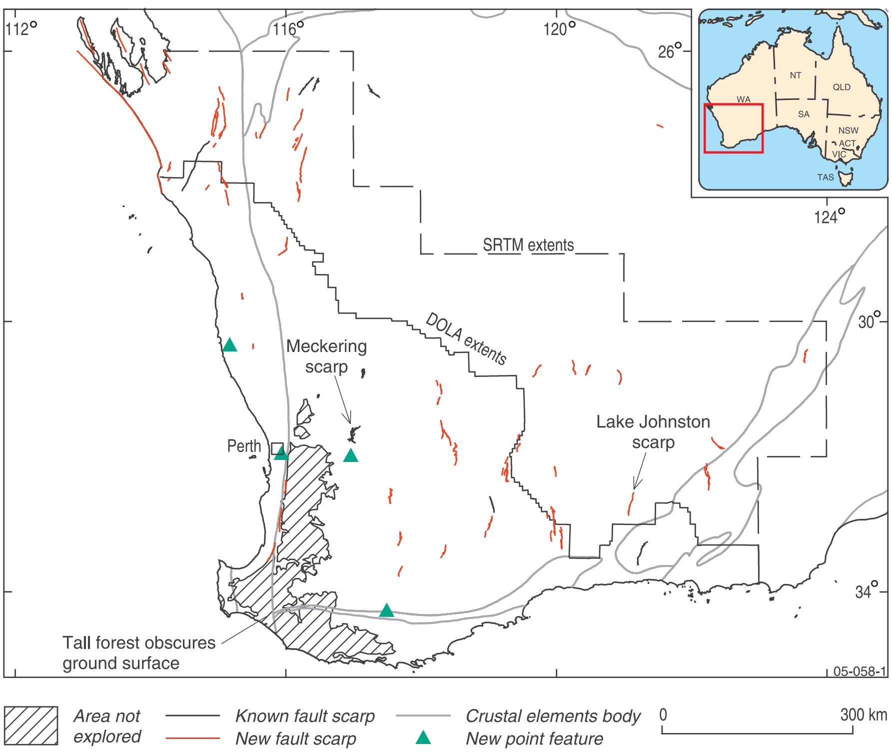

Figure 1. Map of Quaternary tectonic features within the study area (new features are in red).

Implications for intraplate seismic hazard

Information about the recurrence rates of large earthquakes associated with individual scarps is needed to improve the certainty of seismic hazard assessments for short return periods (e.g. the one-in-475 year event in the current hazard map, figure 4a). However, the fault scarps presented here identify 'earthquake-prone' regions (forming, in effect, an earthquake 'hotspot' map, as in figure 1) that could be used in further investigations.

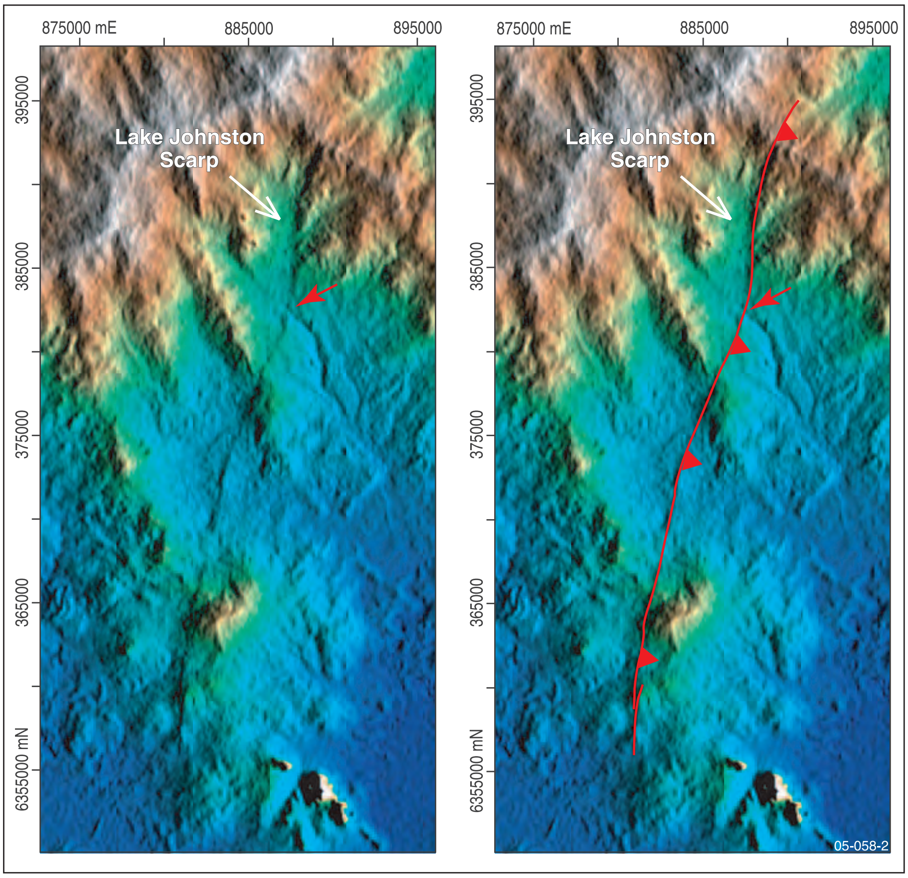

Figure 2. SRTM DEM over the 40 km long and up to 8 m high Lake Johnston scarp. Image on right shows interpretation of the fault. Red arrow marks a point where a stream has cut into the scarp. Illumination is from the east.

