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AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS

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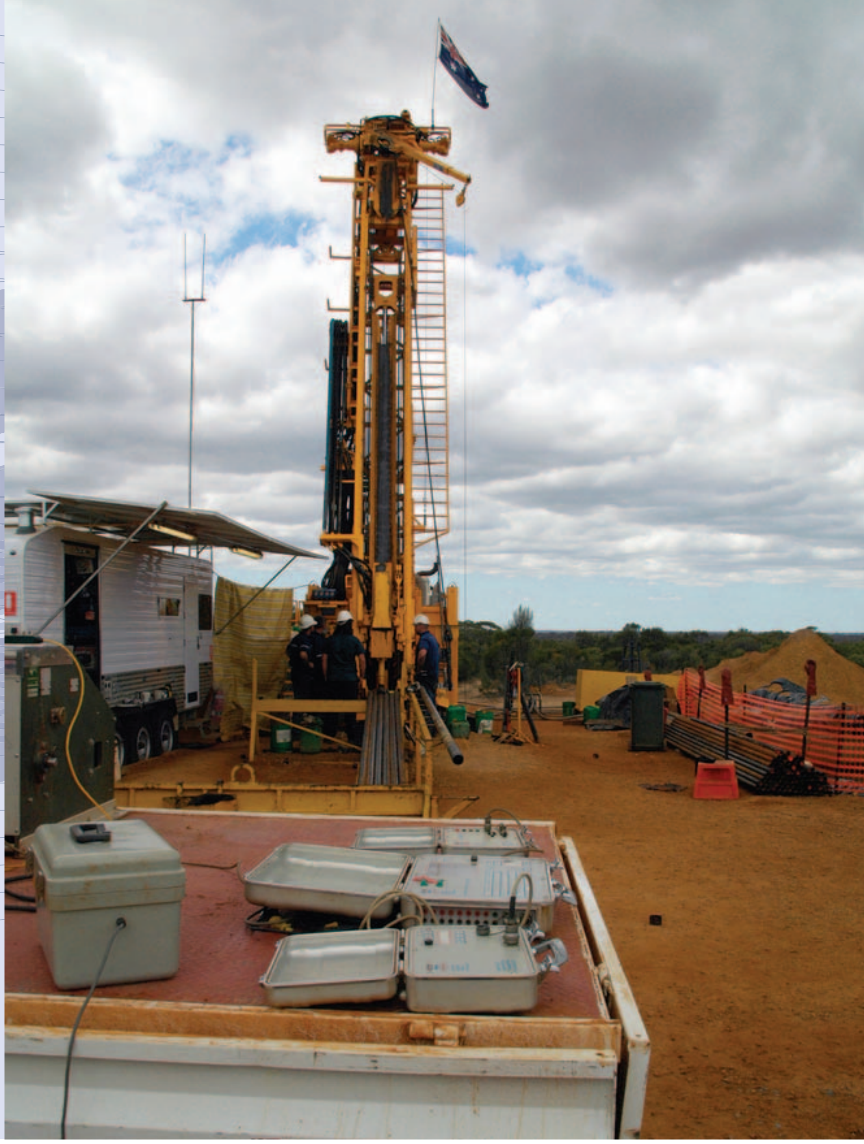

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The cover image is of the Habanero 3 flow-test, which started on 17 March 2008, showing steam and water discharging from the separator. Credit: Geodynamics Ltd, see p. 16.

Preview is available online at:
www.publish.csiro.au/journals/pv

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ASEG 09

20TH INTERNATIONAL GEOPHYSICAL CONFERENCE AND EXHIBITION

Call for Papers

Invitation

On Behalf of the Australian Society of Exploration Geophysicists (ASEG) and Petroleum Exploration Society of Australia (PESA), we cordially invite you to participate in the 20th International Geophysical Conference and Exhibition to be held in Adelaide, South Australia during 22-25 February 2009.

The conference theme:
'Brighter • Deeper • Greener – Geophysics in a changing environment' reflects not only changes in the natural environment but also the challenges facing the geoscientific community as we strive to operate with ever changing expectations and targets.

The collaboration of two of Australia's premier geoscientific bodies promises to make this conference a stand out forum for resource exploration geophysics community.

Location and Overview

The diverse nature of South Australia's resource sector is reflected in the many established and emerging companies operating out of Adelaide. The testing environment in which the local resources sectors operates in has lead to the development of a dynamic sector characterised by ingenuity and adaptability.

Adelaide also offers the world's best food and wine in arguably Australia's most liveable city. Located between sheltered gulf waters and a range of low hills, Adelaide stretches some 65 kilometres from its southern suburbs to its northern most outposts. Adelaide enjoys a Mediterranean climate, a relaxed lifestyle and a range of restaurants offering cuisine from almost every country. Some of Australia's premier wine regions are only an hour away.

