AGSO
AUSGEO news
APRIL 2000 ISSUE No. 57

Mineral provinces
some new thoughts

Ocean boundaries
in AGSO's sights

RABAUL VOLCANOES
fire passion

Taiwan's BIG shock

PP 255003/00048

Also: ***Sun activity peaks, perfect zircon found, great new CD plus much more...***

AUSGEO News
April 2000, issue no. 57

Editor Julie Wissmann
Graphic Designer Karin Weiss
Photographer Brett Ellis

This publication is issued free of charge. It is published six times a year by the Australian Geological Survey Organisation.

The views expressed in AUSGEO News are not necessarily those of AGSO, or the editor, and should not be quoted as such. Every care is taken to reproduce articles as accurately as possible, but AGSO accepts no responsibility for errors, omissions or inaccuracies.

ISSN 1035-9338

Printed in Canberra by
National Capital Printing

Australian Geological Survey Organisation

GPO Box 378
Canberra ACT 2601
Australia

cnr Jerrabomberra Ave & Hindmarsh Dr
Symonston ACT 2609
Australia

Internet: www.agso.gov.au

Chief Executive Officer
Dr Neil Williams

Subscriptions

Dave Harris
Phone +61 2 6249 9333
Fax +61 2 6249 9982
E-mail dave.harris@agso.gov.au

AGSO products

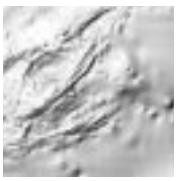
Judy Kley, Chris Thompson
Phone +61 2 6249 9519
Fax +61 2 6249 9982
E-mail sales@agso.gov.au

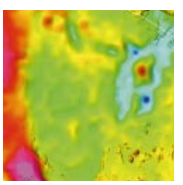
Editorial enquiries

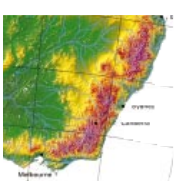
Julie Wissmann
Phone +61 2 6249 9249
Fax +61 2 6249 9984
E-mail julie.wissmann@agso.gov.au

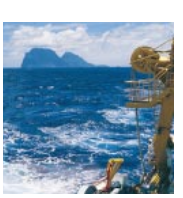
AUSGEO News is available on the web at www.agso.gov.au/information/ausgeonews/

CONTENTS









Lord Howe Island in sight. AGSO scientists are busy mapping Australia's eastern seabed jurisdiction. Photo taken from the deck of French research vessel *L'Atalante*. See article page 22.

Photo: Peter Hill, leader of the AUSTREA-1 cruise

ORIENTATION

ORIENTATION CHANGE gives Broken Hill new prospects

George Gibson, project manager of the Broken Hill Exploration Initiative, offers a couple of new ideas to those looking for further world-class ore bodies in Australia's Curnamona province.

There are two major barriers to exploration in the Broken Hill-Olary region says Dr Gibson: commonly held beliefs about the regional structure and interpretations of the aeromagnetics.

The Broken Hill region, known for its silver, lead and zinc deposits, is dominated by structures formed during two deformational events (D2 and D3). This deformation sequence is superimposed upon an earlier history of basin formation and contemporaneous bimodal magmatism at 1710–1690 million years ago.

Moreover while sedimentation happened at a higher level, mafic and felsic magmas were intruded at deeper levels. Later this basin inverted either during D1 or D2 deformation. D2 structures in the northern part of Broken Hill region are shallow dipping and verge towards the north-east—about 90 degrees to that commonly believed.

At a later stage (c. 1580–1570 Ma), these structures are overprinted by north-west verging D3 shear zones and thrust faults that overprint the shallower dipping D2 structures. The D3 deformation is thus more or less orthogonal to earlier D2 structures.

For years, many thought most shear zones around Broken Hill dipped towards the north-west. Through seismic surveys and detailed structural mapping, Dr Gibson and the BHEI team tested this interpretation. Results confirm a south-east dip for the D3 shear zones, diametrically opposite to previously held viewpoints.

Dr Gibson believes that this new information about the orientation of major structures is important because some shear zones in the Broken Hill region (e.g. Apollyon Valley shear zone) are associated with significant base-metal mineralisation.

'We believe that many of these shear zones are high-temperature structures that focused fluid flow, and most were subsequently reactivated', he says.

'But the important point is that they dip towards the south-east and in between you can see flat structures that we think represent bedding or the earlier D2 regional fabric.'

Dr Gibson says there has been a lot of emphasis on stratabound or stratiform mineralisation. He believes mineral exploration companies might have further success if they 'broaden their horizons'.

Editor's note

Minerals Open Days, held December 7–8 last year, were a prime opportunity for participants from industry and State Surveys to meet staff and influence the direction and types of projects undertaken by AGSO's Minerals Division in coming years.

As promised, in this issue we look at further presentations from those two days.

You may have noticed that two major projects have not been covered—Gilmore and NABRE. They will be larger articles in coming issues.

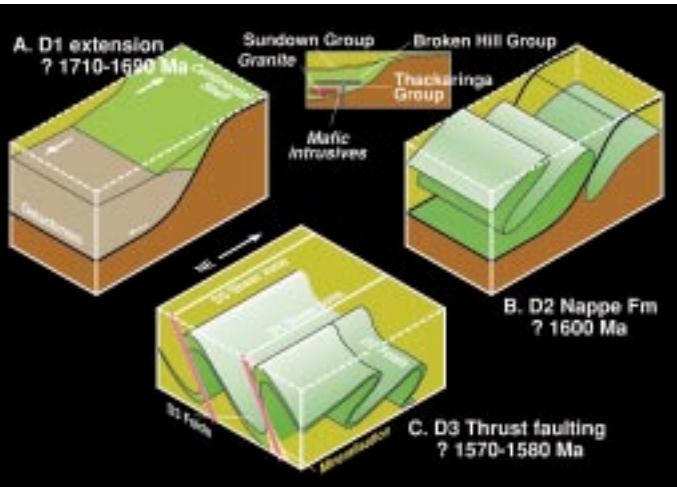


Figure 1. Shallow-dipping D2 structures overprinted by more upright D3 folds.

ORIENTATION...

'Some of the mineralisation at Broken Hill is shear controlled, although whether the line of lode is similarly shear-hosted remains uncertain', he says.

'Many of the zinc anomalies for example seem to fall on the trail of structures with the same north-east trend as the D3 structures.'

Shear-hosted copper–gold mineralisation occurs at Copper Blow south of Broken Hill and silver, lead and zinc in the Allendale region to the north.

'And if we take this one step further and argue that the line of lode for Broken Hill is structurally controlled—because in the open pits we see a lot of shearing in the line of lode—where could we look for continuation of line of lode?' Dr Gibson asks.

He suggests searching on the other side of the Stephens Creek shear zone because this region is underlain by a synformal structure cored by granitic gneiss very similar to that observed in the Broken Hill synform.

'So if the rationale holds, namely that the line of lode sits along the western margin of a synform cored by granitic gneiss, then this is where we should start searching', he says.

In regard to aeromagnetics Dr Gibson says that it cannot be assumed that they are all stratiform.

'Some are stratiform and some sit within melt rocks (pegmatites). A large number, however, are structurally controlled, particularly the more linear north-east trending anomalies.'

He adds that a lot of the linear magnetic anomalies displayed by the aeromagnetics sit in the D3 fabrics and a few lie in D2 high-strain zones.

The BHEI started up in 1994 in response to industry predictions that the Broken Hill ore deposit would be exhausted within 12 years. Mining company Pasminco shuts its last major mine in Broken Hill in 2006. Economic prosperity for Broken Hill looks grim unless government agencies such as AGSO alert mineral exploration companies to other possibilities in the region.

The BHEI is a Commonwealth–State government venture involving AGSO, the New South Wales Department of Mineral Resources, and South Australia's Department of Primary Industries and Resources.

For more details phone George Gibson on +61 2 6249 9727 or e-mail george.gibson @agso.gov.au

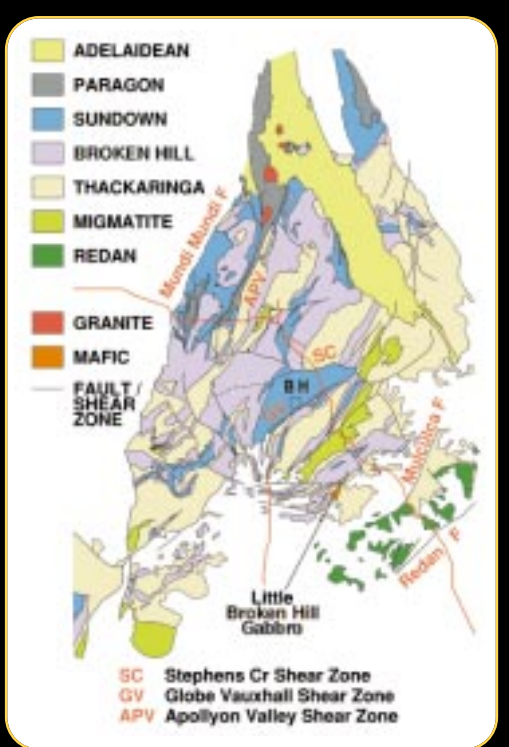


Figure 2. Simplified geological map of the Broken Hill region showing BHEI seismic lines. (Modified from NSW Department of Mineral Resources 1:100 000 map)

MINERAL PROVINCES

crustal geometry subject of major seismic research

Take a thousand kilometres of reflection data, add refraction and gravity data, and you probably have $3 million worth of data about Australian mineral provinces gathered by the Australian Geodynamics Cooperative Research Centre (AGCRC) over the last seven years. The AGCRC ceases operation this year, but not before it demonstrates its province and continental-scale syntheses at a couple of workshops.

'We have been trying to get a better understanding of the crustal geometry in some mineral provinces and, in the long term, look at potential plumbing systems on a regional scale', says Russell Korsch AGCRC Research Coordinator.

Seismic results

AGCRC work focuses on mineral provinces around Australia, specifically the Yilgarn Craton, Mt Isa Inlier, Broken Hill, western Victoria and the eastern part of the Lachlan Orogen.

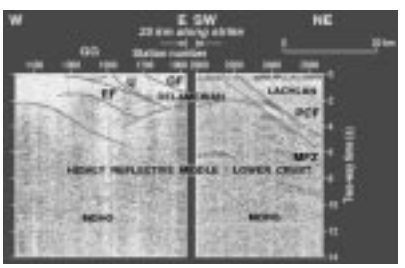
Yilgarn

In the Yilgarn Craton the AGCRC has done some geodynamic modelling of the Kalgoorlie area. Data is being compiled from three seismic surveys (1991, 1997 and 1999). The survey in September last year focused on the highly mineralised Bardoc Shear. It was carried out as a grid of five lines to build a three-dimensional picture of the crust in the Kalgoorlie area. Data is still being interpreted but it appears the greenstones have a thrust–stack geometry, and the Moho occurs at a depth of 35 kilometres. The first-pass interpretation of data will be presented at a workshop in Kalgoorlie on May 2–3.

Mt Isa

Deep seismic reflection data, refraction data and geological mapping along a seismic transect were used to produce a crustal-scaled depth section of the Mt Isa Inlier. For the refraction survey six

▲ **Figure 1.** A 350-kilometre north-west to south-east refraction line shot across the Broken Hill block. The six shots were fired in a single day.



▲ **Figure 2.** Data from a seismic reflection transect across the boundary of the Lachlan and Delamerian Orogens shows east-dipping (west-directed) thrust faults dominate the Delamerian.

explosions were let off in one day—three tonnes at either end of the transect and four single-tonne blasts in the centre.

'You need that sort of oomph to put enough energy into the ground for the p-waves to travel 500 kilometres to where we were recording data', says Dr Korsch.

The crust is very thick in Mt Isa. It is about 55 kilometres compared with 35 kilometres in the Yilgarn. There are two high-velocity, lens-shaped bodies in the lower and middle crust that are mafic to ultramafic in composition. The Mt Isa Fault is part of a group of west-dipping faults. One of these, the Adelheid Fault, is a highly reflective zone in the seismic data.

Broken Hill

The main aim of AGCRC work in the Broken Hill area was to look at the Tasman Line in western New South Wales. The Tasman Line is defined as the boundary between surface outcrops of Proterozoic and Palaeozoic rocks in Australia. When the Tasman Line was defined, there were no known Proterozoic or Archaean rocks on the surface east of it.

In 1997 a 350-kilometre north-west to south-east refraction line was shot across the Broken Hill block (see figure 1). Again six shots were fired in a single day.

'It is effectively a very simple crustal structure in the Broken Hill area—a two-layered crust', says Dr Korsch.

'The Moho is about 35 kilometres on the east and west and dips down to roughly 43 kilometres under Broken Hill.'

The lower crust maintains a constant thickness of about 14 kilometres. There is no evidence of a mid-crustal body that might have sourced mafic dykes and no evidence of an underplated lower crustal layer.

'The Tasman Line as defined on the surface is marked by the Darling River lineament', says Dr Korsch.

'But the real boundary between the Tasman Line or between the Broken Hill block and the rocks in the east shows up in the seismic as a change from east-dipping structures to a series of west-dipping structures', he says.

Western Victoria

A seismic reflection transect across the boundary of the Lachlan and Delamerian Orogens was part of a study into geodynamic factors controlling gold mineralisation in western Victoria.

The orogens are divided by the east-dipping Moyston and Pleasant Creek faults. East-dipping (west-directed) thrust faults dominate the Delamerian, while the Lachlan Orogen is dominated by a west-dipping fabric (see figure 2). The Escondida Fault is overlain by the younger post-Ordovician Grampians Group.

Eastern Lachlan

The initial work, in 1997, was done in the area between Canberra and Dubbo in New South Wales. It comprised a 350-kilometre, north-south refraction survey along the Molong volcanic belt. As well, in 1997 and 1999 a total of 290 kilometres of reflection data were acquired in the Orange and Forbes-West Wyalong districts.

The main aim of the refraction survey was to look at the difference between the Ordovician turbidites and Ordovician volcanics. Again six shots were fired and the blasts produced a 'noticeable wiggle' on the seismometer in the AGSO building.

'The crustal geometry under the Lachlan Transfer Zone, continuing north through Ordovician volcanics is quite different to the southern part', says Dr Korsch.

'The Moho goes from a thickness of about 46 kilometres in the south and gradually thins to about 40 kilometres in the north', he says.

Ordovician volcanics underlie the Hill End and Cowra troughs that flank the Molong volcanic belt. East-dipping faults cut the Molong volcanic belt.

A summary of results from last year's seismic work that was looking at an igneous complex near Lake Cowal in the eastern Lachlan Orogen will be presented towards the end of the year at a workshop in Orange.

Geological information system

Data gathered by the AGCRC is held in PREDICT. It is a geological information system accessed by a single web interface. Through Netscape users can interrogate templates or a series of events tables to compare tectonostratigraphic histories.

'We've also developed a petroleum information management system with tables that look at plays, organic-rich rocks or source rocks, reservoirs, seals, traps and the maturation and migration of the hydrocarbons', says Dr Korsch.

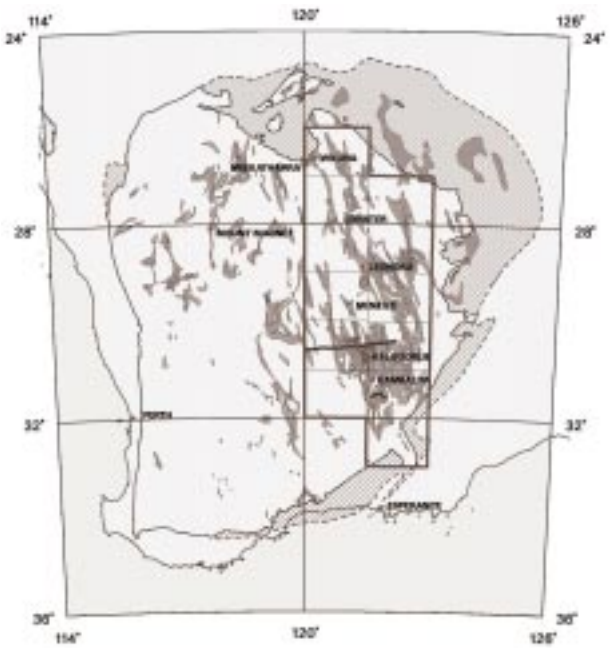
'Eventually, based on the petroleum system, we hope to develop a minerals information system and a predictive system for minerals.'