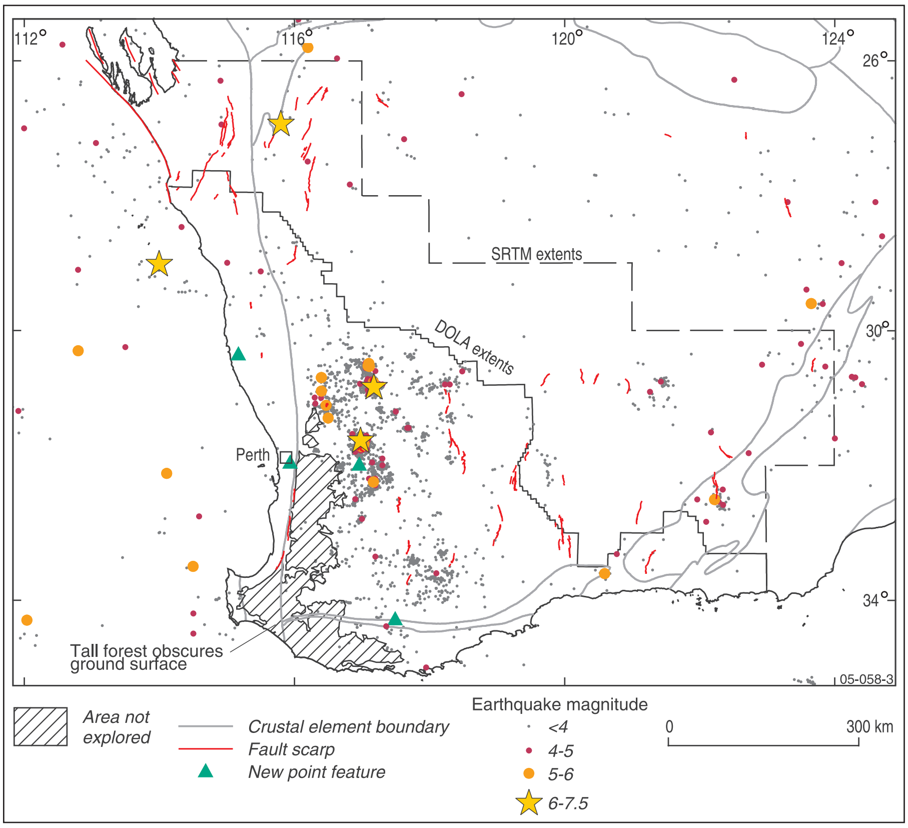

Figure 3. Comparison of Quaternary scarps and earthquake epicentres. Note that most scarps are not associated with earthquakes.

The hotspot map may be suitable for immediate application to hazard assessments for longer return periods, such as the tens of thousands of years scale required for dam siting and design.

A schematic hazard map (figure 4b) for a return period equivalent to the average recurrence interval for large earthquakes on a typical WA intraplate fault is based on the new DEM data. The map was created by constructing areas of potentially damaging ground-shaking around each scarp and basing their size on the Meckering event.

However, it must be stressed that because recurrence information exists for only a handful of scarps in Australia, and the return periods obtained vary from tens to hundreds of thousands of years, an exact return period cannot yet be set for figure 4b. Furthermore, it might be expected that ground-shaking would be significantly more intense than 0.1 g proximal to a scarp in the event of a large earthquake.

Acknowledgments
We thank the WA Department of Land Information and the contributors to the SRTM dataset (most notably NASA) for providing their data.

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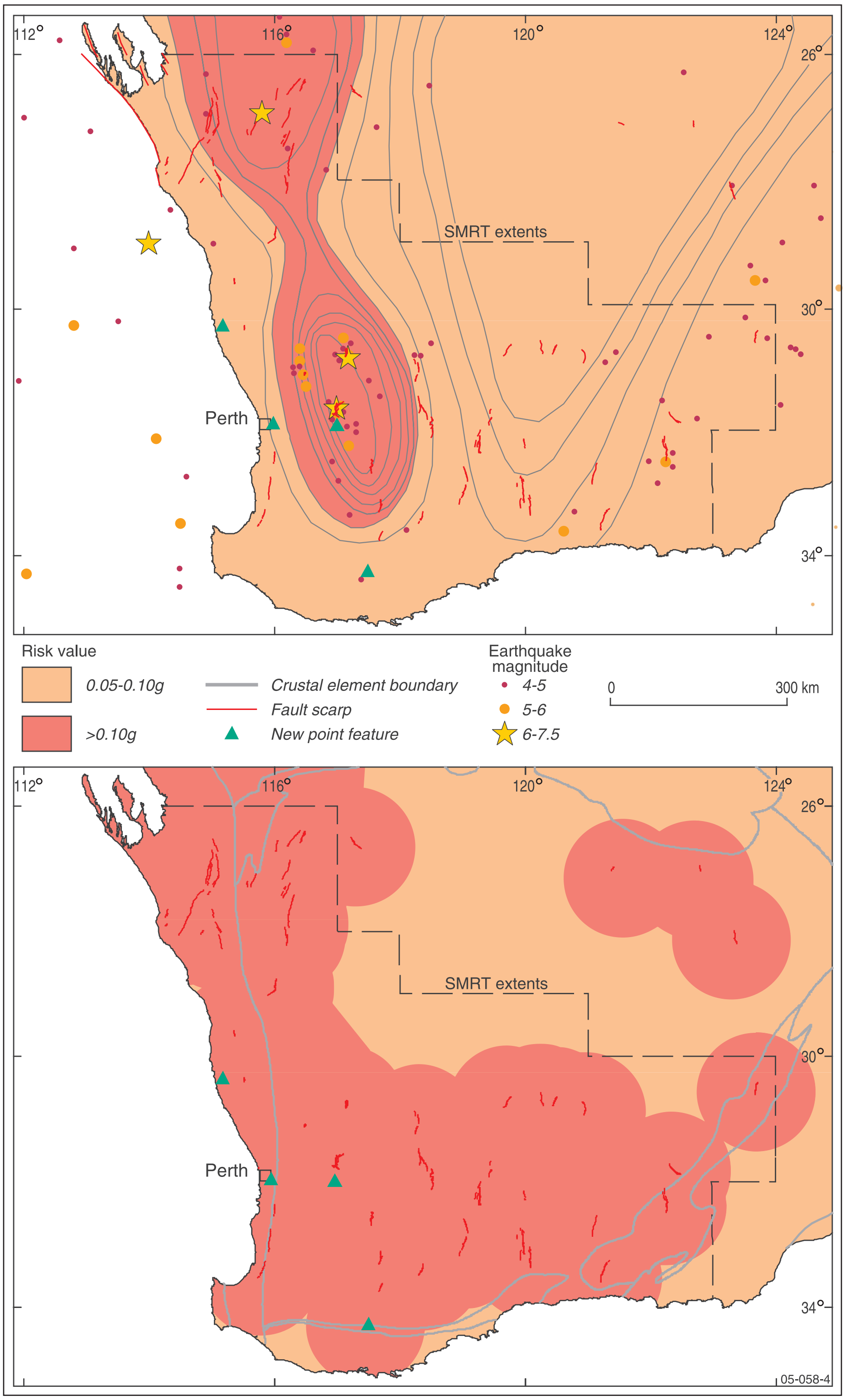