Venue

The venue for the convention and exhibition will be the Adelaide Convention Centre, which overlooks the picturesque Torrens River lake and parklands. The exhibition area adjacent to the meeting halls has ample room, excellent telecommunication outlets, good ceiling height (10.2m), well planned access points via ramp or goods lift (height 4.85m and width 7.2m) and excellent storage facilities. In fact, it provides everything to make exhibiting as easy as possible.

Who will be there?

In line with recent conferences, the 2009 Conference & Exhibition is expected to attract approximately 700 delegates from a variety of geophysical fields and a range of countries. There will be strong representation from the following fields:

- Petroleum Geophysics – Acquisition, Processing and Interpretation
- Minerals Geophysics – Acquisition, Processing and Interpretation
- Geothermal Geophysics
- Groundwater & Environmental Science
- Coal Seam Methane Geoscience
- Extractive Coal Geoscience
- Research Centre Initiatives
- Government Legislation, Regulation & Initiatives
- Landholder and Native Title liaison
- Geophysics in Unconventional Reservoirs/ Play types

Program Outline

The Conference and Exhibition will be held at the Adelaide Convention and Exhibition Centre from 22–25 February 2009.

The conference will commence with the icebreaker reception on Sunday 22 February and then follow with up to 5 concurrent technical streams from Monday through Wednesday.

Workshop and Field Trips

Workshops are planned in conjunction with the conference, with possible field-trips to project areas (and associated wine regions) being programmed.

Social Program

A welcome icebreaker and dinner during the conference will be complemented by the annual ASEG/PESA golf tournament at the conclusion to the conference.

Conference Secretariat

Sapro Conference Management
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South Australia 5031
Telephone: (+61) 08 8352 7099
Facsimile: (+61) 08 8352 7088
Email: aseg2009@sapro.com.au
www.sapro.com.au/ASEG/home.htm
www.aseg.org.au/conference/

Important Dates

Abstract Submission — **Friday 16 May 2008**
Note: All submissions will be acknowledged. If you have not received acknowledgement of the receipt of your abstract within two weeks of submission, please contact SAPRO Conference Management.

Notification Of Acceptance — **Friday 27 June 2008**
Note: Guidelines for short papers will be provided with advice of acceptance.

Submission of extended abstracts for review — **Friday 26 September 2008**
Note: Papers that do not meet the guidelines will not be published on the conference CD.

Call for Papers

Abstract submissions are invited for Conference technical presentations. Authors may elect to present a paper or a poster. Each submission should be associated with a technical area. No commercial promotion or overt advertising of techniques and services will be permitted. The Technical Papers Sub-Committee will make the final decision regarding the acceptance of papers and posters. Initial abstracts or extended abstracts for all presentations will be published in the conference proceedings.

Submission of Initial Abstracts

Abstracts are to be prepared as single Microsoft Word.doc attachments and emailed to: **aseg09@sapro.com.au** by **Friday 16 May 2008**.

Name the file aseg followed by the first four letters of the last name of the presenting author, followed by the author's first initial. For example **asegcitij.doc** for an abstract with the presenting author John Citizen.

Further abstract information including formatting details can be downloaded from **www.sapro.com.au/aseg.htm** or requested by email from **aseg09@sapro.com.au.**

Guidelines for Presenters

Oral presentations will be 20 minutes, plus 5 minutes discussion.

Accepted authors are expected to submit an extended abstract (max 4 pages) for publication on the conference CD. Extended abstracts will be reviewed for technical content and undergo editorial review.

Extended abstracts that do not meet the guidelines provided with acceptance advice will not be published.

Poster presentations will be displayed on 1.8 m x 1.2 m panels. The program will allow for informal presentation and discussion around the posters at specific times. Accepted poster authors are strongly encouraged to also submit extended abstracts for publication.

Initial Abstract Specifications

Abstract: The abstract should be a condensation and concentration of the essential qualities of the paper or poster presentation. Do not include acknowledgements, figures or references.

Length: maximum one A4 page.

Technical Area: identify the preferred technical area from the suggestions below.

Presentation: indicate preference for paper or poster submission.

Presenter Profile

A brief personal profile of the presenter (maximum 100 words in sentence format) is required with the abstract.