Research group

The AGCRC is an unincorporated venture involving AGSO, CSIRO Exploration and Mining, the universities of La Trobe, Melbourne and Monash, and Compaq Computers.

For further information phone Russell Korsch on +61 6249 9495 or e-mail russell.korsch@agso.gov.au

YILGARN MAPPING
provides golden opportunity



▲ **Figure 1.** Eastern Goldfields NGMA project area

The Eastern Goldfields National Geological Mapping Accord (NGMA) Project winds up this year. Project manager, Alan Whitaker, offers a snapshot of what geologists found in this mineral-rich province of the Archaean Yilgarn Craton.

Think of the Yilgarn and you think of gold—Kalgoorlie gold. There is much more to the Yilgarn than Kalgoorlie, however, and a push is on to find large resources of the precious metal elsewhere in the craton.

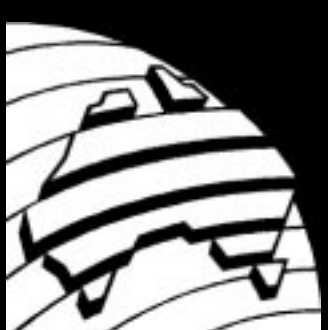
Since 1990 AGSO and the Geological Survey of Western Australia have carried out a major geoscientific program in the Eastern Goldfields Province (see figure 1). This work involved mapping results of geology, geochemical and isotopic studies; carrying out seismic reflection surveys; and interpreting the newly acquired geophysical data.

Ongoing complementary regional studies of geophysical and geochemical data put NGMA project work in a craton-wide context and provide insights for exploration opportunity.

Of the forty-two 1:100 000 sheets mapped in the northern Eastern Goldfields, AGSO was intimately involved in 26.

Yilgarn results focus of upcoming seismic workshop

2–3 May 2000
WMC Conference Centre, Kalgoorlie



The Australian Geodynamics CRC will be hosting a two-day workshop on the 2–3 May 2000 to coincide with the early release of seismic reflection data from the AGCRC's 1999 Yilgarn seismic survey.

Researchers will present the results to date of the seismic reflection traverses and three-dimensional fluid flow modelling. The workshop will be an opportunity to discuss implications of this research with the earth sciences community and get feedback from interested parties. Researchers from AGSO, CSIRO and the Geological Survey of Western Australia will give presentations.

Seismic survey

The seismic project involved the collection of a grid of deep seismic reflection data within the Kalgoorlie terrane, Eastern Goldfields. Complementary gravity data was also collected along each of the traverses.

The five new seismic traverses are providing new information on the three-dimensional geometry of the Eastern Goldfields. The first results from the seismic data indicate there are significant variations in structure within the region.

Fluid flow modelling

The numerical modelling project has produced further models of the Kalgoorlie region based on the deep seismic data. These address the potential for lateral fluid flow and fluid mixing proposed in recent studies, and the influence of thermal structure on fluid production and migration.

For more details phone Lindsay Saker on +61 2 6249 9766 or e-mail lindsay.saker@agso.gov.au

'Out of that work we believe there was early extension and doming of granitoids bringing high-grade greenstones up largely in concordant contact with the granite domes', says Mr Whitaker.

'We also believe that deformational sequence in the northern Eastern Goldfields is the same as that in the southern part and should have similar gold exploration potential', he says.

Mr Whitaker says that studies in the Leonora area indicate that early D1 structures were mineralised with gold. Therefore there was an early gold event which is contrary to the belief that gold mineralisation only occurred in a single event late in the structural history at about 2630 million years ago.

Geophysical data

Fourteen 1:250 000 sheets of gravity were acquired over the Eastern Goldfields, generally at four-kilometre spacing with some two-kilometre spacing over some of the greenstones. Aeromagnetic data at 400-metre flight line spacing was acquired over a dozen 1:250 000 sheets in and adjacent to the province, with more being added this year (see Stanley, Youanmi and Robert in product news this issue).

These data show that the craton is generally composed of granitoid (80%). Two main types of structures dislocate the geology: brittle-ductile shears that are strike extensive (+80 km) and define structural corridors five to 10 kilometres wide; and shorter (generally <40 km) narrow brittle overprinting faults and fractures that caused only minor dislocations.

Five geophysical rock units are inferred: undivided gneiss-migmatite-granite, sinuous gneiss, parallell-banded gneiss, greenstone, and discrete granite plutons. The greenstones of the Eastern Goldfields are quite dislocated and disrupted relative to greenstone in provinces farther west. Granite plutons are far more abundant in the greenstone belts of the Eastern Goldfields than in the extensive regions of granitoid between the belts. Many of the plutons are spatially associated forming intrusive corridors. Parallel-banded gneiss is found along the margins of the gneiss-migmatite-granite domains and commonly includes small enclaves of highly metamorphosed greenstone.

Seismic work

Roughly 200 kilometres of east-west seismic reflection data were acquired in the Kalgoorlie region. Interpretation of the seismic data shows the greenstone belts are four to seven kilometres thick and that the crustal thickness under western granitoids is roughly 33 kilometres. Under the greenstones the crust thickens to about 38 kilometres. A detachment zone is inferred at the base of the greenstones.

'One of the major things to come out of the seismic work was the discovery of major deep crust penetrating faults or shears', says Mr Whitaker.

'These structures possibly provided the plumbing for mineralising fluids', he says.

Granite geochemistry

There are five main granite types in the northern Eastern Goldfields. Two types dominate. Intrusion occurred from more than 2720 to less than 2630 million years ago, but the major reworking of the crust was between 2675 and 2640. Almost all dated granites are of similar age or younger than the greenstones. The implication from their geochemistry is that the granites developed from pre-existing felsic crust. They are not melts of the greenstone belts.

Granite-related gold is dominantly associated with two of the five granite types—that is, mafic granites and syenites—even though mineralisation appears to post-date intrusion of these granite types.

In terms of gold exploration opportunities, there are several located away from traditional mining centres.

In the north of the craton, greenstone is inferred under thin Bangemall Basin cover adjacent to outcropping Archaean (interpreted) granite on the Nabberu and Stanley sheets.

Mr Whitaker says that having seen some of the aeromagnetic data in the south-east of the craton, and interpreted the Rason-Throssell data to the north, he believes there is another 30 to 50 kilometres of craton east from that area of subcrop at readily explorable depths (generally <50 m cover).

'There's also potential for gneiss-hosted gold, for example, in the northern Southern Cross Province where a major shear system runs north-north-west and cuts sinuous gneiss', he says.

For more details phone Alan Whitaker on +61 2 6249 9702 or e-mail alan.whitaker@agso.gov.au

Workshop focus

The workshop content includes the following:

- regional geology and structure of the region;
- timing of deformation events;
- a crustal cross-section for each traverse;
- near-surface structure for each traverse;
- seismic signature of key structures including shear zones, detachment surfaces and domes;
- geometry of granites;
- weathering profiles;
- implications for regional tectonics; and
- thoughts on mineralisation and fluid pathways within the crust.

Fees

Registration costs $135 (students $45). The price includes a copy of workshop proceedings, lunch and morning and afternoon tea.

Correction: This figure should have appeared on page 13 of the February issue in the article 'Signs of oil and gas off Lord Howe'. It is a map of a large part of the Fairway Basin showing the distribution of the largest 'salt' domes and ridges, and of the 'bottom simulating reflector' representing gas hydrates, in relation to water depths.

GRAVITY properly planned is a PRECISION TOOL

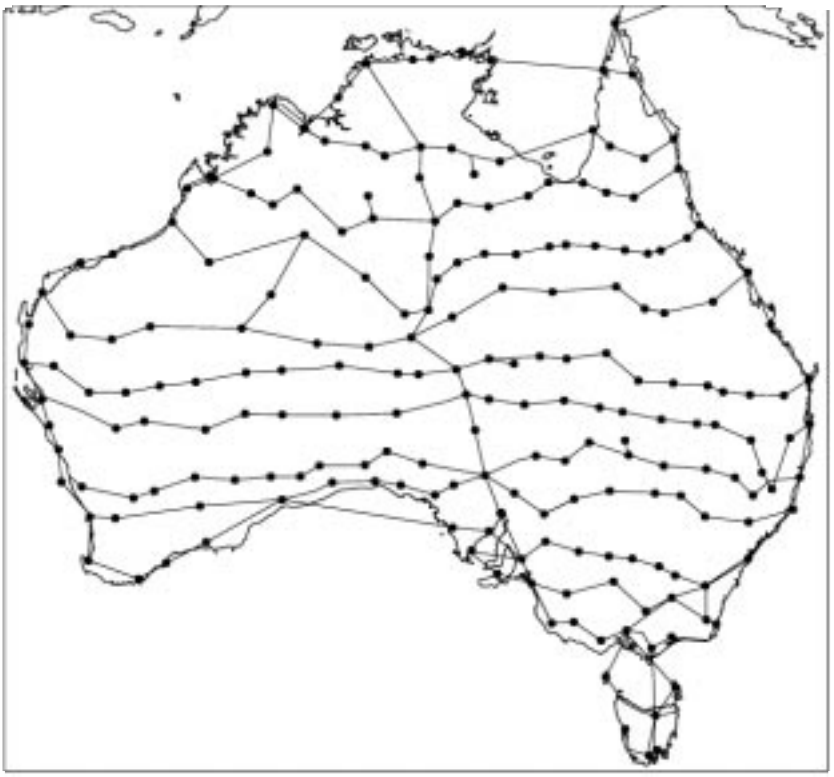


Figure 1. Location of Australia's Fundamental Gravity Network stations.

If Alice Murray, leader of AGSO's National Gravimetry Project, has her way gravity will not be auxiliary to geological interpretations but used systematically in projects from the start.

'Gravity is not something you grab like a map to verify your previous interpretations', says Ms Murray.

'It is a precision tool that with proper planning offers much more than background regional information.'

Project functions

The National Gravimetry Project maintains the National Gravity Database, Fundamental Gravity Network and national gravity standards.

The National Gravity Database contains data from more than 900 thousand point gravity observations derived from over a thousand surveys dating back to 1937. Currently the database is being translated from an in-house system to an Oracle-based one. Gravity will be integrated into AGSO's corporate database and into the multi-disciplinary geophysical processing systems.

The Fundamental Gravity Network comprises roughly a thousand marked and documented gravity reference points at 300 localities around Australia. Systematically, over the years companies and the State Surveys have been basing their surveys on these AGSO reference stations.

'That means we have a consistent, continent-wide coverage without the problem that arose in the airborne surveys where we've got a mismatch between individual surveys and we had to micro-level', says Ms Murray.

Providing national standards for gravity is a very important function Ms Murray says, because gravity is an expensive tool if it is used indiscriminately.

'It costs roughly $60 a station for pure land work and $100 a station for helicopter work, so for a quarter million sheet at about four-kilometre spacing you're talking about $1050', says Ms Murray.

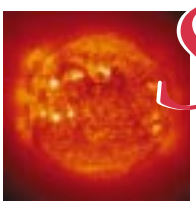
'You really can't afford blanket coverage of the whole continent.'

Continued page 14

SURGES, BLACKOUTS

glowing skies as Sun activity peaks

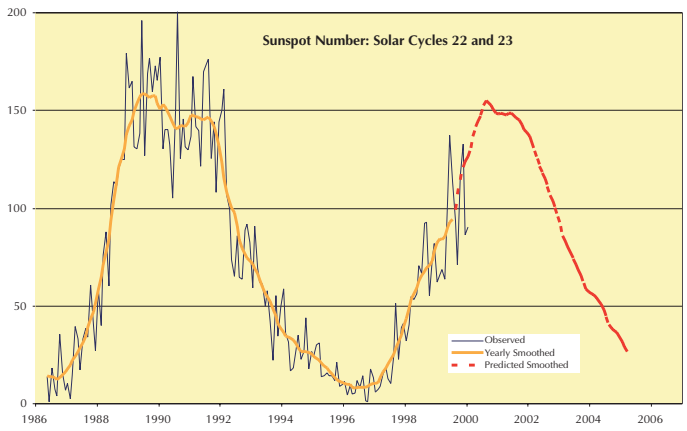
The Sun's activity, measured by the average number of sunspots, is expected to peak this year, based on projections by the Ionospheric Prediction Service (IPS), Department of Industry, Science and Resources.



Sunspots are areas on the Sun's surface that are cooler and so darker than their surroundings. They are areas of complex contortions of the Sun's magnetic field and are a good indicator the activity of the Sun as a whole.

The Sun exhibits an 11-year cycle of activity (approximately), the last maximum of which (Cycle 22) occurred in 1989. The chart below shows the sunspot numbers since 1986, the beginning of Cycle 22. The current cycle (number 23) began in 1996 when activity was at a minimum once again.

Coincident with the occurrence of numerous sunspots is the increased likelihood of solar flares. These are observed as a sudden brightening within an active region on the Sun's surface. They last roughly up to an hour. During this time high energy electromagnetic radiation and particles are ejected from the Sun. If directed towards the Earth, they can result in disturbances to the ionosphere and the geomagnetic field causing a number of unusual and hazardous effects.



Coronal holes

Solar activity builds up to a maximum much more quickly than the decline afterwards (see the chart). In the declining phase there is an increased frequency and longevity of coronal holes. These regions in the solar corona are of relatively low density and low temperature and are sources of high-energy enhancements to the solar wind. (The identity of coronal holes was discovered by Skylab. Prior to their proper identification they were called M-regions.)

A coronal hole can persist for as long as 18 months. Ionospheric and magnetic disturbances on Earth caused by a coronal hole tend to repeat every 27 days—the apparent rotation period of the Sun.

▲ Top left: The Sun observed in He II 30.4 nm light at 0719 on February 22, 2000. Flare activity is seen at the limb on the left of the picture. The bright areas or plages indicate active regions out of which flares are born. Photo courtesy of Solar & Helioscopic Observatory.

Disturbances

The combined effect of solar flares and coronal holes brings about a peak in occurrence of ionospheric and geomagnetic disturbances some time after the sunspot maximum and generally before sunspot minimum.

If the predictions for Solar Cycle 23 eventuate, expect a relatively high sunspot number at solar maximum, as has been the case for the two most recent cycles.

During strong disturbances, or storms, the radiation that bombards the Earth will cause changes in the ionosphere. These changes will affect radio communication paths resulting in freak propagation conditions. Large electric currents will flow in the ionosphere creating a rapidly changing magnetic field that will induce large currents in long conductors such as pipelines and power lines. This will bring about accelerated corrosion of the former and surges in the latter that can result in damage to transformers and blackouts.