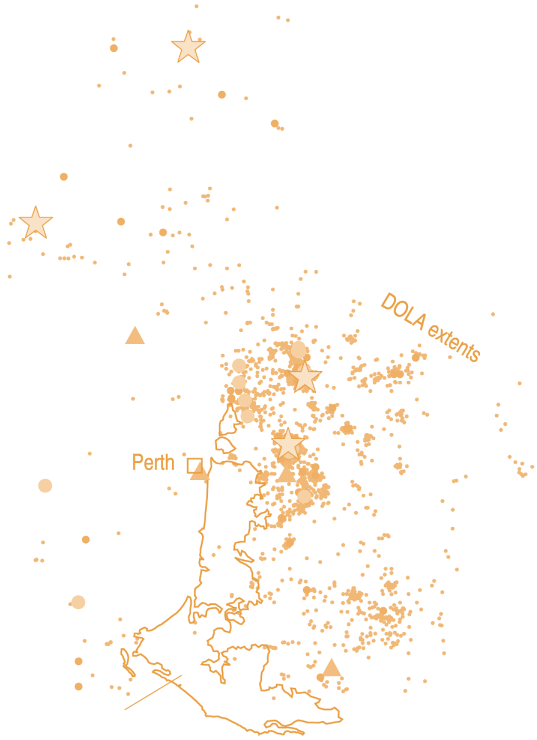

Figure 4. Earthquake hazard maps. a) Current hazard map with contours of ground acceleration as a proportion of g for a one-in-475 year event. b) Schematic hazard map for a return period equivalent to the average recurrence interval for a large earthquake on an Australian intraplate fault.

RIVERINA GEOCHEMICAL SURVEY

a national first

Patrice de Caritat, Megan Lech, Subhash Jaireth, John Pyke and Ian Lambert

Baseline geochemical surveys have been conducted for most developed countries, but not yet for Australia. In a country as large and diverse as Australia, an initial step in the development of a national low-density geochemical map needs to be the pilot testing of geochemical survey methodologies in representative regions displaying contrasting topographic, drainage and climatic conditions.

Undertaken collaboratively by the Cooperative Research Centre for Landscape Environments and Mineral Exploration (CRC LEME) and Geoscience Australia, the first such pilot project has been completed in the Riverina, a prime agricultural Riverina region in southern New South Wales and northern Victoria. A second pilot study has commenced in the remote, flat, dry Gawler Craton of South Australia, where there is very limited stream drainage.

The Riverina survey has delivered cost-effective, internally consistent and quality-controlled data on the inorganic chemical composition of surface and subsurface sediments of large catchments in the region

The resulting geochemical maps show concentrations of 62 elements. Independent data on the distribution of radioactive elements potassium, thorium and uranium corroborates the findings, clearly indicating that the methodology works.

This multi-element geochemical data layer will be made available to decision makers, catchment management authorities, farmers, mineral explorers and other stakeholders to guide activities and decisions in a multitude of land-use and resource management applications.

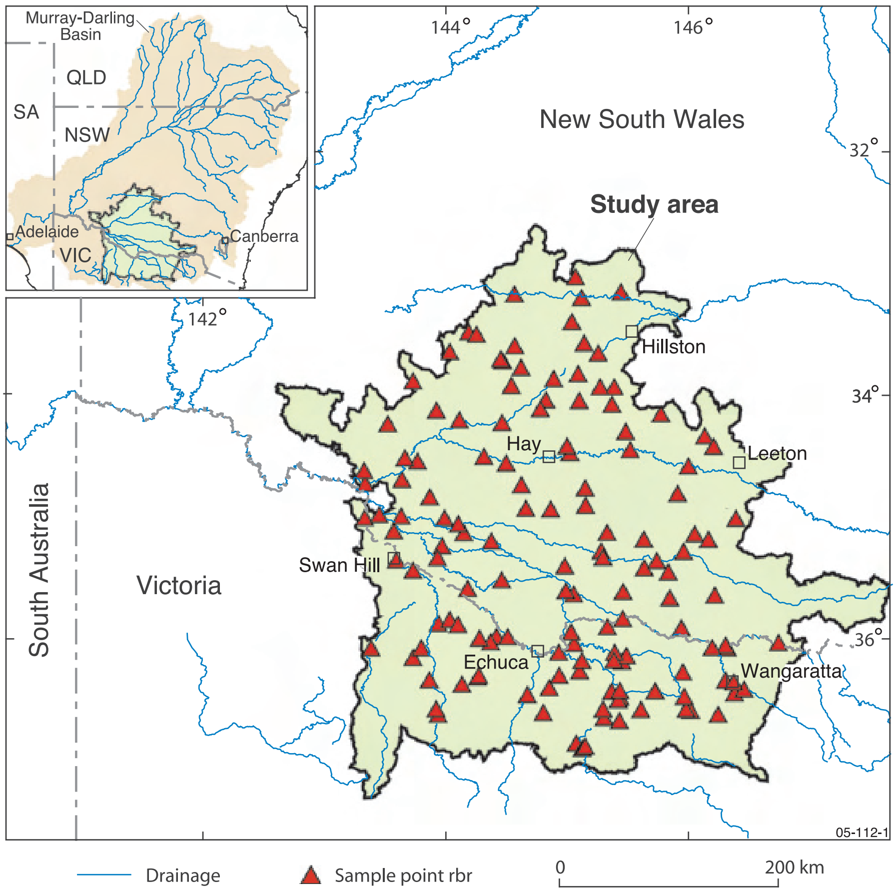

Figure 1. Location of the Riverina study area and sampling sites.

Among a range of findings, the survey identified:

- patterns of calcium and chlorine levels with implications for soil acidity and salinity
- patterns of arsenic and antimony dispersion from known gold mineralisation
- concentrations of some elements above or below national and international guidelines for agricultural soils.

The Riverina survey was designed to prove the value of geochemical mapping and to fine-tune sampling and analytical protocols for a well drained region with modest relief and temperate climate.

Why geochemical mapping?

Australia's regolith—the blanket of soils, sediments and weathered rocks covering fresh bedrock—is the natural resource upon which our multimillion dollar agricultural industry is based. It also hosts much of our precious groundwater resources and contains or covers ore bodies vital for our economic development.