Please note:

- Presenters are expected to register and pay for the day of presentation or the fulltime program at least one month before the conference.
- All costs to attend the conference, including travel and accommodation, must be met by presenters.
- All correspondence should be directed to the ASEG 2009 Secretariat at: **aseg09@sapro.com.au.**

Technical Areas

Minerals

- Uranium exploration
- Base metals exploration
- Exploration through cover case histories
- Other case histories
- Technological innovations for mineral exploration
- Software innovations for Mineral exploration
- Modelling with petrophysical constraints
- Hyperspectral techniques
- Crustal – solid earth

Petroleum

- Seismic data acquisition (2D, 3D, 4D)
- Electromagnetics (particularly CSEM)
- Reservoir stress paths/fracture characterisation
- Advances in seismic processing
- Seismic imaging, depth migration and depth conversion
- Anisotropy and multicomponent seismic
- Borehole geophysics
- Interpretation and exploration case histories
- Reservoir characterisation/rock properties
- Modelling and inversion
- Gravity and magnetic
- CO2 geosequestration
- Case studies
- Coal seam gas
- Unconventional hydrocarbon plays

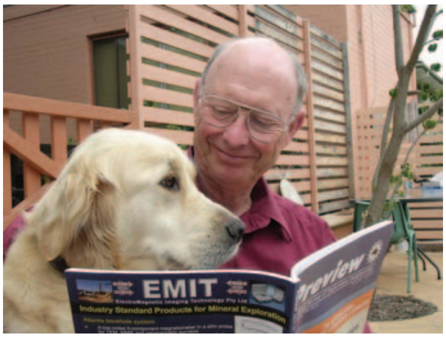
Environmental

- Groundwater
- Salinity
- Forensic and archaeological geophysics
- Mine site geophysics
- Agricultural geophysics
- Hydrogeophysics
- Case histories

Geothermal

- Fluid flow in EGS HDR systems
- Geophysical challenges in geothermal power production
- Geomechanics in high temperature environments
- Case histories
- Exploration and identification of geothermal resources using geophysics
- New temperature logging technology

BRIGHTER • DEEPER • GREENER – GEOPHYSICS IN A CHANGING ENVIRONMENT



There's a lot of good stuff in this issue and I would like to draw attention to the excellent review articles on airborne gravity by Dan DiFrancesco and on airborne EM by James Macnae. We then have some new results from the Canning Basin, a paper on radiometric interpretation and all sorts of other goodies.

In the February *Preview* Eristicus waxed eloquently about an Open Access regime, which became law in the US late last year. Richard Hecker from CSIRO Publishing has provided some counter arguments on the OA issue and I have asked Eristicus to comment further. Rather than including these contributions in the letters section I have included them in the Editor's Desk because of their importance for learned societies such as ours.

Further comments from members are welcome but more contributions from Richard Hecker and Eristicus will not be published. And Eristicus hopes to contribute his regular column in the next issue of *Preview*.

Open Access: what your mother didn't tell you

I read with no small interest Eristicus' comments on Open Access (OA) in *Preview* 132, p. 16. The example provided relates to George Bush's Consolidated Appropriations Act (H.R. 2764) that directs research funded by USA's National Institutes of Health to be lodged in an OA database. (Herein lies the first complication of OA. It is important to distinguish between 'green OA', in which papers, unrefereed preprints, or even raw data are lodged a database or institutional repository, and 'gold OA' in which formally peer-reviewed papers are published for a fee. The distinction is critical.) There are good arguments for citizens to have unfettered access to taxpayer-funded health research.* Eristicus' commentary mentions this arose 'despite extensive lobbying from the academic publishing industry' without representing the publisher's reservations on the OA business model. A competent publisher can work with OA or subscription models, so long as operating monies come in. From the perspective of variously a researcher, a modestly sized developed nation, and a learned society, let me share notes of caution on the OA business model:

Standards: Poor work published under a subscription business model loses subscribers. OA removes this editorial quality control; moreover, payment for publication is a positive encouragement for a weak-willed editor to accept poorer material.

Fairness: Under a subscription business model the only impediment to publication is quality. Under an OA model the impediment to publish is the ability to pay. Consequently, OA undermines research from the developing world and from less wealthy institutions.

Libraries: Extensive uptake of OA models would require taxpayer-funded agencies such as the ARC to divert the limited research monies away from libraries to researchers. Local academic libraries are thus gutted and become less able to provide the necessary infrastructure, let alone act as a counterbalance to publishers.

Societies: Learned Societies with an associated publication provide the publication as a benefit of membership. An OA model eliminates this benefit.

Peer-review: The value of published material, whether a subscription or gold OA source, is that the material possesses the imprimatur of quality that peer-review provides. Papers in a database following the green OA model need not be peer-reviewed. A casual reader cannot identify which papers have been formally assessed.

Industry: For Society publications such as *Exploration Geophysics* and its ilk, private industry gains information without needing to contribute to the Society via the publisher. The benefits of taxpayer-funded research are diverted to private industry without cost to industry.

Publishers: Subscriptions need work, and publishers are forced to provide ever-better services, including author and reader support, to maintain, let alone grow, subscriptions. Adopting OA takes away this stick once a publisher provides a minimal online presence.