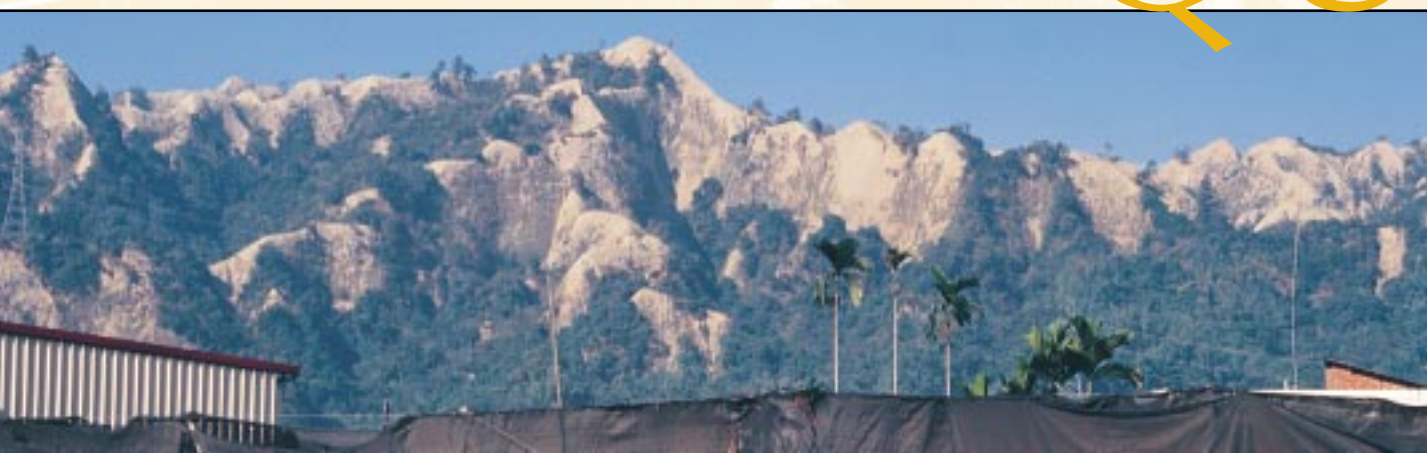
During the most active phases of magnetic storms, expect to see auroras (or the southern and northern lights) much further towards the equator than usual. Displays may be visible from New South Wales (and further south), usually as a diffuse deep red glow low in the southern night sky.

Satellites are particularly exposed and vulnerable to the hazards that accompany solar activity. Charged particles can cause a build-up of electric potential on these craft resulting in damage to sensitive electronic instruments. Atmospheric heating results in increased satellite drag and the degradation of their orbits. Highly energetic charged particles due to solar activity pose a serious hazard to astronauts.

AGSO's Geomagnetism Section continuously monitors the geomagnetic field at observatories in Australia and Australian Antarctic Territory. In collaboration with the IPS, it produces indices of geomagnetic and ionospheric disturbance that are used to assist in the mitigation of any adverse effects of high solar activity.

For further information telephone Peter Hopgood on +61 2 6249 9359 or e-mail peter.hopgood@agso.gov.au

BIG EARTH QU



What a home coming for marine geoscientist and seismologist Dr Chao-Shing Lee. Just three hours after his return to Taiwan from work with AGSO in September 1999 an earthquake, magnitude of 7.3 on the Richter scale, sent shock waves through his homeland. The big earthquake ruptured much of Taiwan, destroyed some 20 thousand buildings and killed an estimated 2500 people.

Top left: Ninety-nine Mountains (translated) with vegetation peeled back due to the September 21, 1999 earthquake in central Taiwan. *Photo: Songfa Liu*

Top right: A public school not far from the small town of Chi Chi, very close to the epicentre of the September 21, 1999 earthquake. *Photo: Songfa Liu*

Since that fateful day, Taiwan's government and National Science Council are channelling what will amount to approximately A$200 million towards community awareness and scientific research such as deep crustal and rock chemistry studies, airborne surveys, and determining the history of Taiwan's earthquakes—their frequency, locations and extent of 'geohazard'.

'We need at least several thousand years of earthquake history, not just a record of the last 100 years', Dr Lee says.

'Taiwan sits in a very active area but until the big one the devastated region had been quiet for a long time.

'Now is the perfect case (sic) for studying the so-called seismic gap', he says.

Earthquake history

Taiwan's paleohistory will be reconstructed by collecting sediment samples from drill holes along active faults. It is hoped data gathered offers insights into earthquake cycles and seismic gaps. In addition, seismometers as well as strain, groundwater, and GPS detectors will be permanently buried in strategic places along known faults to monitor current activity.

Taiwan's geology shows a number of faults. Those in the centre and south are thrust-type faults while those further north tend to be strike and extensional. During the September 1999 earthquake, a 100-kilometre long reverse thrust-type fault caused large ruptures that raised the ground by up to five metres.

Dr Lee says that after this earthquake a lush mountainous area looked as if someone had peeled off the skin. As well, due to the earthquake a mountain moved; one river became a permanent dam; and another that had an even, unremarkable flow now has a five-metre waterfall.

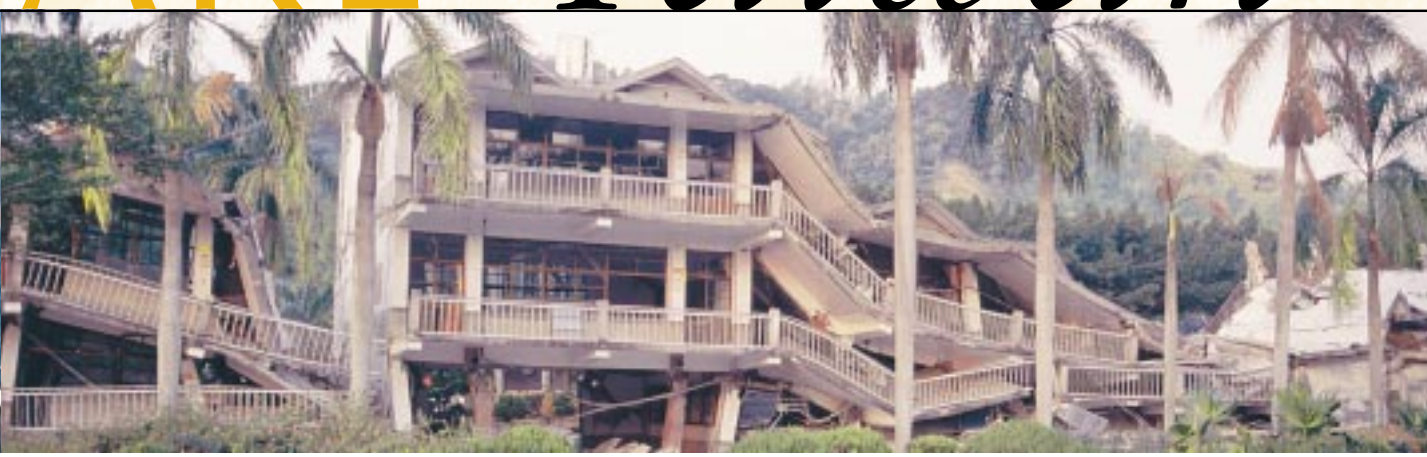
'Now we really have a lot of work to do', he says.

'Our surveying people have to re-measure because Taiwan has changed; the land has been extended in some areas and shortened in others because of the earthquake.'

Most buildings near the fault line fell down particularly any built on unconsolidated conglomerates and liquefied sandy soils. But Dr Lee tells of one lucky resident.

Before the earthquake the resident's two-storey house was on a level road. Now the house stands about four metres above what remains of the road. The neighbours' homes are gone. The house was designed to be five

rouses AKE Taiwan



storeys high to accommodate a son and his soon-to-be wife. But the son changed his mind about marriage, and a two-storey home was built on foundations designed for a much higher building.

'This may be the way for our future building code particularly near any active fault', says Dr Lee.

Mountain building

Taiwan's crustal movement is about eight centimetres per year in the south and gradually reduces to the north. For a small area there is a difference of roughly 11 thousand metres from the highest mountain in the centre of Taiwan to a deep-sea trench. There are a number of sedimentary basins from Taiwan to the Chinese coast. As well, Dr Lee claims there are about 68 submarine volcanoes in the area that scientists know of to date.

Dr Lee says that through oceanic crust subduction and then thrust, Taiwan's mountains are being formed beginning from the south. He believes that evidence of subsidence lies in the very low northern part of Taiwan and in gravity data that show there are submarine canyons offshore.

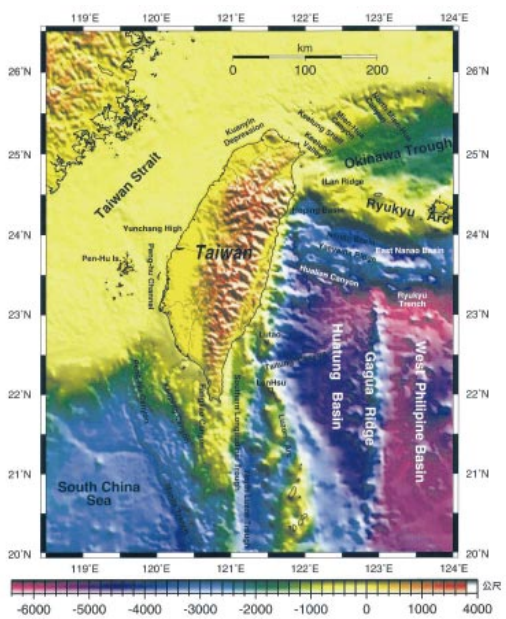
He believes the Philippines plate subducts to the north underneath the Eurasian plate and that part of the Eurasian plate subducts underneath the Philippines plate.

'Our region is becoming very hot because there could be more than 100 submarine volcanoes', says Dr Lee. 'That is why the French and Japanese are very interested in studying the area.'

In May Dr Lee will be a guest on board a Japanese submarine that surveys the 'sea's mountains'.

But in the meantime, Dr Lee's geology students in Taiwan have asked him to send them an e-mail before he leaves Australia this time—just in case.

Dr Chao-Shing Lee works for the Institute of Applied Geophysics, National Taiwan Ocean University. He presented this information as a guest speaker at AGSO in February.



Location map of Taiwan showing basins and ridges. From the highest mountain in the centre of Taiwan to the sea trenches is roughly 11 000 km.

▲ Top: Rabaul's natural harbour caused by a caldera collapse. In the background is Tavurvur and part of Rabaul destroyed by the 1994 eruption.

Middle: Ash loading from Tavurvur's 1994 eruption destroys buildings, roads and vegetation.

▼ Bottom: The landscape left lifeless and monochromatic from Tavurvur's ash.

RABAUL VOLCANOES
fire 30-year passion

Few would know New Britain's volcanoes like AGSO's Dr Wally Johnson and none could be more passionate about them, particularly about those that destroyed the town of Rabaul in 1994. With more than 30 years' experience researching this volatile area in Papua New Guinea, Dr Johnson gave a glimpse of the attraction for him and other volcanologists at a recent AGSO lecture.

6.10 a.m. September 19, 1994. Rabaul, New Britain. Tavurvur erupts. One hour and 10 minutes later Vulcan, on the opposite side of the harbour, spews rock and ash high into the air. The simultaneous eruption of two volcanoes on the island of New Britain in the eastern end of the Bismarck volcanic arc is a repeat of events of 1937 and 1878.

Rabaul, once a tropical paradise, is devastated. Most damage happened in the first 24 hours. Roofs collapsed with ash loading, roads were blocked, power and communication lines came down, and all vegetation disappeared. The damage bill reached $300 million Australian (1994 values). There were four deaths.

Tavurvur's eruption was wet. Dark ash (and accretionary lapilli) was driven over the town by the strong south-east trade winds at that time of year. If the eruption had taken place during the north-west monsoon season, the town would have remained intact.

Vulcan was a drier eruption. It belched pumice and ash and produced a plinian plume that rose more than 20 kilometres. During its ascent the plume caught winds of different speed and directions that spread it wide over the Bismarck Sea. Part of the cloud turned south over mainland PNG and then east and into Fijian airspace. It comprised mainly ice crystals but also small particles of ash. Only small amounts of sulphur dioxide and sulphuric acid aerosols were in the cloud.

Expertise enlisted

The eruptions showed there was a dire need for a much better understanding of the deep interior of Rabaul volcano and of how the magma system 'works' there. Monitoring also needed to be stepped up at other high-risk volcanoes in PNG.

Australia's aid agency, AusAID, has invested A$6.5 million in strengthening the PNG volcanological service. AGSO managed that project which is drawing to a close after three and a half years. Much has been learned but a lot is still unknown because of the complexity of activity around Rabaul.

Structural understanding

PNG and the western part of the Solomon Islands is an area of great current tectonic activity. It is quite unique because of its complexity. There may be as many as four minor plates sandwiched between the Indo-Australian and Pacific plates, with the Solomon plate being subducted beneath the South Bismarck plate at about 70 degrees. Volcanoes are associated with most of the plate boundaries. The main volcanological feature in PNG is the Bismarck volcanic arc (about 1000 km long). Rabaul, on the island of New Britain, sits at the north eastern end of the arc.

A diverse range of magma compositions is found throughout the New Britain area. The magmas differ in composition, depending on the position of the volcanoes above the dipping slab of Solomon Sea plate underlying

New Britain. At the volcanic front (over where the dipping Solomon Sea plate is quite shallow), the magmas have high uranium to thorium ratios and extreme depletions in tantalum, niobium and rare earths. The uranium enrichment event is quite old—at least 100 thousand years.

The rocks at the volcanic front also show an abundance of beryllium 10 and boron. Both are effective tracers of sediment recycling and neither has been fractionated from one another during fractional crystallisation or partial melting. Beryllium 10 has a half-life of about 1.5 million years—just long enough for the beryllium to form, be absorbed by sediments, taken down into the subduction zone and erupted. It is thought that the cause of the high beryllium is a separate process from that of the uranium enrichment.

Ring structures at Rabaul

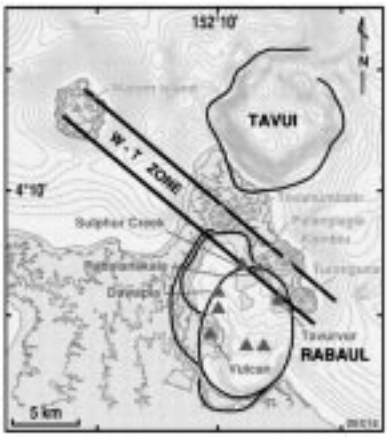
Rabaul volcano is only one of several young calderas in the New Britain area. It had an unusual seismic annulus up until the 1994 eruption, identified as a result of many years of earthquake monitoring. Cross-sectional diagrams show that the earthquakes cut off at a depth of about four kilometres, possibly representing the top of the main magma reservoir around Rabaul. There has been a series of caldera collapse events at Rabaul and sometime in the not-too-distant past the caldera system was breached by the sea and formed a natural harbour.

Three different volcanic systems can be identified in the Rabaul area. The first is the series of 'nested' calderas making up Rabaul volcano itself, and enclosing eight, smaller volcanoes, most of them within one kilometre of the seismic annulus. The magmas of these volcanoes—including Tavurvur and Vulcan—are thought to come directly up to the surface from ring dykes.

The second volcanic system is made up of a line of strato-volcanoes extending from Watom Island in the north-west to Turanguna (South Daughter) in the south-east, making up the 'Watom-Turanguna zone'.

Many of the magmas of Rabaul are mixed magmas. They represent mixing of different magma batches and the retention of magmas for substantial periods in reservoirs

Map showing the location of Rabaul, its volcanoes and the W-T zone. ▶



before a basalt injection causes a further eruption. Basalt injections seem to be a common eruptive mechanism at Rabaul, and may explain the origin of the many large volume (10 km^3 or greater) eruptions there, including the large ignimbrite deposit. Interestingly, recent argon-argon results suggest that there may have been more large-scale eruptions at Rabaul in the last 20 thousand years than in earlier times.

The third component is the largely submarine Tavui caldera, some 10 kilometres wide and more than a kilometre deep. The Raluan pyroclastics, formed as recently as 7000 years ago, may have originated from Tavui.

Magma reservoir beneath Rabaul

Current ideas point to there being two separate mantle sources beneath the Rabaul area—one that feeds the Tavui volcano and another for the Watom Turangunan (WT) zone and Rabaul caldera.