Baseline geochemical surveys provide invaluable information about the natural concentrations of chemical elements in this substrate on which we live, grow crops and raise livestock, and from which we extract water, raw materials and mineral wealth.

Overseas data collated from multimedia and multi-element geochemical surveys carried out over large areas indicates that natural concentrations of chemical elements in water, sediment, soil and plants vary spatially by up to several orders of magnitude due to geological, climatic, biological and other factors (Reimann & Caritat 1998).

It is important to know the natural concentrations and distributions of elements in the near-surface environment so that:

- baselines can be established against which future changes can be quantified
- appropriate and responsible land-use policies can be formulated
- localised contamination can be identified and better remediated
- new mineral potential can be recognised
- local salinity stress can be detected and better understood
- areas for mineral exploration can be selected
- potential geohealth risks can be identified
- comparative suitability of particular land uses can be assessed.

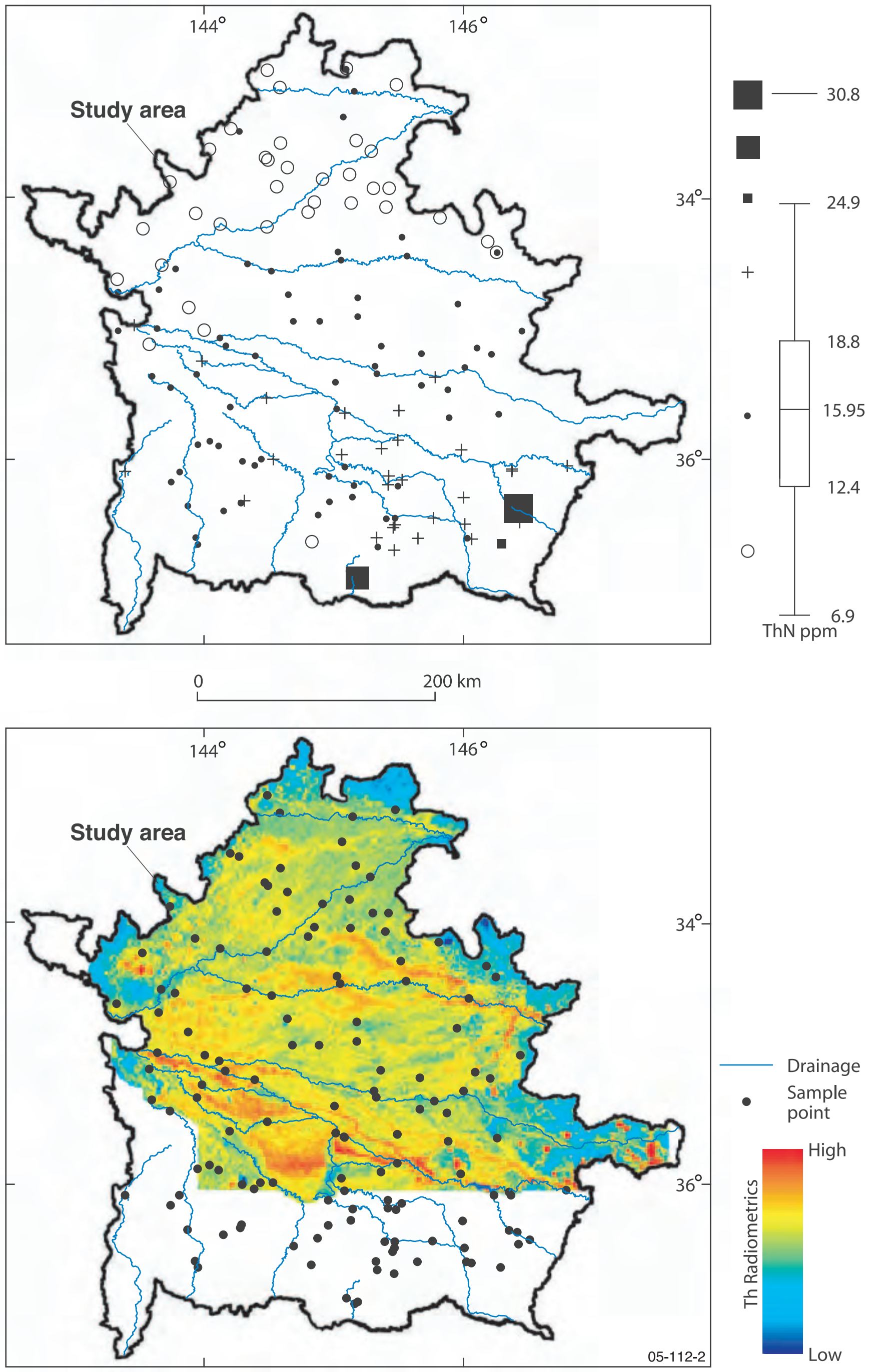

Figure 2. Geochemical map of total thorium (ppm) in TOP Riverina overbank sediment samples (analysed by INAA) (a), compared to airborne gamma-ray distribution of thorium (b).

Low-density geochemical mapping

Based on experience elsewhere (e.g. Reimann et al 1998), a multimedia sampling strategy cost-effectively yields information about sources, sinks and pathways of chemical elements in the near-surface environment.

The main sampling medium used for the Riverina survey was overbank (levee or floodplain) sediments near outlets from large drainage basins or catchments. As this material accumulates during active widespread erosion related to flooding episodes, it is judged to best represent the average lithological input of whole catchments (Ottesen et al 1989). Deposited outside main drainage channels onto floodplains, this fine-grained sediment has an enhanced propensity to host adsorbed and absorbed chemical species.

We believe that this sampling medium is ideal for Australia's low-relief, regolith-dominated landscapes in tropical to arid climates. It had not previously been used here for low-density geochemical mapping and needed to be tested under local conditions. Other sampling media trialled in the Riverina pilot project were plant leaves and groundwater, which will be discussed in forthcoming reports.

The concept of low-density sampling for geochemical mapping has been around for a long time (Nichol et al 1966, Garrett & Nichol 1967, Reedman & Gould 1970) and has recently experienced renewed interest in Europe (Reimann et al 1998, 2003), the United States (Gustavsson et al 2001) and China (Li Jiaxi & Wu Gongjian 1999), for instance. Darnley et al (1995) have suggested a framework for global geochemical mapping, and the sampling media selected include overbank sediments. Sampling densities used for geochemical surveys elsewhere range from high (~1 sample/1 km2) (e.g. Austria: Thalmann et al 1989) to 'ultra low' (~1 sample/1000 to 10,000 km2) (e.g. Europe: Plant et al 2003, Reimann et al 2003).

The Riverina region

For the purposes of the pilot project, the Riverina was defined as the 123,000 km2 area encompassing catchments that are wholly or partly contained within the Riverina Bioregion (figure 1; see Lambert et al 1995 for bioregion concept).

The Riverina is part of the Murray–Darling basin, a significant agricultural, social and mineral district in Australia, which:

- covers 1.06 million km2, or 14% of the country's total area
- contains 45% of the Australian crop area and 43% of the total number of farms
- is Australia's most important agricultural region, accounting for 41% of the nation's gross value of agricultural production
- is an important provider of resources such as wheat (34% of national production), cotton (96%), dairy products, rice and grapes
- is home to nearly two million people, or 11% of the total Australian population.

Sampling and analysis

The Riverina was the focus of a recent airborne geophysical data acquisition initiative led by the New South Wales Department of Primary Industries, which resulted in new digital elevation model, airborne gamma-ray and total magnetic intensity data coverages (NSW DPI 2005).

Theoretical sample sites were located by conducting a hydrological analysis of the digital elevation model to determine the lowest point in large river catchments (see Caritat et al 2004). These sample sites were carefully adjusted in the context of drainage and road/track coverages and field considerations such as land accessibility, landscape position and possible anthropogenic interferences. A total of 142 sample sites were selected near outlets or spill points of large catchments, yielding an average sampling density of one sample per 866 km2.

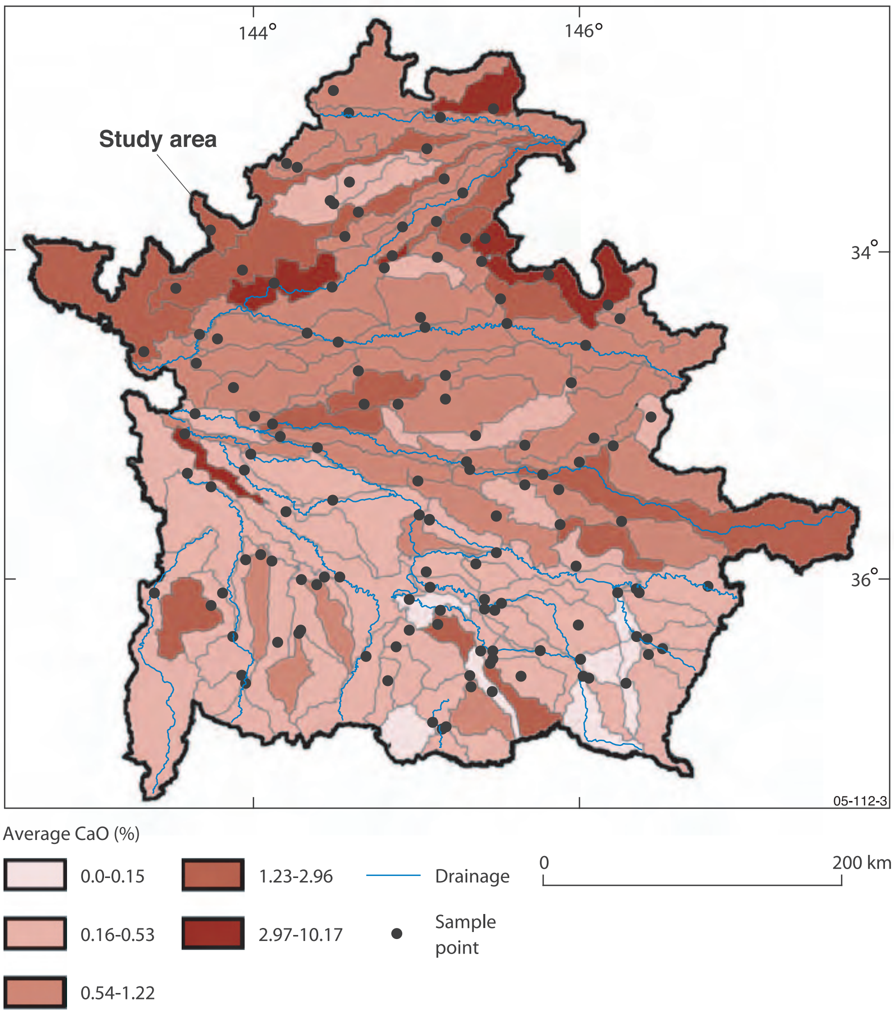

Figure 3. Geochemical map of total calcium (ppm) in BOT Riverina overbank sediment samples (analysed by XRF).

Two sediment samples were taken at each site:

- a near-surface overbank sediment sample (TOP) from 0–10 cm below the root zone
- a bottom overbank sediment sample (BOT) from a ~10 to 15 cm interval between ~65 cm and 95 cm below the root zone.

All samples were subjected to a detailed site description in the field, where measurements of pH, texture and moist and dry Munsell colours were also taken. In the laboratory, pH 1:5 (solid:water), EC 1:5, moisture content and laser particle size distribution were determined. Sediment splits were dried and sieved to <180 mm then analysed by X-ray fluorescence (XRF), inductively coupled plasma mass spectrometry (ICP-MS) and instrumental neutron activation analysis (INAA) (see Caritat et al 2004).

The concentrations of 62 elements were determined, providing data for maps showing the spatial and statistical distributions in the TOP and BOT samples and of the TOP/BOT ratios (report in preparation).

Results and potential applications

Sampling at upper and lower levels at each site allows for a more detailed understanding of the potential sources of chemical elements in the environment. TOP samples are susceptible to the influence of human activity (e.g. fertiliser use), while BOT samples from well below tilling depth reflect more closely natural background levels.

Median concentrations of most elements were higher in BOT samples, reflecting progressive mineral breakdown during weathering and ensuing mobilisation of soluble products. However, median concentrations of silver, lead, antimony, sulfur, yttrium and most rare earth elements were similar at both depths, while median concentrations of bromine, hafnium, manganese, phosphorus, silicon, zirconium and organic matter were higher in TOP samples.