Preliminary seismic tomography results indicate there is a low velocity anomaly that underlies the seismic annulus in the Rabaul area. A similar body has not been found beneath Tavui to date, but the tomography survey was designed for a depth of only 10–12 kilometres.

The roof of the reservoir beneath Rabaul caldera is about three or four kilometres deep. The velocities involved show that this body could not be 100 per cent magma, but most likely is a mixture of solid and magmatic material. The WT magmas are injected into this main magma reservoir beneath Rabaul and the mixed magmas come up the ring fault and form volcanoes such as Tavurvur.

The basalt magma injection at the intracaldera volcanoes in the east at times could have been sufficiently robust to reactivate the whole of the dactic magma reservoir. Proper monitoring therefore must be continued at Rabaul to avoid devastating consequences for the population of the Rabaul area.

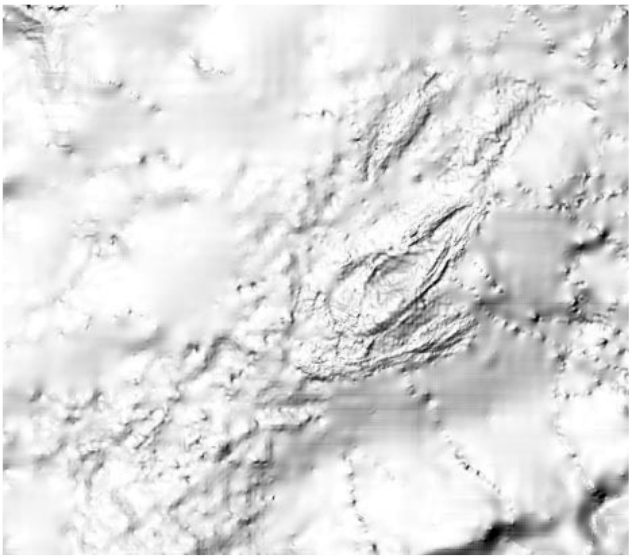
Present day

Rabaul is not a place for people. Civilisation exists there only by geological consent. After the 1994 eruptions the PNG government moved residents to Kokopo, a safer place than Rabaul because it is outside the active caldera. Kokopo, however, is still an area with geological hazards.

The volcanoes of PNG have caused hundreds of fatalities over the last 150 years. The vulnerability of communities is increasing because of a growing population and increased investment, particularly in coastal areas. Responsibility for hazard and risk management now rests with the PNG government and its scientists. But AusAID is currently considering how its investment can be sustained—particularly how to continue the vital work of the Rabaul Volcanological Observatory.

Dr Johnson is the Chief of AGSO's Geohazards and Geomagnetism Division. He was presented with the Harold Raggatt Award for this lecture, the first of the AGSO Distinguished Lecture series for this year. In forty-five minutes he presented only a small aspect of 30 years' research. For further information telephone Dr Johnson after April on his return from PNG on +61 2 6249 9377 or e-mail wally.johnson@agso.gov.au

▶ *Continued from page 8*



◀ **Figure 2.** Gravity can pick up very fine details (even in greyscale). This is a microgravity grid of the Broken Hill area. The area being mined is easily distinguished.

Ms Murray says that forethought into which areas warrant gravity coverage or additional coverage is important. She says those planning a survey should be clear about the results and benefits they want before they start planning, and suggests keeping these questions in mind:

- Why do we want to do the survey?
- Is it economic or scientific?
- For what are we looking—what is the shape, size and density of the geological body?
- What is the prevailing trend direction in the area?
- What coverage do we already have?
- Can it be supplemented by doing in-fill in particular restricted areas?
- Do we want uniform coverage or can we define smaller areas of more detailed coverage?
- How much money can we spend? (That determines the number of stations and how much detail can be added.)

Another part of the standards is ensuring that all work is based on the fundamental network and all surveys have been properly levelled together.

'Otherwise if you pass a filter over the whole country you'll end up with lines all over the place that are caused by differences in datum rather than geological features', she says.

Scientific survey planning

Ms Murray says that you can get much more than is initially obvious out of, for example, a four-kilometre gravity dataset (depending on the orientation of the things you are looking for).

'If you are looking for dykes and lineaments, if you incline your survey grid at a low angle to the strike you can get more definition in the direction you want than the four-kilometre spacings would imply', she says.

'If you do it at 45 degrees to the strike you are going to get a resolution of 2.5 kilometres and you can pull that down to less than one by doing it at a fine angle.'

However, Ms Murray warns that by going too fine the body you are looking for can be missed altogether.

Ms Murray says the project has been quite successful in the southern goldfields of Western Australia because they were targeting on the basis of known geology. She says it was the first gravity survey she has seen that showed such an extensive series of dykes. (The coverage for three sheets was four kilometres and in the greenstone areas the coverage was two kilometres.)

'We are beginning to gain a lot more geological knowledge by doing a survey in a planned, scientific way', she says.

Project future

In the past the project was very busy reacting to loads of data coming in. Nowadays they are concentrating on national standards and information exchange. Ms Murray says they plan to increase the accuracy of the base network and increase the speed at which stations are established. They are also looking into optimal gridding of the continent and hope to produce a composite grid that is 200 metres over the whole of Australia. Isostatic and terrain corrections will be applied. Within the decade they hope to use airborne gradiometry to solve geological problems.

'In the past we've very much been the data-gathering project, just producing postage stamp maps and doing routine processing', says Ms Murray.

'But we want to work more closely with geological projects and be an advisory centre because we have the expertise that can solve quite a few problems.'

For more details phone Alice Murray on +61 2 6249 9264 or e-mail alice.murray@agso.gov.au

Mineral resources and advice activities: *AGSO's role extended*

Much less than one per cent of Australia is devoted to mining activities, yet from that small area the returns have been very high. Once that was a significant argument for allowing mining to take place almost anywhere.

Nowadays the government grapples with a 'triple bottom line'—the community expects a balance between economic, environmental and social values. Transparent and well-informed land-use decisions are demanded.

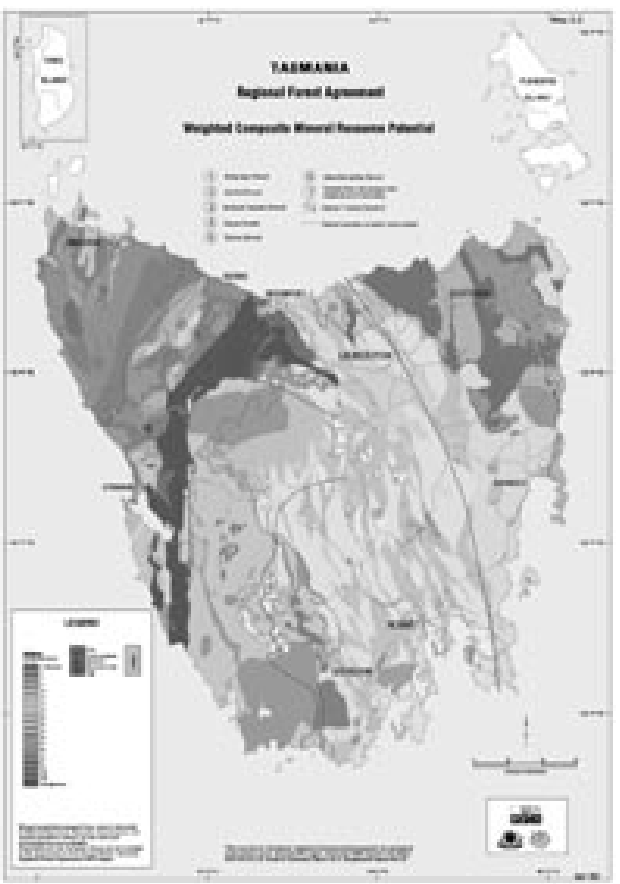
Driven by the requirements of government policy areas and industry needs, AGSO's role in supplying advice on Australia's mineral resources has expanded to include issues concerning resource access and land management. AGSO is being asked to provide scientific input to facilitate complex decisions on high profile (and often emotive) issues such as land use in areas with conservation significance, and land degradation—particularly salinity.

'While many land-use decisions reside formally with the States', says Ian Lambert, Group Manager of AGSO's Resources and Advice activities, 'the Commonwealth is generally involved where there are decisions to be made on nationally significant issues'.

Transparent and informed land-use decisions require integration of geoscientific information with other data. It is here that AGSO, with its geoscience and technical expertise, is playing an important role, often working with the States and other interested parties.

'We use advanced GIS-based decision support systems (DSS) that are very effective in guiding decisions on land use and related issues', says Dr Lambert.

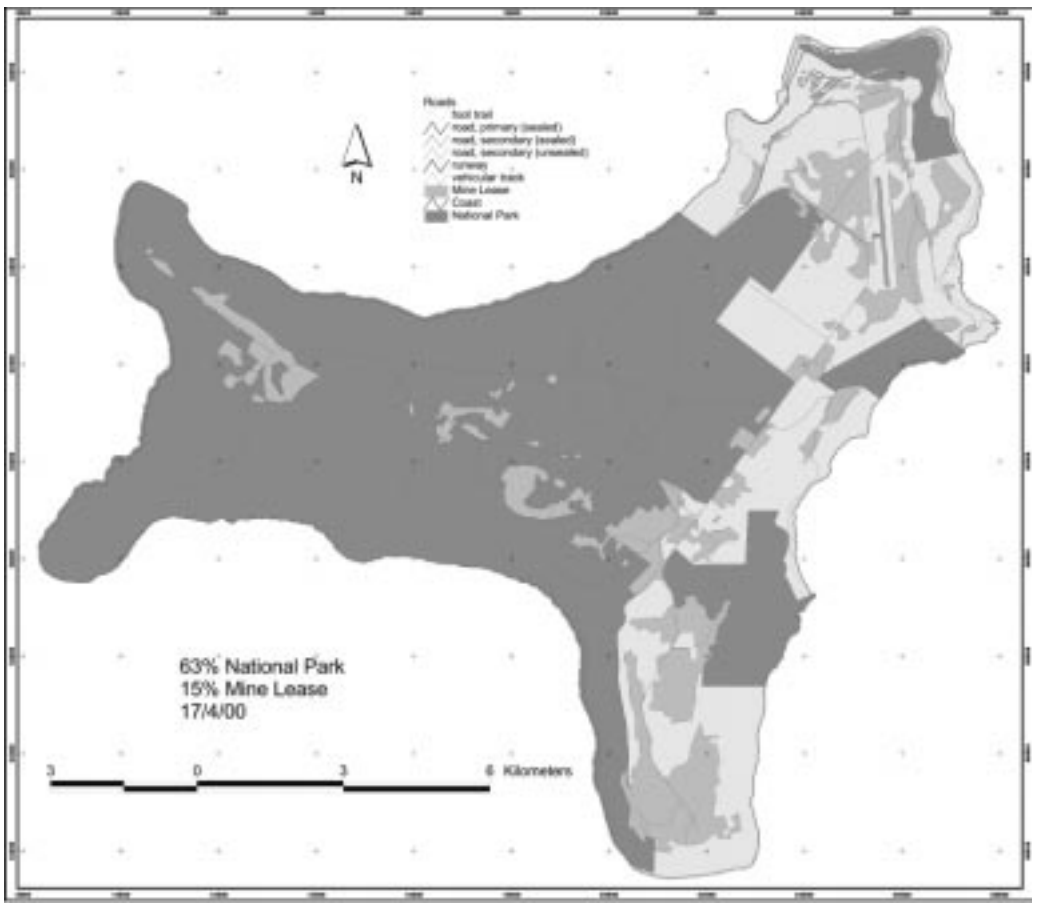
Data such as mineral deposits, geology, regolith properties, earthquake risk, wilderness, endangered species, forest values, land tenure and agricultural land use can be readily shown to decision makers, and manipulated in real time.



▲ **Figure 1.** In the Regional Forest Agreement process AGSO has been preparing mineral potential maps. This is the weighted composite mineral potential map for Australia's southern–most state, Tasmania.

Dr Lambert notes that there are extensive prospective areas with no currently known mineral deposits. He says that lack of known resources in a region does not necessarily equate with 'no potential' for future discoveries of concealed mineral deposits and so this needs to be factored into land-use planning.

'The rationale is that, while we cannot have a perfect picture at any given time, we do the best we can based on existing data because decisions will be made anyway', says Dr Lambert.



▲ **Figure 2.** Map of Christmas Island showing the national park and mining leases.

'And they can be made in ignorance if we don't factor in all of the relevant data that we have', he says.

Dr Lambert says that information on known and potential mineral resources was important input for many land-use decisions. AGSO's participation in the Commonwealth–State Regional Forest Agreement (RFA) process had established this.

Regional Forest Agreement

In the RFA process AGSO has been preparing 'mineral potential maps' for individual styles of mineral deposits. A weighting is done by a panel of experts who know the geology of the areas concerned as well as the relative economic significance of the different types of deposits. For example, a massive sulphide style deposit in volcanics might be weighted nine out of 10 whereas tin veins may score four. These results are collated and displayed as maps of various types (see figure 1). They are held in a GIS system that enables them to be overlaid with other values in considering options for conservation reserves.

Christmas Island

Another important application of such decision support systems is illustrated by AGSO's work on Christmas Island, an Australian Indian Ocean territory with a long history of phosphate mining (see figure 2). The island presented a dilemma when the Commonwealth Government-owned mining operation ceased in 1987. Mining re-commenced in 1990 following an employee buy-out of the Commonwealth's operation. A 21-year mining lease was granted by the government in 1997. Mining mainly comes from the discarded stockpiles of the upper layers of phosphate that are valuable as direct-application phosphate in several Asian markets.

'Prior to granting this lease, we assessed the remaining phosphate resources, the viability of future mining, developed the mining schedule, advised the government on royalty options, recovered a lot of old hard-copy data and put all the relevant data into a geographic information system', says Dr Lambert.

With the GIS and orthophotos of the whole island, and at a cost of $200 000, instead of around $5 million for a traditional survey, 300 stockpiles were accurately located. In the phosphate-rich environment many stockpiles had become overgrown by dense vegetation, and were very often hard to recognise on the ground.

Another problem on the island where the GIS has helped concerns the plight of the Abbotts booby, an endangered seabird. The GIS helps prioritise areas for rehabilitation. These areas minimise the wind turbulence that is causing the booby chicks to plummet to the

ground on their first flight, where they are eaten by crabs.

The Christmas Island GIS and technical advice provided by AGSO has facilitated a situation where the island has been shipping up to 700 000 tonnes of phosphate annually. This is being combined with maintenance of the environmental values in the island's extensive national park.

The successful outcomes for the islanders, government, industry and wildlife have led to further requests for help with land-use decisions. The most recent are current projects on Nauru and Cocos Island.

There was also an unexpected outcome. Being near the equator, Christmas Island is an ideal launching site for satellites.

'With our high-quality digital infrastructure, we were able to sit down with the proponents and identify the most suitable site for the facility in a matter of hours', says Dr Lambert.

'We rapidly found a site that minimised sterilisation of phosphate ore and many of the associated problems such as loss of livelihood and compensation to the mining company', he says.

'It also minimised earth works requirements', he added.

The *future*

AGSO will continue to develop and apply GIS-based DSS that can integrate, weigh and model diverse data on known and potential mineral and petroleum resources and other geoscience values with environmental and other land values including those related to land and water degradation.

'Currently, we are collaborating with the Bureau of Rural Sciences to make a powerful and adaptable decision support system by combining the RFA GIS system with the ASSESS system used to identify suitable sites for a national low-level radioactive waste site', says Dr Lambert.

'We will use this system to integrate and analyse detailed and diverse datasets at a range of scales.'

Other important geoscience data layers that will be dealt with increasingly in land use DSS include radiometric layers and airborne magnetics and electromagnetics. Radiometric layers can assess the distribution of natural radioactivity and assist with geological, regolith and soil mapping. Airborne magnetics and electromagnetics will be used more widely to help in understanding the extent and causes of land degradation, including salinity and acid sulphate generation.