These variations reflect relative concentration of more resistive minerals (quartz, zircon), precipitation of secondary weathering products (manganese oxyhydroxides), greater concentration of organic matter and perhaps fertilisers, and possibly evaporation of irrigation water near the surface.

As a means of independently evaluating the geochemical patterns obtained through this survey, we compared the geochemical map of thorium in TOP samples with airborne gamma-ray spectrometry patterns for the same element (figure 2). The coincidence of patterns is striking and the geochemical maps are faithful to a high degree of detail, clearly indicating that the patterns are real.

Acidity and salinity

The survey found obvious patterns of calcium and chlorine distribution in overbank sediments which have implications for soil pH and salinity management applications in agricultural soils. Calcium in BOT samples increased from south to north, reflecting the increasing occurrence of carbonate material observed (figure 3). Interestingly, the TOP calcium map shows an east–west ridge of values going through the middle of the study area, with lower values to both the south and the north.

Indicators of gold mineralisation

Arsenic and antimony are well-known pathfinder elements for gold mineralisation. The Victorian goldfields are located immediately to the south of the study area, and the arsenic and antimony distribution maps clearly show a progressive decrease from the southern edge of the area towards the north (figure 4). We interpret this as a representation of mechanical dispersion trains from the source regions to the south and perhaps also concealed sources below shallow basin sediments.

Antimony levels range up to nearly 11 mg/kg, over 20 times the median world soil concentration (Reimann & Caritat 1998). This confirms the anomalous nature of the sediments in the southern part of the study area and highlights the potential for the minerals exploration industry to use such surveys for regional orientation purposes.

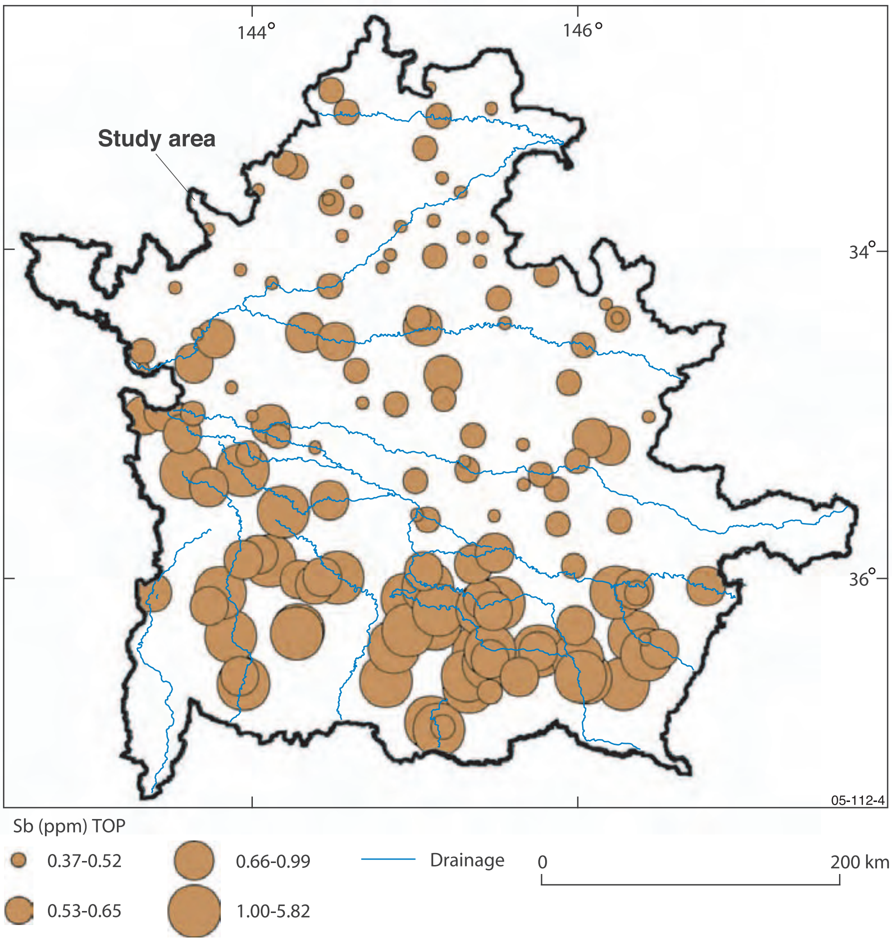

Figure 4. Geochemical map of total antimony (ppm) in TOP Riverina overbank sediment samples (analysed by INAA).

Trace element enrichments and deficiencies

Several trace elements were found to be above or below national and international guidelines for maximum allowable concentrations for agricultural soils, soil remediation and biosolids application. Concentrations of arsenic, barium, bromine, cadmium, chromium, copper, iron, gallium, nickel, antimony, uranium and vanadium were locally elevated above these guidelines. Cobalt, copper and molybdenum were found to be potentially deficient in parts of the region.

Concentrations of chromium increase smoothly towards the south (figure 5). Over half of the overbank samples collected contain more than 50 mg/kg Cr, which is the Western Australian 'ecological investigation limit' (WA DOE 2003). Five samples (max = 162 mg/kg) have elevated values above 100 mg/kg, which is the maximum allowable soil contaminant concentration for application of biosolids to agricultural land (NSW EPA 1997). Two of these samples were from the southern central portion of the study area and were elevated in both TOP and BOT samples. These catchments drain a ridge of Cambrian mafic volcanics. Another possible source of elevated Cr is the Quaternary tholeiitic basalts located near the edge of the Riverina region. While high chromium levels may have human health implications (Reimann & Caritat 1998, Adriano 2001), even the maximum total value in the Riverina is unlikely to yield excessive available Cr based on the results of a study in Italy, which found that <0.1% of total Cr was bioavailable (Maisto et al 2004).

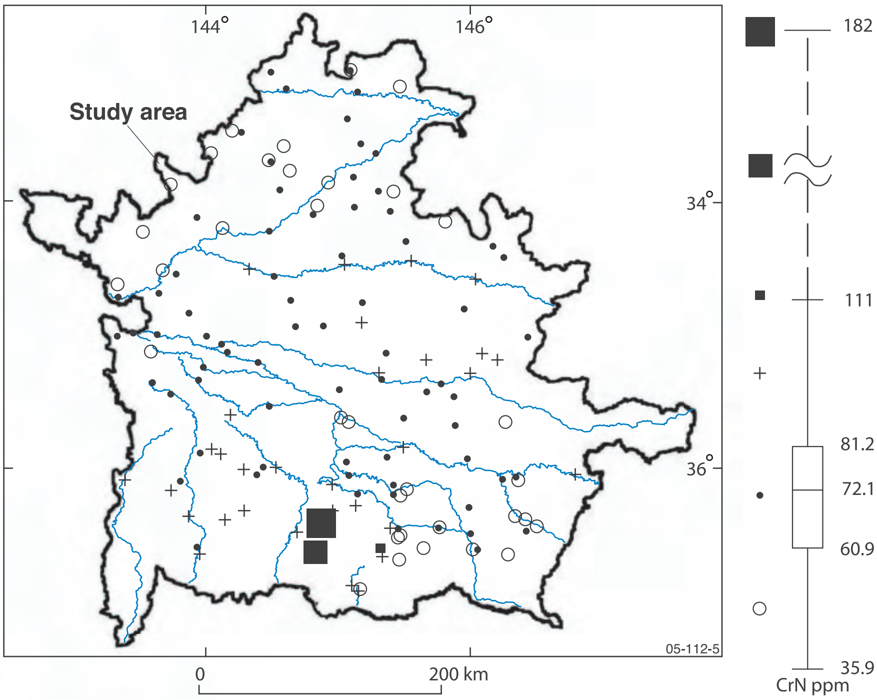

Figure 5. Geochemical map of total chromium (ppm) in BOT Riverina overbank sediment samples (analysed by INAA).

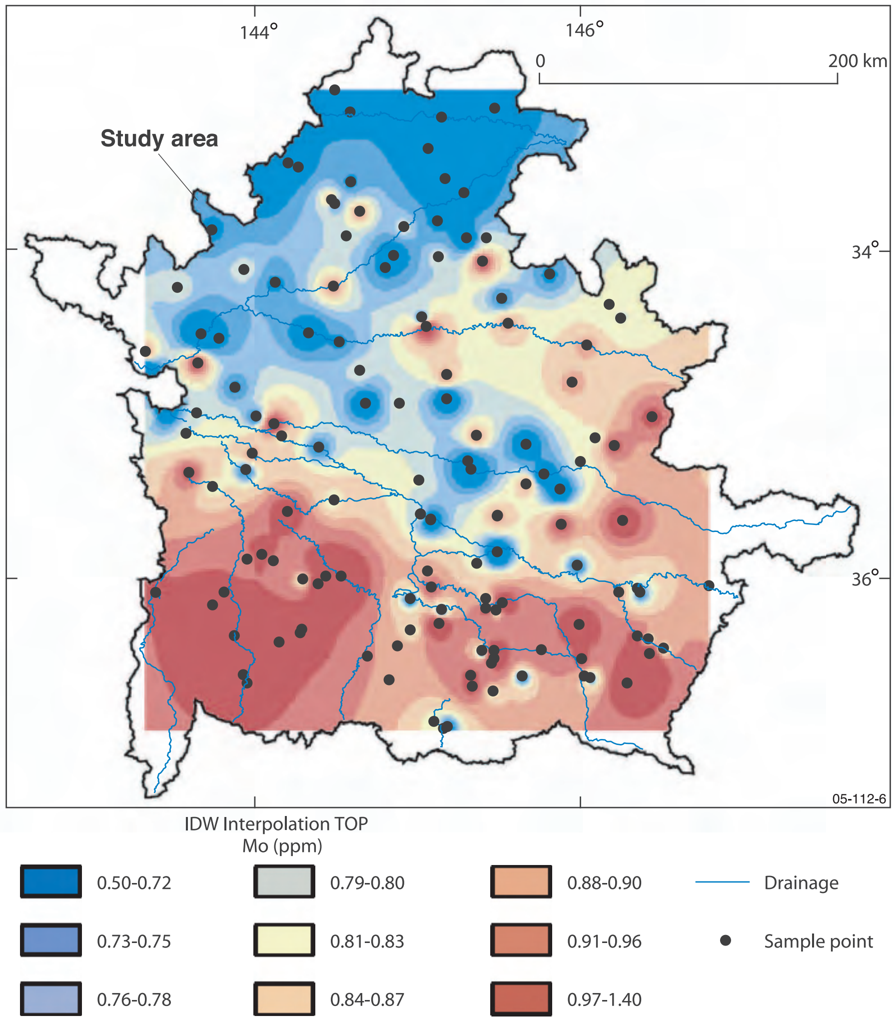

Figure 6. Geochemical map of total molybdenum (ppm) in TOP Riverina overbank sediment samples (analysed by ICP-MS).

Molybdenum is an essential nutrient to many crops. While the global average concentration of molybdenum in soil ranges from 0.2–5 mg/kg (Adriano 2001), the median value in the study area was 0.8 mg/kg. Levels at or below 0.5 mg/kg can be considered low, and those with concentrations of 0.1–0.3 mg/kg can be expected to produce molybdenum deficiencies (Adriano 2001). Six samples from the Riverina survey contained molybdenum concentrations of 0.5 mg/kg amongst 37 samples with concentrations of 0.6 mg/kg or below. There is no obvious pattern to the location of low molybdenum concentrations (figure 6). Molybdenum has lower bioavailability in acid soils, so those in the southeast are more likely to be prone to deficiencies. This corresponds to observations by farmers that soils in the south of the study area were molybdenum deficient and that fertiliser applications reversed this problem (C. Simpson, pers. comm., December 2004).

Conclusions

Australia is one of few developed nations without nationwide baseline geochemical information at the disposal of government, industry, landholders and the general public.

The results of the Riverina survey illustrate how low-density geochemical surveys convey information about regional patterns in soil quality, mineral prospectivity and potential geohealth risk. Ongoing interpretation of this data will provide information on chemical element residence and mobility in the environment.

Pilot projects such as the Riverina geochemical survey contribute to establishing and fine-tuning sampling and analytical protocols that can ultimately be applied at the national scale.

The authors

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The maps illustrate a variety of presentation styles, each with advantages and drawbacks. The simplest and most factual maps are the dot-maps (figures 2a, 5), where real concentrations are shown at the exact points where they were obtained.