Dr Lambert emphasised that collaboration and data sharing between geoscience, land management and environmental agencies can only be beneficial.

In addition to these interesting decision support projects, AGSO's Resources and Advice activities encompass many other tasks. These include publishing each year a report on Australia's known mineral stocks for all major and several minor commodities, contributions to the 'Red Book' on international uranium resources and demand, advice on on-shore and offshore exploration, mining, and processing, as well as on metals and the environment.

For further information phone Ian Lambert on +61 2 6249 9556 or e-mail ian.lambert@agso.gov.au

A discussion of mass attraction

Australian palaeomagnetism, rock magnetism & environmental magnetism

discussion meeting 3–4 May 2000

Organised by AGSO, the Australian National University, and CSIRO Exploration & Mining this meeting is for those who undertake: investigations in palaeomagnetism, rock magnetism, or environmental magnetism; use or might use the results of investigations; or require laboratory and scientific services in these areas. It is a particularly important meeting given the uncertain future of the major laboratory facilities provided traditionally by CSIRO and AGSO.

Those who have an interest in the area or wish to learn about the capabilities of methods used would also find this meeting useful.

Scope

The program will be informal, and will combine the presentation of new results, discussion of problems, and development of new initiatives. The emphasis will be on the applications of palaeomagnetism, rock magnetism and environmental magnetism, and their effectiveness for problem solving. Users and potential users will have an opportunity to learn more about the tools employed and how they might be of benefit to them.

Structure

The first day of the meeting will cover a range of topics, and will include an invited talk by Professor Chris Powell. The second day will centre on a discussion of the Palaeozoic apparent polar wander path for Australia.

Cost

The meeting is being held at the Australian Geological Survey Organisation in Canberra. A registration fee of $30 covers the cost of light refreshments and minor benefits. A dinner will be held on Wednesday evening (May 3), at a cost not exceeding $35 per person.

If you are interested in attending please phone Charlie Barton on +61 2 6249 9611 or e-mail charles.barton@agso.gov.au

Happy coincidence ideal for national program pilot

▲ Australian Capital Territory Chief Minister Kate Carnell and Education Minister Bill Stefaniak thumb through some of the many resources available in AGSO's Earth Science Education Centre.

The Geological Society of Australia and the Science Educators Association (ACT divisions) launched their Mentor and Resource Link program at AGSO's new education centre on March 13. At this stage it is a pilot program for what will most likely become a national scheme.

Canberra is initiating the program because it has ideal conditions for its success.

'In Canberra you have the happy coincidence of a medium-sized population of 300-odd thousand people, 29 high schools and colleges, and a very high concentration of geoscientists at AGSO, the Bureau of Rural Sciences, CSIRO and the universities', says Greg McNamara, manager of AGSO's Earth Science Education Centre.

'We've got the concentration of professionals that can mentor and manageable numbers of teachers and students in need of that service.'

ACT Chief Minister Kate Carnell and ACT Education Minister Bill Stefaniak launched the program.

Ms Carnell says that mentor programs like this one that provide a vital link between education, science and the Australia's future are endorsed by her government.

She says that given the importance of earth sciences to Australia she is very 'proud' that Canberra has been chosen to pilot the program.

'Since the gold rush of the 1850s Australia's mineral exports have brought the country wealth and created a lot of opportunities not only in geology and mining, but also in research, government, tourism, urban planning and development—and the list goes on', she says.

'And even though our export base is changing over time to focus on such things as tertiary products and information technology, our mineral resources still contribute significantly to the country's export earnings—and will continue to do so.'

She says that for the last 150 years those involved in earth sciences—whether it be in industry, research or even teaching the next generation of geoscientists—have played an enormous part in Australia's development and its future.

Mr Stefaniak thanked the ACT division of the GSA for its education policy that shows long-term commitment towards improving teaching and learning in scientific and environmental studies in Canberra.

'We have a lot of students that are going to get enormous benefit out of this program', he says.

'I give my whole-hearted support to this outreach program because it will not only give teachers help when and where it is needed, but it will also motivate student involvement in earth sciences well beyond their years of schooling.'

The idea for the program was floated in Canberra's geoscience community in mid-1999 and 70 scientists put their names forward as possible mentors.

The mentors are volunteering to respond to teacher calls for help. The type of help requested will vary. But it can be as simple as helping teachers find information or a book in a general library or AGSO library or lending some material from a personal collection. It could also involve talking to students or being involved in a session at the Earth Science Education Centre.

Mentor details are held on a database in the education centre. The centre will also obtain quarterly and half-yearly feedback from mentors and teachers who have used the program.

For more details phone Greg McNamara on +61 2 6249 9571 or e-mail greg.mcnamara@agso.gov.au

▲ ACT Chief Minister Kate Carnell (centre) shares anecdotes with guests at the launch of the Mentor and Resource Link program. (From left) Greg McNamara, Patrick Lyons (Secretary GSA ACT), Ken Lawrie (Chair GSA ACT), Sonia Cousins (GSA Promotions and Education Manager), Neils Hider (Vice-president SEA*ACT), and ACT Education Minister Bill Stefaniak

DID YOU *know?*

On February 21 this year the *Endeavour* space shuttle on a voyage to acquire data on the Earth's topography extended its mission by 10 minutes to include a final pass over Australia.

All of Australia was covered with one pass and roughly 94 per cent with a second pass. The shuttle collected Australian data during its ascending orbits (south to north) and, after reflector orientation changes, during its descending orbits. Repeat passes were designed to improve the quality of elevation data.

Approximately 123 million square kilometres of Earth were mapped during the 11-day mission. Most land surfaces between $60^{+/-}$ degrees latitude were mapped.

PNG VOLCANO AWARENESS INCREASED WITH CAMPAIGN HELP

Public awareness, an essential element of the Papua New Guinea–Australia Volcanological Service Support (VSS) Project, will be stepped up in late April with the release of a new information kit, 'Dangerous volcanoes of Papua New Guinea', prepared by AGSO and the Rabaul Volcanological Observatory (RVO).

▲ The latest information kit, 'Dangerous volcanoes of Papua New Guinea' published in Pidgin English.

This kit is part of an ongoing campaign directed at giving PNG's people accurate information about the volcanoes they live with, and ensuring that valuable equipment is not damaged or removed from monitoring sites. In the past these volcanoes killed people and destroyed homes and crops.

The campaign began three years ago in the Rabaul area prior to starting the Rabaul Earthquake Location and Caldera Structure (RELACS) survey. This geophysical survey of the Rabaul caldera involved the temporary deployment of many land and ocean bottom recorders around the Gazelle Peninsula to increase what was known about the deep structure of Rabaul volcano.

'We had a lot of recorders around the Rabaul area and we knew very early in the project that we had to make sure the equipment was not damaged or stolen', says project team member Shane Nancarrow.

Armed with information brochures and a video produced by the VSS Project titled *The voice of Kaia*, RVO Community Liason Officer, Donald Okole, and observatory staff visited villages, schools and community groups around the Gazelle Peninsula area. They built awareness of the RELACS survey and the importance of the work being performed. Local people were asked to care for the RELACS equipment and the extensive state-of-the-art network that the RVO was using to forecast any future eruptions of the volcanoes in the area. As a result, only a few minor incidents were experienced.

The role of RVO staff was expanded to include regular visits to the Rabaul community and to invite local people on observatory tours.

'Visiting the observatory that sits high up on the caldera wall was a big step for some locals', says Mr Nancarrrow.

'Historically local people would not go near the site and the observatory did not encourage visits.'

Since the campaign started many groups have visited and the theft and vandalism rate of the RVO network has been reduced.

'We're finding that local people have taken a real interest in the observatory and are trying to be as helpful as they can', he says.

Elevation data were acquired by special equipment on *Endeavour*, namely radar electronics and antennas in the payload bay and, once in space, a 60-metre mast with outboard antennas attached to its end. Radar was used because it operates day and night and penetrates cloud cover. Antenna in two separate places on the shuttle produced two different images. The difference between the two images is used to calculate surface elevation. All mapping data were saved to recording devices onboard.

The preliminary digital elevation maps available use data from a single mapping pass and have not been calibrated or verified. Precision products will be generated over the next two years and eventually a comprehensive, high-resolution, three-dimensional map of Earth will be available.

A research team from AUSLIG, Australia's national mapping agency, will help validate the Australian elevation data.

Due to the success of the Rabaul public awareness campaign, activities now will include the four other high-risk volcanoes associated with the project—Ulawun, Karkar, Manam and Lamington.

The new information kit is printed in Pidgin English and English—PNG's two main languages—and has a companion video, a 30-minute documentary titled *Living with volcanoes* (also in the two languages). The kit is very pictorial because photos and cartoons will help RVO staff members tell villagers, some of whom have low literacy levels, about their volcanoes, the observatory's role and evacuation procedures.

Mr Nancarrow says that the PNG Department of Mining, the West New Britain Provincial Government, and the National Disaster Management Office have been very supportive of the campaign.

'For a start, the National Disaster Management Office supplied 17 500 kina towards producing this kit', he says.

Schools also have appreciated these materials. In addition to campaign materials, last Christmas all 147 high schools in PNG were sent a teacher resource package by the project. It contained textbooks and posters on volcanoes, earthquakes and landslides.

'We've already had positive feedback from some schools', Mr Nancarrow says. 'They've sent very nice letters to us, the Australian High Commission, and the RVO expressing their thanks.'

The PNG–Australia VSS Project is funded by AusAID, the Australian Government's international development agency.

Letter of thanks to the VSS Project from one PNG high school for the learning materials they received last Christmas.

MAJOR PROGRESS FOR GEOLOGICAL UNITS DATABASE

The Australian Geological Units database was given a huge boost in January-February when more than 600 bibliographic references and new information on 13 000 geological units including about 1400 new names were added to the database by 10 temporary staff employed during university holidays.

New geological references were indexed for stratigraphic names and other geological unit data. As well, the data for many of the existing units was upgraded to include information such as age, geological province and any changes to unit rank or relationships with other units. Also updated were the indicators that show which references contain the most information. The boost to the database is in addition to on-going indexing and the backlog project.

The backlog project is gradually getting all old card-file data, gathered prior to 1969, into the on-line database. Most of the explanatory notes from around Australia have been captured, as well as almost all of the Queensland references data that AGSO held on cards. Data capture is well underway for the other States.

The Australian Geological Units database can be queried on-line at http://www.agso.gov.au/information/structure/isd/database/stratnames.html

For further information phone Cathy Brown on +61 2 6249 9535 or e-mail cathy.brown@agso.gov.au

Perfect zircon for rock dating no fairytale

Once upon a time in a paddock 30 kilometres east of the little country town of Temora in New South Wales something wonderful happened to create an intrusion of gabbroic diorite housing almost pure-state zircon crystals that might soon be used worldwide as a standard for determining rocks ages.

The zircon-containing rocks, buried for 417 million years, have been partly exposed in recent times as civilisation reached the remote paddock. Road building, telecommunications cables and a farmer bulldozing his land brought some of them to the surface.

'We've been searching for 20 years for zircon of this quality', says Dr Lance Black, AGSO scientist and one of the geologists who brought the rock in for initial study.

'We searched in South Australia, Sri Lanka, Canada, the United States and Europe for high-quality zircon that would be suitable as a standard, but all have had some sort of drawback and proven frustratingly imperfect.'

Circumstance has made the Temora rocks and their zircon crystals special.

In a paddock, miles from anywhere AGSO scientists found this boulder containing extremely pure zircon crystals that will allow scientists around the world to date rocks more accurately than has previously been possible.

Left buried and undisturbed for millions of years, the rocks have not suffered the extremes of surface temperature and weathering. They crystallised high in the earth, probably about two kilometres from the surface, and haven't undergone any extreme geological event since they formed. As well, the composition they inherited when they formed proves ideal—there is only one generation of zircon present.

'These rocks are derived from the melting of rocks that didn't have zircon in them', says Dr Black.

'So we don't have the problem of zircon from the parent rock contaminating the zircon of the new rock.

'Such mixtures complicate working out how much lead or uranium has been lost or gained from the zircon that actually crystallised in the rock.'

The scheme used to date rocks is based on the radioactive decay of uranium. Minute traces of uranium locked inside the zircon crystals have been decaying over aeons, producing lead. Scientists know that the decay occurs at a fixed rate and how quickly it happens. By measuring the relative amounts of uranium and lead encased in the crystals, scientists can determine how old the rock is.

But sometimes lead is lost from zircon crystals via processes such as weathering (if the rocks were exposed on the surface) or deformation and metamorphism (if the rocks had crystallised deep in the earth and been subjected to high temperatures and pressure). Hence the special nature of the Temora rocks.

There are many other older zircon-containing rocks in Australia. The oldest zircon recorded on Earth, about 4280 million years old, was found in Western Australia. But its circumstances—formed deep in the Earth, crystals damaged by radioactive decay, its long and complicated history, and lead loss—make the zircon unsuitable as a standard for dating rocks.

Zircon dating allows scientists to get the relative (and, more importantly, absolute) ages of rocks when they can't be determined by fossils or other means like stratigraphy. The age of a rock helps scientists determine the sequence in which rocks formed and their relationship to each other. This information leads to a better understanding of how the Earth formed and evolved, and helps in predicting where ore bodies and petroleum could be found.

There are different methods of dating zircon. One involves chemical decomposition of the zircon crystal (thermal ionisation mass-spectrometry), and another is a micro-beam technique called 'SHRIMP' (sensitive high-resolution ion micro-probe). The chemical decomposition method does not require a zircon standard, and the zircon is dissolved in the process. SHRIMP on the other hand is not particularly destructive and a beam of charged oxygen makes a micron-deep crater in the crystal. The zircon crystal therefore can be dated many times and different parts individually analysed.

SHRIMP dating was used for initial tests on the Temora rocks. Then, in December last year, the sample was sent to the world-recognised authority, Canada's Royal Ontario Museum, for independent analysis and dating via chemical decomposition. The museum confirmed the near perfect quality of the zircon and its age.

Early this year Dr Black and scientists from the Australian National University (ANU) returned to the paddock to recover another tonne of Temora rock.

From this, 40 to 100 grams of zircon crystals should be extracted. Some of these crystals are undergoing the same tests as the first sample. By September scientists will know whether there is enough near perfect Temora zircon to meet the world's geochronological demands for decades.

If not, there is enough from the first boulder to maintain a 10-year local supply.

Dr Black says that both fine-grained and course-grained varieties of gabbroic diorite are found in the paddock. Current tests should resolve whether the considerably more abundant zircon in the coarse phase is as ideal for dating as that in the already proven fine-grained rock.

The rocks were discovered on a routine sampling trip as part of the Lachlan mapping project. It was Friday afternoon and the last site geologists visited on that trip.

'The rock looked nice and fresh, but it did not have much silica in it and so we thought it was unlikely to contain zircon', says Dr Black.

They had doubts about whether they should bother to take samples.

'However we did and when we separated it in the lab we found that not only did it have zircon but it was all of the same type.

'So we talked to Dr Ian Williams, leader of the SHRIMP group at ANU, and it all progressed from there.'

For more details phone Lance Black on +61 2 6249 3125 or e-mail lance.black@agso.gov.au

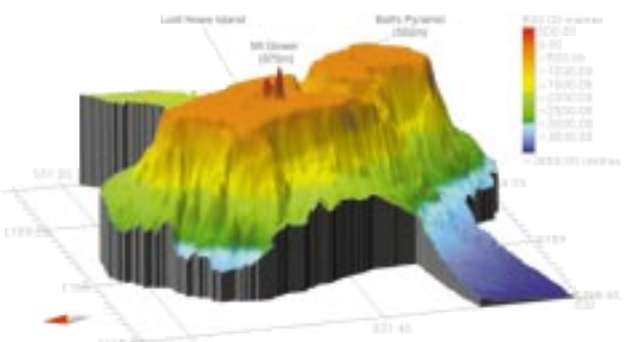
▼ Pictured with the 417 million-year-old rocks that caused much excitement are (from left) property owner Barry Wiencke and the AGSO team Morrie Duggan, Lance Black and Jon Claoue-Long.