For easy interpretation, exploratory data analysis (EDA) principles instruct us that boxplot classification with symbology as used here works best (e.g. Velleman & Hoaglin 1981). The resulting maps represent an improvement in the interpretation capability over growing dots maps (figure 4).

The catchment or 'mosaic' maps (figure 3) assign the value obtained at the bottom of each catchment to the entire catchment. This is based on the assumption that the overbank sediments analysed are the best possible reflection of the average geochemical composition of near-surface materials in the catchment. Although this assumption is fundamentally valid and faithful to geological understanding, the resulting maps are somewhat difficult to read at first.

Inverse-distance weighted maps (figure 6) interpolate concentrations to fill in the gaps between real samples (the search radius used here is 50 km). Thus, they are based on mathematical models that may or may not match how the geochemical composition of sediments really varies around known points (i.e. no account is taken of lithology, erosion and transport processes, discontinuities etc.). These maps, when smooth and 'well behaved' are very easy to read and convey their message efficiently

3D INVERSION MODELLING *in the Tanami region*

New modelling techniques that use existing gravity and magnetic data, such as the recently developed three-dimensional inversion modelling, can enhance our understanding of the Tanami region by enabling construction of 3D geological models.

The highly prospective Tanami gold region in central Australia consists of poorly outcropping basement rock that is largely obscured by thin alluvial cover. Efforts to 'see through' this cover to map the basement stratigraphy have therefore relied heavily on geophysical datasets, primarily gravity and magnetic.

New modelling techniques that use existing gravity and magnetic data, such as the recently developed three-dimensional inversion modelling, can enhance our understanding of the region by enabling construction of 3D geological models.

The Tanami region was the first central Australian region to be subjected to the application of this technique. The results provide enhanced information on the 3D architecture of the Tanami gold mineralising system, such as locations and orientations of structures acting as conduits for gold-bearing fluids, as well as locations of possible target rocks.

3D inversion modelling—which generates full 3D models in an automated environment—is an advance over the more traditional 2D forward modelling. The software was developed by the University of British Columbia's Geophysical Inversion Facility.

The technique transforms observed gravity or magnetic data into a 3D model populated by a mesh of cells carrying density or magnetic susceptibility values. The process is iterative, with adjustments being made to a starting model in order to minimise any misfit between observed and computed data. The final models, containing the density and magnetic susceptibility values, reproduce the observed gravity or magnetic field to within a small degree of error.

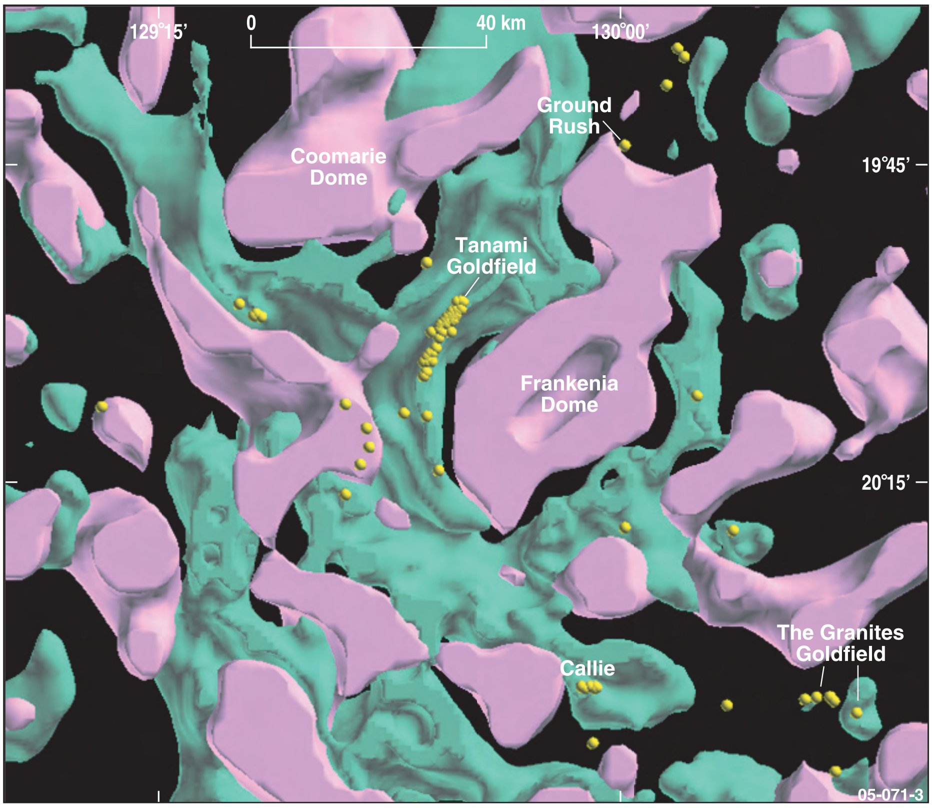

Figure 1. Plan view of a 'zoomed in' portion of the 3D inversion surfaces. Pink surfaces enclose regions of low density in the gravity inversion model, while green surfaces enclose regions of high magnetic susceptibility in the magnetic inversion model. The pink and green surfaces correspond mostly to mapped and interpreted granites and magnetic Tanami stratigraphy respectively, and are interpreted to map the 3D geometries of these lithologies. The locations of gold mineralisation, in yellow, highlight the relationships of the Callie deposit and the Tanami goldfield with respect to the magnetic stratigraphy.

The third-generation 3D Tanami model (figure 1) will be released in June 2005. It incorporates 3D inversion surfaces that were generated to enclose regions of anomalous physical property values. Surfaces enclosing low densities within the gravity inversion model correspond mostly to mapped and interpreted granites and are interpreted to simulate the 3D distributions of the granites.

Surfaces enclosing high magnetic susceptibilities within the magnetic inversion model correspond mostly to the magnetic stratigraphy (banded iron formations and mafic units) within the Tanami group sediments, and are also interpreted to simulate the 3D distribution of these units.

The inversion models, therefore, may be used as a regional-scale guide for determining where the magnetic units—considered to be potential traps for gold mineralisation—may appear at depth, as well as where they might sub-crop beneath younger cover.

For more information, phone Tony Meixner on +61 2 6249 9636 (email Tony.Meixner@ga.gov.au) or visit www.ga.gov.au/map/web3d/tanami/index.jsp