Seabed off south-east Australia a first 1 images

While most Australians celebrated Christmas and New Year at home, three AGSO scientists were at sea mapping a huge area of seafloor never before surveyed off Australia's south-east coast.

The AUSTREA-1 survey was phase one of the first major research program under Australia's $50 million Oceans Policy, a national plan aimed at protecting and managing Australia's oceans. Leader of the four-week 'cruise', AGSO's Peter Hill, gives a run-down on phase one.

▲ **Figure 1.** The track of *L'Atalante* during AUSTREA-1 showing survey areas between Lord Howe Island and the Great Australian Bight. AUSTREA-1 complemented existing AGSO swath-mapping surveys (*Tasmante* 1994, *Sojourn7* 1997).



▲ **Figure 2.** Lord Howe Island and Ball's Pyramid 'hot-spot' volcano—the 3D image is based on the AUSTREA-1 multibeam data below 300 metres water depth. The rugged terrain on the flanks of the seamount (flows, canyons, volcanic cones and pinnacles—many 200–300 metres high) suggests diverse ecosystems.

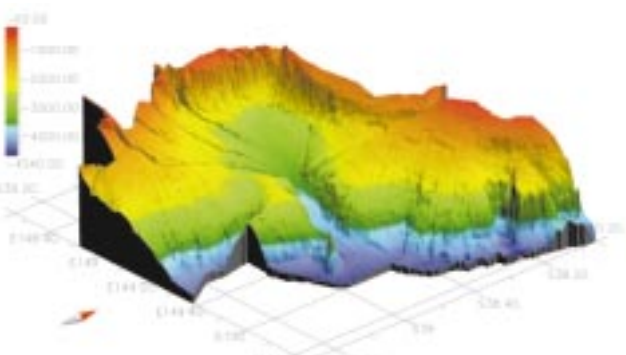


Figure 3. Seafloor topography and canyon systems of the Bass Canyon Complex off Gippsland, produced from AUSTREA-1 swath data merged with data from AGSO's 1997 *Sojourn7* survey. The view is to the north-west and shows an area about 150 kilometres across. The 2000 metre deep, 15 kilometre wide Bass Canyon has been a conduit for sediment shed off the adjacent land and shelves for at least the past 50 million years. The Gippsland oil fields are located on the shelf immediately to the west, and the canyon heads are important deep-sea fishing grounds. ▶

'Australian' scientists (from left) Nadège Rollet, Peter Hill, David Rowland and Clive Calver celebrate success at an end-of-cruise function on *L'Atalante*.

On January 11, the 85-metre French oceanographic and geoscience research vessel *L'Atalante* berthed in Hobart, completing a successful seabed swath-mapping and geophysical survey that began in Noumea 25 days earlier.

Commissioned by Environment Australia and the newly established National Oceans Office, the survey is the first of two AUSTREA geoscience research cruises to be carried out by AGSO off south-east Australia this year.

The cruises provide scientific information on bathymetry and seabed structure for not only geological but also biological research. Data gathered will be used for marine zone planning and management, and assessing seabed living and non-living (petroleum and mineral) resources. They are a major step towards implementation of Australia's Oceans Policy and its Marine Science and Technology Plan.

Area covered

AUSTREA-1 covered 11 thousand kilometres and mapped approximately 120 thousand square kilometres of seabed—an area about 1.5 times the size of Tasmania (figure 1). Notable areas surveyed include:

- the submarine volcanic slopes of Lord Howe Island (figure 2) and the proposed marine protected area out to 12 nautical miles;
- the rugged, canyoned continental slope off the New South Wales south coast;
- offshore Gippsland Basin and the spectacular Bass Canyon complex (figure 3). This extends the area swath-mapped by AGSO in 1997;
- deep-sea fishing grounds and frontier petroleum basins off east, south and west Tasmania. This extends the area swath-mapped by AGSO in 1994 and 1997;
- submarine volcanoes south of Tasmania, including the eastern part of the Tasmanian Seamounts Protected Area. Thirty new volcanic cones were mapped;
- deeply canyoned, and generally sedimented, continental slopes off north-west Tasmania, south-west Victoria and Kangaroo Island;
- the Great Australian Bight Benthic Protected Area of the GAB Marine Park. The research team found that this was generally a uniform slope, but that the gigantic Nullarbor Canyon crossing its south-eastern corner is gouged deeply into deformed Late Cretaceous to early Tertiary sediments.

The maps and ideas generated by this and earlier geoscience cruises will be the basis for follow-up biological sampling and seabed acoustic studies early this year.

CSIRO's research ship, *Southern Surveyor,* will be used for a series of linked research cruises involving AGSO, CSIRO and the National Oceans Office. The maps produced, showing seabed shape, character and habitats, will provide basic information needed by the Hobart-based National Oceans Office for development of the South-east Regional Marine Plan.

The second phase of the AUSTREA surveys takes scientists to Macquarie Island Marine Park and southern parts of Australia's Exclusive Economic Zone. A summary of this phase will be published in the June issue of *AUSGEO News.*

Research team and equipment

L'Atalante, pride of the French research fleet, is equipped with one of the most powerful multi-beam swath-mapping systems in the world, the Simrad EM12D. AUSTREA-1 scientists used this and a wide range of other state-of-the-art geophysical and oceanographic survey systems, including a six-channel GI-gun seismic, a digital 3.5 kHz sub-bottom profiler, gravity meters, a magnetometer, and an acoustic doppler current profiler. With this equipment, they could map approximately 400 square kilometres of seabed an hour and to ocean depths of more than 5000 metres. In addition, the seismic equipment allowed them to analyse sedimentary strata up to five kilometres beneath the seafloor in the Gippsland, Sorell, Otway and GAB Basins, and off eastern Tasmania.

On board *L'Atalante* for phase one were five Australian scientists and 31 French crew, engineers and technicians. The 'Australian' scientific team comprised AGSO's Peter Hill, Nadège Rollet and David Rowland, as well as Clive Calver of Mineral Resources Tasmania, and Jonathan Bathgate of the University of Sydney.

For more information phone Peter Hill on +61 2 6249 9292 or e-mail peter.hill@agso.gov.au or contact Gordon Anderson of the National Oceans Office by phoning +61 3 6221 5009 or e-mailing gordon.anderson@ea.gov.au

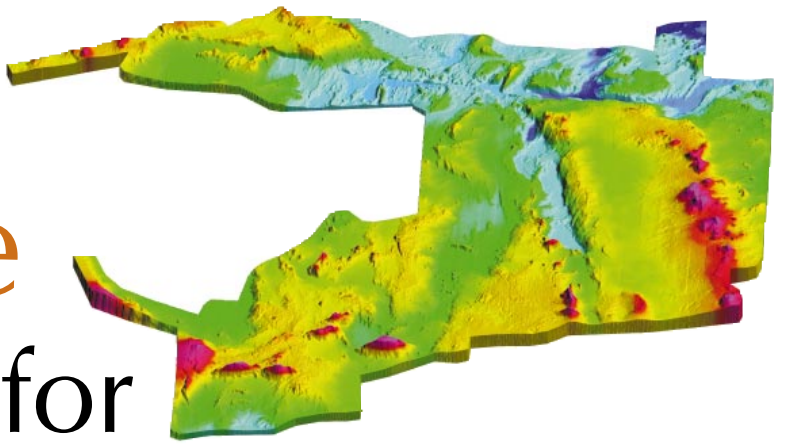


Figure 3. Pseudo-3D perspective view from the south of the FAUST-2 bathymetric data.

Picture builds for AUSTRALIA'S EASTERN LIMITS

Australia is trying to confirm the extent of its seabed jurisdiction (extended continental shelf) east of the 200 nautical mile Australian Exclusive Economic Zone around Norfolk Island.

To get a clearer picture of the region, the FAUST-2 cruise with AGSO and French scientists on board set sail in mid-November last year for an area of complex morphology to the east of the Norfolk Ridge. Results are still being compiled, but cruise co-leader Phil Symonds outlines some of what was found.

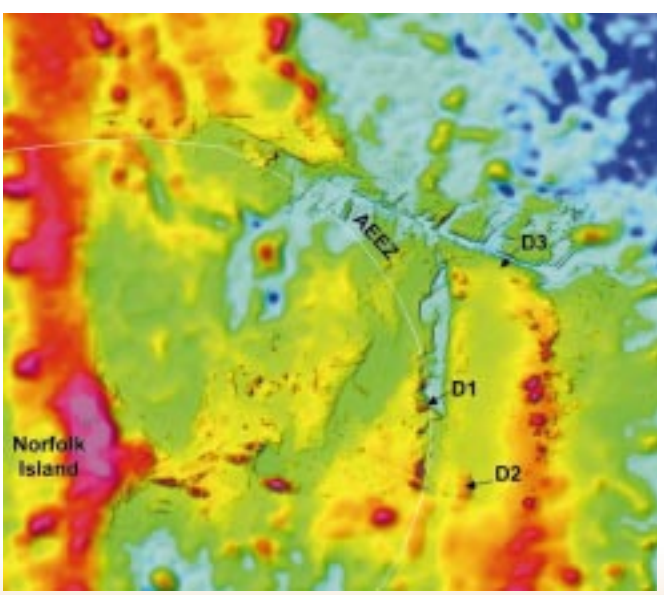


Figure 2. Colour-gridded, hill-shaded bathymetric map of the FAUST-2 study area based on the *L'Atalante* swath-mapping data merged with predicted bathymetry from satellite altimeter data. FAUST-2 dredge sites and the Australian Exclusive Economic Zone (AEEZ) are shown.

The FAUST-2 survey, a 32-day program from November 12 to December 13, 1999, mapped nearly 190 thousand square kilometres of complex bathymetry between Norfolk Ridge in the west and Three Kings Ridge in the east.

It covered a unique part of Australia's marine jurisdiction that contains evidence for convergent tectonism related to collision and subduction along the eastern margin of the Australia plate (figure 1). Several important tectonic features were studied, such as possible subduction-related island arcs and extensional back-arc basins lying between major bounding fracture zones (the Cook and Veining-Meinesz fracture zones).

The survey was carried out on board the French research vessel *L'Atalante*. It has a multibeam sonar Simrad EM12D swath-mapping system capable of producing contour maps and reflectivity imagery of the sea-floor in a swath up to seven times as wide as the water depth. In addition high-speed seismic and potential field systems were used, and three dredge hauls obtained rocks from basement scarps throughout the area surveyed.

Approximately 13 300 kilometres of swath multibeam data, and 3.5 kHz echosounder, gravity and magnetic data along generally north-north-east to south-south-west oriented survey lines were acquired. (This equates to a swath coverage of an area more than 2.5 times the size of Tasmania.) High-speed seismic reflection, magnetic and gravity profiles were recorded along most of the survey lines. These data represent a quantum leap in knowledge of this poorly known area.

Results

The survey has added to data from a 1997 *Rig Seismic* deep-seismic survey in the region conducted for marine zone definition purposes in collaboration with the New Zealand Ministry of Commerce.

The results of the FAUST-2 survey are currently being interpreted in Australia and France. They will provide important new insights into the tectonic development and marine environment of this complex, unusual and virtually unknown part of Australia's marine jurisdiction. Significant results from the survey so far include the following.

Large elongate and small, clustered volcanic sea-mounts were discovered to the east of the Norfolk Island platform on the saddle that separates the North and South Norfolk Basins (figures 2 & 3). Some of these features are up to 30 kilometres in length and shallow (from about 2250 to 800 metres depth). The largest sea-mount mapped occurs in deeper water further east. It is about 50 kilometres long, 28 kilometres wide and rises about 2800 metres above base level to a flat top at about 660 metres water depth.

Also found were several flat-topped sea-mounts that rise from the crest of the Three Kings Ridge at about 2000 metres depth to within 500 metres of sea level.

There is a narrow (about 20 km) north-south trending trough that varies in depth from 2800 metres in the south to 4000 metres in the north. It separates a smooth terrace-like area at about 2500 metres depth that forms the western flank of the Three Kings Ridge, from a region of more complex bathymetry to the west. This trough, which appears to link with the Cook Fracture Zone in the north, shows evidence for normal faulting on its western flank, but possibly some compression on its eastern flank. Dredging of an apparent tilt block on the western margin of the terrace in the south of the survey area (figure 2) produced a full chain-bag containing a variety of sedimentary rocks (figure 4). These included a large volume of conglomerate that contained sub-rounded pebbles and boulders of mainly basaltic composition.

The most spectacular bathymetric feature in the FAUST-2 survey area is the 400 kilometre long Cook Fracture Zone that separates the Norfolk-Three Kings Ridge region from the northern part of the South Fiji Basin (figures 2 & 3). The fracture zone is a very linear and complex strike-slip system that links the Three Kings Ridge in the east with the Loyalty Ridge in the west. Many classic strike-slip features imaged within the fracture zone indicate that the most recent movement along it is left-lateral. Dredging on the southern wall of the Cook Fracture Zone to the west of Three Kings Ridge (figure 2) obtained a full chain-bag of mainly basaltic rocks, including tectonised pillow basalts.

The new data show that there is a continuous but complex connection between the Norfolk Island platform in the west and the Three Kings Ridge in the east that averages about 2500 metres deep, and is nowhere deeper than 3200 metres. In comparison, the adjacent deeper areas of the South and North Norfolk Basins, and South Fiji Basin, vary from 3500 to more than 4000 metres deep.

Four cruises

The FAUST-2 survey was the result of an agreement between AGSO and IFREMER (Institute Francais de Recherche pour l'Exploitation de la Mer) to exchange *Rig Seismic* and *L'Atalante* ship time.

In October 1999, AGSO and IFREMER embarked on a major program of four seabed-mapping surveys off eastern and south-eastern Australia. The initial two cruises were conducted from October to December 1999. The first over the northern Lord Howe Rise and Fairway Basin was reported in the February 2000 issue of *AUSGEO News*. FAUST-2 was the second cruise.

The FAUST-2 cruise included 12 scientists and technicians from IFREMER, AGSO, CNRS-INSU Université Pierre et Marie Curie (Paris), Services des Mines et de l'Energie (Noumea), University of Lille, University of Perpignan, Institute de Physique du Globe de Paris, and the University of Sydney. It was led by Alain Mauffret (Université Pierre et Marie Curie) and Phil Symonds (AGSO).

The other cruises (December 1999 to February 2000) were contracted by AGSO for the National Oceans Office. These were carried out off south-east Australia (see article on AUSTREA-1 this issue) and south of Macquarie Island.

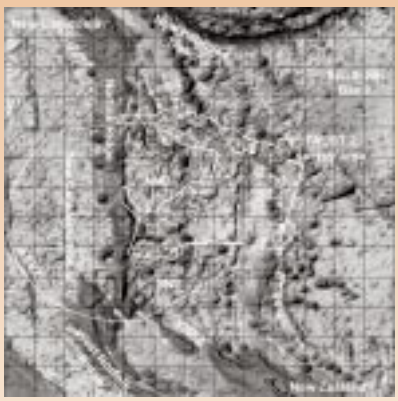


Figure 1. Bathymetric map of the Norfolk-Three Kings Ridge region based on predicted bathymetry from satellite altimeter data. This figure shows the location of the *L'Atalante* FAUST-2 survey area. Abbreviations: CFZ—Cook Fracture Zone; NNB & SNB—North and South Norfolk Basins; VMFZ—Veining Meinesz Fracture Zone.

Figure 4. Deformed pillow basalts from dredge site 3 (D3, figure on opposite page) on the southern flank of the Cook Fracture Zone.

For further information contact Phil Symonds by phone +61 2 6249 9490, fax +61 2 6249 9920 or e-mail phil.symonds@agso.gov.au

Mineralisation: complex but suite story in GRANITE

Ever since it was noted in Scotland more than 200 years ago that granite dykes were intrusive into metamorphic rock, controversy has raged over the origin of granites.

In the past the debate focused on whether granites are of metamorphic origin or formed by the crystallisation of magmas. Today the arguments are about their source rocks and the reasons for compositional variation.

Apart from a desire to answer such questions, granites should be given attention because they are an abundant rock, and they have metallogenic implications. Answer the questions about granites, we're told, and we'll know more about the evolution of Earth's crust and have a few more ideas on where to look for ore bodies.

Workshop

On December 10 last year, a Granite Workshop was held at AGSO for sponsors of the AMIRA (Australian Mineral Industries Research Association) project on Igneous Metallogenic Systems of Eastern Australia, and other geologists. Two well-known granite aficionados presented the workshop: Professor Bruce Chappell, from Macquarie University, and Dr Allan White from the University of Melbourne.

Suites

Both presenters emphasised assigning granites to 'suites' and 'supersuites'. They argued that the suite concept was a key to understanding the petrogenesis of granites.

A suite was defined as a group of granitic rocks with common petrographic, mineralogical and compositional characteristics. When granites are assigned to a suite, an assumption is made that the rocks of a single mappable unit (referred to as a pluton) are co-magmatic. Suites can comprise more than one pluton and these plutons don't necessarily come from a single magma body. What is important is that they have either the same composition or the same compositional trends.

Supersuites are categories for granites with small compositional differences that prevent them from being neatly grouped within a suite. In other words, if a few elements differ, then the rocks are members of the same supersuite rather than the same suite.

Granites produced millions of years apart that show small differences would be assigned to a supersuite. The age of the rock therefore is probably not relevant when assigning granites to suites. The importance of isotopic composition when grouping granites is also questioned because granite can be derived from heterogeneous source rocks.

Composition

Quartz, potassium feldspar and plagioclase are common to all granites. How much of each of these is present in the rock depends on its evolution. Strangely, irrespective of the dispersion of composition, fairly predictable volumes of sodium, potassium and silica are present in almost all felsic or light-coloured granites (roughly 3.5% Na_2O, 4.5% K_2O, and 72% SiO_2). The composition of other granites is not as simple and eventually approaches the compositions of the source rocks.

Professor Chappell says that no matter how the granites evolved, rubidium is an index for the degree of evolution. Granites with large amounts of rubidium are more felsic, more evolved and highly fractionated, and more likely to be mineralised.

Variations in geochemical composition of suites in eastern Australia suggest that different processes could have produced the granites. Various models have been put forward for the variation including: magma mixing or mingling, assimilation or contamination by 'country' rock, fractional crystallisation, restite crystal fractionation, varying degrees of partial melting, hydrothermal alteration, and variation in source rock composition.

In the simplest suites, Professor Chappell suggests that the rocks were formed from magmas derived by partial melting of quartzofeldspathic rocks. Variations within the suite resulted from restite (solid material) and melt fractionation. The granite therefore could comprise parent material, products of melt reactions, and melt.

Generally speaking, low-temperature granites belong to simple suites while high-temperature ones belong to more complex suites.

Mineralisation

In simple suites there is no mineralisation. Therefore don't expect to find minerals in the restite-fractionated suites of eastern Australia. The granites associated with mineralisation are high-temperature granites; those that have undergone extensive fractional crystallisation.

One notable example of mineralisation associated with highly fractionated rock is the tin-bearing Ardlethan Granite in New South Wales. Other examples are the tin deposits of England (Cornwall), Bolivia and Thailand.

Dr White says that he has no doubts that granites also produce porphyry copper.

'When you go to a big porphyry copper deposit like Bingham Utah that has also produced a thousand tonnes of gold, there is no doubt that the mineralisation is directly derived from the granite', he says.

Granites of the porphyry copper–gold deposits are oxidised and high in barium.

'Olympic Dam', Dr White says 'is a good example. It is loaded with barium'.

Dr White has also often seen molybdenum veins near porphyry copper.

'For example, in Butte Montana I went into the mines before they closed and beneath the porphyry copper pit I saw a lot of "molly" veins', he says.

Dr White suggests that deposits of these minerals are directly related.

The biggest 'molly' deposits he knows of are in the mineral belt of Colorado where the granite is

oxidised but more highly fractionated than in porphyry deposits.

Dr White also mentioned that a number of big deposits occur in quartz monzonite—Butte Montana, Bingham Utah. The quartz monzonites and granites have fractionated from monzonite magmas (shoshonites are the fine-grained equivalents of monzonite). He believes that a large magnetic anomaly below Olympic Dam could be monzonite. At Cripple Creek Colorado gold occurs in an alkaline shoshonite complex.

'I wonder if the more monzonitic rocks produced all the goodies', he says.

Ideas on mineralisation are controversial and the debate about the origin of granites still rages. No doubt the complexities will take time to unravel but the suite concept may just hurry along the process.

GEOSCIENCE EDUCATION ON INTERNATIONAL AGENDA

Twenty-four countries were represented at the third international conference on geoscience education (GeoSciEd III) held at the University of New South Wales in Sydney from January 16–21. Although official delegate numbers were modest—174 in all—for international conferences, those participating were fired up about the importance and relevance of teaching geoscience.

'The opportunity to share ideas and resources are limited for just about all geoscience educators because many do it as an adjunct to their regular jobs as geologists', says Gary Lewis, Manager of AGSO's Geoscience Awareness and Marketing Unit.

▲ On duty in the AGSO booth at the 3rd GeoSciEd international conference are (l-r) Cindy Trewin, Gary Lewis and Greg McNamara from the Geoscience Awareness and Marketing Unit.

'So there is a real hunger for teaching materials and contact with others trying to give geoscience the prominence it deserves', he says.

Mr Lewis says the delegates' enthusiasm for geoscience education was evident in the fact that some of them had to raise funds to attend the conference.

'This was especially true for delegates from developing countries such as the Philippines, Bangladesh and Mozambique.'

At one key meeting during the conference, the International Geoscience Education Organisation (IGEO) was launched. The IGEO aims to raise public awareness of geoscience and promote geoscience education internationally. Its main function will be fostering communication worldwide among geoscience educators and geoscientists. Membership of this organisation is free.

Another important part of the conference, for geological and social purposes, was a field trip to Prospect Park Water Reservoir, the Blue Mountains and the Jenolan Caves.

Mr Lewis says it was a great honour for AGSO to be one of the conference conveners and he felt proud when Australia was applauded for its attention to geoscience education.

GeoSciEd IV will be held in Calgary, Canada, in 2003.

For more details phone Gary Lewis on +61 2 6249 9570 or e-mail gary.lewis@agso.gov.au

Stay updated with quarterly petroleum exploration report

Are you on AGSO's mailing list for the quarterly report *Australian Petroleum Exploration and Development Activity?* If you're not, then you may not know that there were 11 offshore and 11 onshore petroleum discoveries in 1999 and that there were significant discoveries in the Carnarvon Basin off north-west Australia.

The report lists the discoveries, summarises drilling and rig activity, and outlines seismic survey activity. Numerous tables and figures precis such data as number and type of wells, metres drilled, and the 'success' rate over the last decade.

The latest report, which summarises activity to the end of 1999, shows that the total of 51 offshore exploration wells drilled last year is on par with the average number drilled over the last 10 years. There was a significant increase in offshore exploration drilling in the last quarter, but a drop in onshore exploration drilling for the year.

Without knowing what effect high crude oil prices will have on exploration budgets and drilling programs this year, the industry forecast is an average of 54 exploration wells drilled offshore and 59 onshore in 2000.

AGSO gathers the report's statistics from various sources including the petroleum exploration industry and State and Territory mines departments.

There is no subscription fee for this report, so if you want to be on the mailing list contact AGSO's Sales Centre.

For more on the information contained in the report phone Eugene Petrie on +61 2 6249 9270 or e-mail eugene.petrie@agso.gov.au

EVENTScalendar

Compiled by Steve Ross

Australian Science Festival

29 April to 8 May

Various venues, Canberra

Contact: Australian Science Festival, PO Box 193, Civic Square ACT 2608.

phone +61 2 6205 0588

fax +61 2 6205 0638

www.sciencefestival.com.au

AGSO Open Day

7 May

AGSO Building, Canberra

Contact: Steve Ross at AGSO

phone +61 2 6249 9263

fax +61 2 6249 9990

e-mail steve.ross@agso.gov.au

2000 APPEA Conference and Exhibition: Innovations for the Third Millennium

Australian Petroleum Production and Exploration Association

7 to 10 May

Convention & Exhibition Centre, Brisbane

Contact: APPEA, GPO Box 2201, Canberra ACT 2601.

phone +61 2 6247 0960

fax +61 2 6247 0548

e-mail lgordon@appea.com.au

Broken Hill Exploration Initiative: 5th annual conference

29 to 31 May

Field excursions 26 to 28 May, 1 to 2 June

Entertainment Centre, Broken Hill

Contact: George Gibson at AGSO

phone +61 2 6249 9727

e-mail george.gibson@agso.gov.au

16th World Petroleum Congress

11 to 15 June

Calgary, Canada

Contact: 16th WPC Canadian Organising Committee, 1350 144 Fourth Avenue SW, Calgary, Alberta, Canada T2P 3N4.

phone 0011 1 403 218 2000

fax 0015 1 403 218 2002

e-mail cdn.assoc@wpc2000.comm

EXPANDED WHOLE-ROCK GEOCHEMICAL DATABASE RELEASED

AGSO has released a first version of OZCHEM, its whole-rock geochemical database of major and trace element analyses of Australian rocks. This database was previously known as ROCKCHEM.

'OZCHEM release 1' features data from 29 547 samples from Australia, and includes data from about 3438 new analyses. Its highlights include the geochemical data from analyses of:

1. Bottom-of-hole samples from the seismic traverse across the Mt Isa Inlier;
2. Bottom-of-hole samples from the seismic traverse across the Broken Hill Block;
3. Bottom-of-hole samples from the seismic traverse across Tasmania (TASGO project);
4. Samples from drillcore in the Gunnedah and Cranky Corner Basins, mostly of clastic sedimentary rocks;
5. Granites, granodiorites and syenites (including gold values) from an original study centred on the Granny Smith gold mine, Western Australia;
6. Carbonates from an original study in the Amadeus, Daly River, Hamersley and McArthur Basins and Mt Isa Inlier;
7. General whole-rock geochemical samples from NGMA mapping in the North Pilbara, Western Australia;
8. General whole-rock geochemical samples from NGMA mapping in the Lachlan Fold Belt, New South Wales.

Like earlier releases, the data have been packaged into a series of regional and thematic data sets. These, and the new prices, are tabulated below.

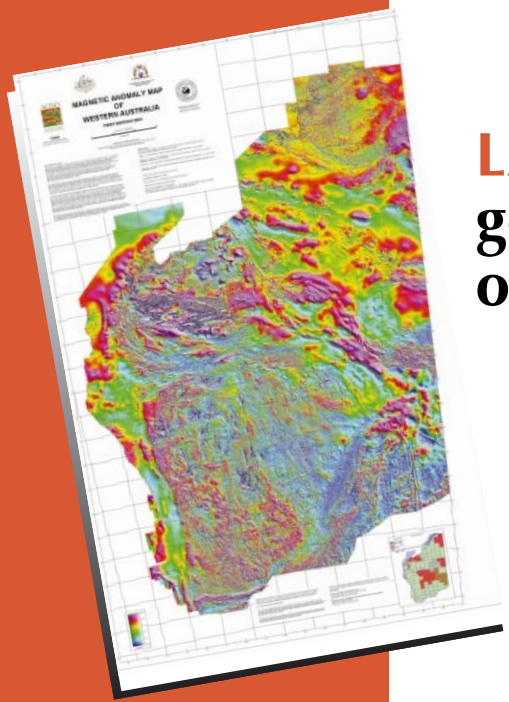
A 33 per cent discount applies to purchasers of the complete database, which is available for $39 600. Previous purchasers of the complete database may purchase copies of updates (approximately 3438 analyses) for roughly $4610 (plus postage and handling charges). Large (>500 samples) customised datasets can be prepared on demand for a fee of $2 per analyses (plus postage and handling charges). Smaller, customised datasets attract an extra extraction fee of $500 in addition to the $2 per analyses charge. Customised data sets can be selected for a 1:100 000 sheet area, 1:250 000 sheet area, geological province stratigraphic unit, or by rock type.

The data are available in the following relational database formats: Oracle export, fixed-length relational ASCII, and comma-delimited relational ASCII. For those who do not have relational databases, a fourth option—standard, comma-delimited (non-relational) ASCII format—will be offered.

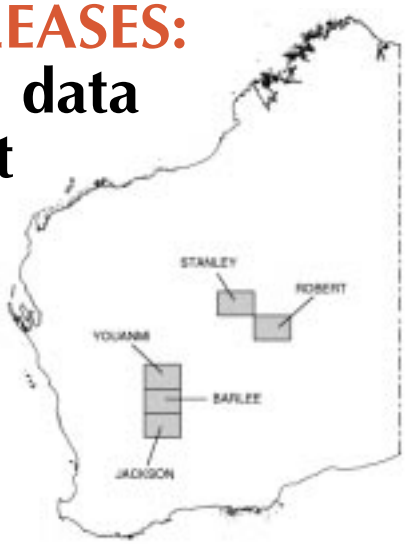
For further information, phone Anthony Budd on +61 2 6249 9574 or e-mail anthony.budd@agso.gov.au. Data can be ordered on-line from the web at http://www.agso.gov.au/information/structure/isd/database/rockchem.html

Data set	New analyses	Total analyses	Price ($)
North Queensland	2	3525	7050
Mt Isa Inlier, Georgina Basin	1281	4020	8040
Pine Creek Inlier	—	2627	5254
Lachlan Fold Belt	680	3413	6826
South Australian Proterozoic	131	678	1356
Western Australian Proterozoic	123	1506	3012
Musgrave Block	—	65	1312
McArthur Basin	267	1747	3494
Arunta Block	34	1184	2368
Tennant Creek	3	1657	3314
Yilgarn Block	284	4757	9514
Pilbara	633	2312	4624
Alkaline Rocks of Australia	—	914	1828
Broken Hill	—	551	1102
Total	**3438**	**29 547**	**$59 094**

Approximate numbers only are given here. For exact numbers of samples and pricing, please see the web site.



LATEST RELEASES: geophysical data on the West



CHECK THESE MAP PRICES

We've been getting phone calls about prices of our airborne geophysical maps. So here they are. Use the list below as a yardstick. Generally the prices listed are consistent from area to area across Australia. Postage and handling charges are not included in the prices shown below.

Compilation pixel image maps	
TMI colour	$200
TMI greyscale	$175
Both TMI colour and greyscale	$350
Pixel image maps	
1: 250 000 sheet area	
Colour	$150
Greyscale	$125
Both colour and greyscale	$250
Digital (BIL) in colour	$300
Digital (BIL) in greyscale	$250
Contour maps of semi-detailed data	
1: 250 000 and 1:100 000	
Dyeline	$40
Transparency	$120
Depth to basement maps	
Transparency	$120
Interpreted geology maps	
Hard copy	$50
Digital version	$150
Magnetic anomaly map of Australia	
1:5 million scale, edn 3	$50

Since our last issue a number of geophysical products focusing on Western Australian terrain have been released, including the following.

Magnetic anomaly map of Western Australia at 1:2.5 million scale. Data from several high-resolution surveys not included in the Magnetic Anomaly Map of Australia have been incorporated in this map. It has a high level of detail and complements the Geological Map of Western Australia. It retails at $50 plus postage and handling.

Various digital data and line maps for the **Stanley, Youanmi** and **Robert** 1:250 000 sheet areas have been released by AGSO and the Geological Survey of Western Australia as part of the National Geoscience Mapping Accord.

A merging of a 1999 government survey and a 1986 private-company survey has allowed the compilation of high-quality digital airborne magnetic, gamma-ray spectrometric and elevation model data for the **Stanley** 1:250 00 sheet area in the Capricorn Orogen region.

Magnetic and gamma-ray spectrometric point located data are available on a per kilometre basis. Elevation model data are available for the 1999 survey area only and are included in any data purchase. The full dataset (58 600 km) costs $8500; a partial dataset 15 cents per kilometre plus a set-up charge of $250 (minimum order $400 for 1000 line-km). Grids with a cell size of 80 metres can be purchased in 1:100 000 sheets ($400) or for the entire 1:250 000 sheet area ($2000). Total magnetic intensity images are also an option. Radiometric images however have not been produced as yet.

Digital airborne magnetic, gamma-ray spectrometric and elevation model data for the **Youanmi** 1:250 000 sheet area in the Southern Cross Province also are available. Data has been compiled from a 1999 government survey and four private-company surveys flown between 1987 and 1997. Except for the full dataset (80 500 km) which costs $12 000, the options and product prices are the same as that listed above for the Stanley sheet.

An outcome of the geophysical mapping program undertaken in the Eastern Goldfields was the release in March of various digital data and line maps for the **Robert** 1:250 000 sheet area. Since then high-quality colour and greyscale airborne magnetic pixel maps have been added to the list of product options.

In May, two 'interpreted geology' maps of the **Barlee** and **Jackson** 1:250 000 sheet areas will be released. The maps show Archaean geology plus magnetic units in overlying cover rocks.

For the price of pixel image maps for 1:250 000 sheet areas and interpreted geology maps see 'Check these map prices' in this issue.

Copies of maps can be bought from the AGSO Sales Centre by completing the enclosed order form, by phoning +61 2 6249 9519, or e-mailing sales@agso.gov.au. For point located data and grids phone Robert Reitsma on +61 2 6249 9210 or e-mail robert.reitsma@agso.gov.au

Vulcan Sub-basin geohistory models on CD

A new CD-ROM available from AGSO, referred to as 'Vulcan on WebBury', presents interactive geohistory models of the Vulcan Sub-basin and adjacent Ashmore Platform and Londonderry High in the Timor Sea.

The models are based on a comprehensive geohistory analysis undertaken by AGSO and Paltech Pty Ltd to constrain the thermal and hydrocarbon expulsion history of the region, and to quantify the thermal effects of Late Tertiary fluid flow events. They are generated by the WinBury 1D burial and thermal geohistory modelling software, which incorporates a simplified transient heat pulse function to simulate the thermal effect of hot fluid flow events.

The steady state and transient thermal history models are constrained by conventional vitrinite reflectance (VR) and limited fluorescence data (VRF, FAMM), together with apatite fission track analysis (AFTA) and fluid inclusion palaeo-temperature data.

The burial and thermal models are applied to two source units to constrain the timing and relative volumes of expelled liquid/gaseous hydrocarbons: Oxfordian marine shales of the Lower Vulcan Formation, and Lower-Middle Jurassic fluvio-deltaic shales and coaly shales of the underlying Plover Formation. New kerogen kinetic data for these source facies are used in the expulsion models.

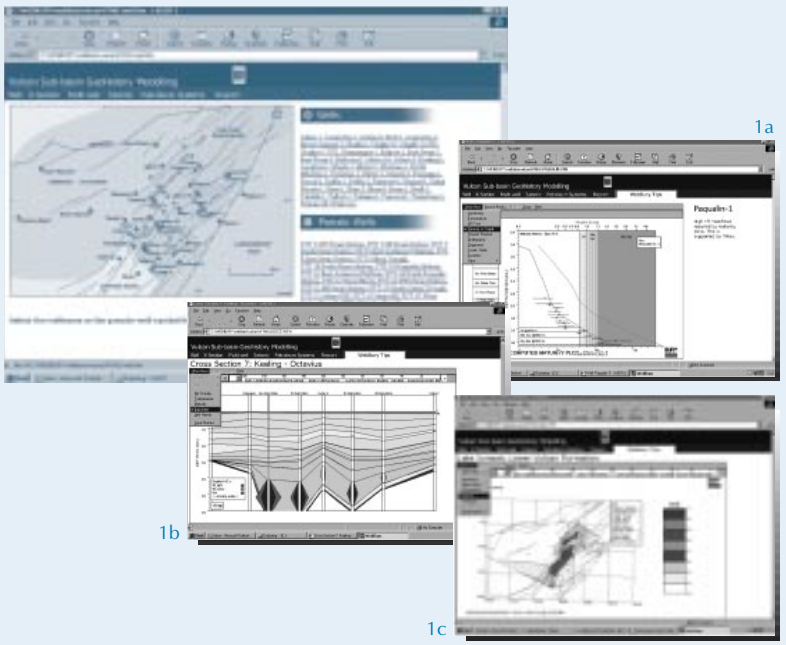


Figure 1. Screen captures of Vulcan on WebBury showing well base map. a. Paqualin-1 maturity plot. b. Cross-section Keeling-Octavius showing present-day oil (dark brown) and gas (red) expulsion. c. Maturity map of the Lower Vulcan Formation source unit at the onset of oil expulsion (Late Eocene, ~35 Ma).

Contents of CD

The modelling package is divided into the following six sections.

Wells. This section presents individual geohistory models for 44 wells and 18 depocentre sites constrained by sequence interpretation of AGSO's high-resolution 1995 VTT Vulcan Sub-basin seismic survey. Geohistory, temperature, heatflow, tectonic subsidence, maturity, source rock and hydrocarbon generation plots can be interactively selected for each well or depocentre site (figure 1a).

X-sections. In this section well-to-well cross-section geohistory models are displayed. Temperature, maturity and hydrocarbon expulsion overlays can be interactively displayed on each section. The cross-sections can be animated through time for user-specified time periods—for example, 200 Ma to present day (figure 1b).

Multi-well. Multiple-well geohistory curves and basin-wide maps for the modelled source units are found in this section. Tectonic subsidence, heatflow, temperature, maturity and hydrocarbon generation and expulsion time-plots and contoured maps can be interactively displayed, including animations through time and rate maps for user-specified time periods (figure 1c).

Seismic. Interpreted seismic lines showing the regional structural setting of modelled wells and depocentre sites are found in this section. Geohistory models for wells and depocentre sites also can be interactively selected from the seismic displays.

Petroleum systems. This section presents a schematic summary of the active petroleum systems in the Vulcan Sub-basin, and summarises the relative timing of modelled oil/gas expulsion and major structural events (compression, extension and reactivation).

Report. This text-based section presents full details of the geohistory analysis, including a discussion of charge history and implications for hydrocarbon prospectivity.

Users can easily select multiple views and options within each section via point and click buttons and drop-down windows. No prior knowledge of the WinBury modelling software is needed. A 'help button' provides additional information to assist the user at any stage.

Temporary modifications to existing data can be made, or new data can be added in the well models (e.g. stratigraphic units/depths/age, maturity and fission track data, alternative palaeo-bathymetry/heatflow, kerogen types, etc.). The corresponding maturity, generation and expulsion models based on these changes can be viewed and printed directly from the screen views but will not be saved on exit from the well. Current users of WinBury modelling software can copy well data files from this package to their WinBury working directories.

What models show

The geohistory models suggest that hydrocarbon expulsion in the Vulcan Sub-basin was restricted to Oxfordian-Kimmeridgian source rocks (Lower Vulcan Formation) within the Swan and Paqualin grabens, together with minor late gas expulsion from the deepest portion of the Cartier Trough. Due to the high activation energies of the kerogens, relatively high temperatures (145–160ºC) are required to generate hydrocarbons from this source.

Generation of hydrocarbons occurred mainly in the Late Jurassic to Early Cretaceous, but the main phase of oil expulsion was compaction-driven and did not occur until the mid-late Tertiary. In contrast, the main phase of gas expulsion took place in the Late Jurassic to Early Cretaceous, coincident with the main phase of gas generation. Later phases of compaction-driven gas expulsion occurred in the early Tertiary and Pliocene to Recent.

Expulsion from shales and coaly shales within the Lower-Middle Jurassic Plover Formation may also have occurred if the immature organic-rich facies intersected in the Skua Trough extend westward beneath the Swan and Paqualin Grabens and the Cartier Trough.

The limited area distribution of expelled oil predicted by the models suggest that long migration pathways (longer than hitherto believed) are required to charge traps remote from the Swan and Paqualin source kitchens.

The models indicate that 'saline' hot-flush events, while important in understanding the fill-spill history of shallow trap structures, do not affect the timing of generation and expulsion in the depocentres. However 'non-saline' hot-flush events, presumably relating to hydrocarbon charge, may be responsible for elevated heatflows in shallow drilled structures. As a consequence, most exploration wells are not truly representative of the thermal regime of nearby source kitchens.

Usage requirements

The package requires 30 Mb hard disc space, Windows 95/98 or NT operating systems, and a standard web browser (Internet Explorer or Netscape Navigator). The CD-ROM, with the official title of *Record 1999/40: Vulcan Sub-basin Geohistory Modelling* is available from the AGSO Sales Centre for $350 plus postage and handling.

For further information contact John Kennard on +61 2 6249 9204 or e-mail john.kennard@agso.gov.au, or phone Ian Deighton, Paltech Pty Ltd on +61 2 6492 7201 or e-mail paltech@acr.net.au

INCREDIBLE VALUE FOR NORTH QUEENSLAND STREAM SEDIMENT GEOCHEMICAL DATA

If you are looking for geochemical data on north Queensland, these two AGSO products should interest you: new data on the Croydon goldfield area and AGSO's entire north Queensland stream sediment geochemical data set.

Croydon region

982 samples analysed for Ag, As, Ba, Be, Bi, Ce, Co, Cr, Cu, Fe, Li, Mn, Mo, Nb, Ni, Pb, Rb, Sn, Th, Ti, U, W, Y and Zn

This is the first release of stream sediment geochemical data covering most of the outcropping portion of the Mesoproterozoic Croydon Province in north Queensland. The province contains the significant Croydon goldfield. The ASCII data files—containing sample number, sample site location (AMG in metres or latitude/longitude in degrees and decimal degrees) and element values—are available as MS-DOS files on 1.44 Mb disks. The price for this data is $1000.

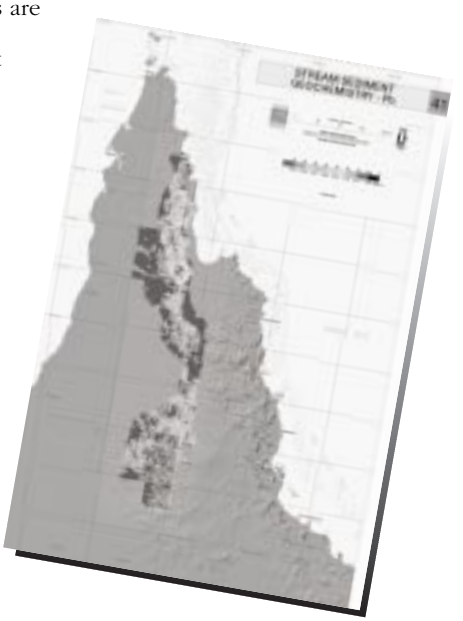
North Queensland data set

8752 samples analysed for some or all of the following elements: Ag, As, Au, Ba, Be, Bi, Cd, Ce, Co, Cr, Cu, Fe, Ga, Ge, Hf, La, Li, Mn, Mo, Nb, Ni, P, Pb, Pd, Pt, Rb, Sb, Sc, Se, Sn, Ta, Th, Ti, Tl, U, W, Y, Zn and Zr

This is the single largest publicly funded stream sediment geochemical data set available in Australia. The data set covers roughly 80 thousand square kilometres of Proterozoic and Phanerozoic north Queensland and contains 235 914 analyses. It has a replacement value of more than $2 million.

The ASCII data files—containing sample number, sample site location (AMG in metres or latitude/longitude in degrees and decimal degrees) and element values—are available as MS-DOS files on CD. The CD includes PDF files of accompanying data records and atlases of coloured image maps.

The data (less the new Croydon data set) and associated reports and atlases previously sold in nine separate data sets for a total of more than $36 500. With the new arrangements, and at an incredible price of $8750, small explorers are offered greater access to an invaluable exploration data set and simultaneously streamline data handling in AGSO. Eventually, when AGSO has moved to full e-commerce capability, these data will be available on-line and clients will be able to select and purchase, on a pro-rata basis, just the data required.



For more information phone John Bain on +61 2 6249 9282 or e-mail john.bain@agso.gov.au. Products will be available in June from the AGSO Sales Centre by phoning +61 2 6249 9519 or e-mailing sales@agso.gov.au

LAST ISSUE BEFORE JOURNAL AMALGAMATION

The final issue of the *AGSO Journal of Australian Geology and Geophysics* has just been printed. From now on papers destined for the AGSO Journal will be published in the *Australian Journal of Earth Sciences* (AJES).

Eighteen papers were included in the final issue (volume 17 number 5/6). Unlike earlier issues, this one does not focus on a single theme. Instead it features papers on Australian petroleum exploration, environmental impacts in Australia's coastal-marine zone, and Antarctica in the Cainozoic. A precis of article titles follows:

- Seabed mapping using multi-beam swath-mapping systems
- Architecture and evolution of the Australian continental margin
- Where is Australia's petroleum and how long will it last?
- Undiscovered hydrocarbon resources of the Bowen and Surat Basins
- The problem of inconsistency between thermal maturity indicators used for petroleum exploration
- Sequence stratigraphy concepts and application to petroleum exploration
- Quaternary Antarctic ice-sheet fluctuations and southern ocean paleoceanography
- The late Cainozoic East Antarctic ice sheet
- Paleocene-Eocene biostratigraphy and paleoenvironment of East Antarctica
- Glacial-interglacial paleoceanography from Australian margin sediments
- Sediment–water interaction in Australian coastal environments
- Use of sediments to assess environmental impact on a large coastal catchment (Hawkesbury River)
- Aluminium and iron in acid runoff from acid sulphate soils (Richmond River)
- Impact of runoff on nutrient patterns in northern Port Phillip Bay
- Flushing of Australian estuaries, coastal lakes and embayments
- Microbial nutrient cycling in seagrass sediments
- Contaminant dynamics in offchannel embayments of Port Jackson
- Methane anomalies in seawaters of the Ragay Gulf, Philippines.

Numerous diagrams and maps appear throughout this 248-page volume. An A1-sized colour chart of transects of the Australian continental margin is included in a cover sleeve.

Copies of AGSO Journal 17:5/6 can be bought from the Sales Centre for $80 (plus postage and handling) by phoning +61 2 6249 9519 or e-mailing sales@agso.gov.au

The AJES is published by Blackwell Science for the Geological Society of Australia. AGSO is responsible for one thematic issue this year.

What a bargain!

This 1:5 million scale map normally costs you $19.95 plus $5 postage and handling. While stocks last we'll let you have this 'Elevation image of Australia' map for just $8.95 plus $4 postage and handling. That's roughly 50 per cent off the original price.

Major lakes, river systems and other large-scale and subtle features of Australia's topography are easily recognised on this gradient-enhanced colour map. The map will interest a wide range of people including those wanting copies for land-use, education and recreation purposes.

Don't miss out on this genuine bargain. Order your copy by phoning Dave Harris on +61 2 6249 9333 or e-mailing the AGSO Sales Centre on sales@agso.gov.au