Sustainability: The Public Library of Science, the poster-child of OA, required to increase their publishing fee by 60% within three years of operation as well as, above and beyond the US$10 million seed fund, a total of US$13 million injection from philanthropic foundations to maintain the business.†

The changes in academic publishing over the past decade have been terrifically interesting. The subscription model, in play since the founding of the *Philosophical Transactions of the Royal Society* in 1665, is deserving of challenge and initiatives such as OA are welcomed. All can acknowledge the subscription model is far from perfect. Eristicus fails to show the defects of OA nor makes clear which OA is considered. We observe now hybrid models emerging which ameliorate the limitations of both the subscription and OA models, as we have here at **CSIRO** PUBLISHING. But for a pure OA model, I cannot share Eristicus' breathless enthusiasm.

Richard Hecker
CSIRO PUBLISHING

Eristicus replies

Firstly I would like to thank Richard Hecker for raising the issue of Open Access to research results. This is a very important issue because governments around the world are investing billions of tax payers well earned money into research.

Dr Hecker argues that the OA Business Model is flawed, unfair, reduces standards, threatens libraries, the peer-review process and does all sorts of other nasty things. If these are the arguments that the publishing industry put in the US to try and have the legislation stopped then I can see why George W. Bush approved the OA legislation.

We are dealing here not with a *business model* but with a *basic principle*. Essentially the key question is how best can the results of research that are funded by the public be accessed? I hope that everyone would agree that if the taxpayer funds the research then the taxpayer should be able to access the results.

Let us look at what was legislated in the US. Here is the language that is now law:

> The Director of the National Institutes of Health shall require that all investigators funded by the NIH submit or have submitted for them to

*See, for example, www.taxpayeraccess.org.

†D. Butler, *Nature* **2006**, 441, 914. doi:10.1038/441914a.

Continued on p. 17

Looking back and the future

This will be my last President's Piece. After the next Annual General Meeting in May, Peter Elliott will be taking over as President of the ASEG.

Looking back, it's been a very interesting year for me although regrettably I was not able to devote more time to the Society. This is a perennial issue for learned societies that rely largely on volunteerism. The fact that the ASEG manages to run its affairs and functions well is a testament to the service of a number of dedicated members.

Nevertheless, I believe that, these days, members are demanding more from their learned societies, whether it's additional services or greater access to information online. The ASEG needs to ensure that it is close to its members and understands what the new generation of professionals are looking for. It is well known that this new generation prefers to access member benefits through the web for example. With this in mind during this last year the Federal Executive undertook a thorough review of the ASEG website. This review resulted in some important enhancements to the site, which will continue in the future.

An important event during the year was of course the Conference in Perth. This is the ASEG's signature event and is dependent on the active support of members. Importantly, it also relies on the goodwill of sponsors, without whose support the Conference would not be such a success. We should strive to ensure that we measure up to people's expectations, not only in terms of the technical program, but also all the other important things that go towards making a successful conference. ASEG's Conference will no doubt go from strength to strength and I look forward to the next one in Adelaide in February 2009. I wish the Organising Committee good luck.

Despite the improvements and successes, in my view we need to seriously think about taking the ASEG to a higher level of effectiveness while minimising our reliance on volunteerism. Of course improved effectiveness must manifest itself in better or additional services to members – if we cannot guarantee this then there is no point in moving forward. Recently the ASEG Federal Executive took an important step to address this issue by initiating an independent business review of the Society. The objective is to undertake a comprehensive review of ASEG's operations, the results of which will be used for process improvement and identification of control weaknesses and strategic options that will ensure more effective management of the Society and improved delivery to its members. An important part of the review is to benchmark ourselves against what are considered 'best-in-class'. The strategic options that will be defined will, I am sure, enable the ASEG Federal Executive to make more informed decisions about the future running of the Society, given the outlook over the next five years. Any such decisions will be made with appropriate input from members.

I think the future for the ASEG looks exciting and we now have an opportunity to do some serious planning that will better position the Society to tackle the challenges with confidence and importantly to increase its relevance to members.

Joe Cucuzza
joe.cucuzza@amira.com.au

Exploring Geophysics online

In *Preview* 132, I covered what an online presence has done for *Preview* during 2007. For this issue, we'll look at the ASEG's main research publication *Exploration Geophysics*. A research journal requires and benefits from an online presence more than a magazine style publication like *Preview*.

Exploration Geophysics is available online at www.publish.csiro.au/journals/eg. Some of the facilities you'll find on the website include:

- Current issue content and archive, including paper abstracts;
- General journal and ASEG information;
- Links to other websites of interest;
- Dynamically updated lists of most-read papers; and
- Upcoming conferences.

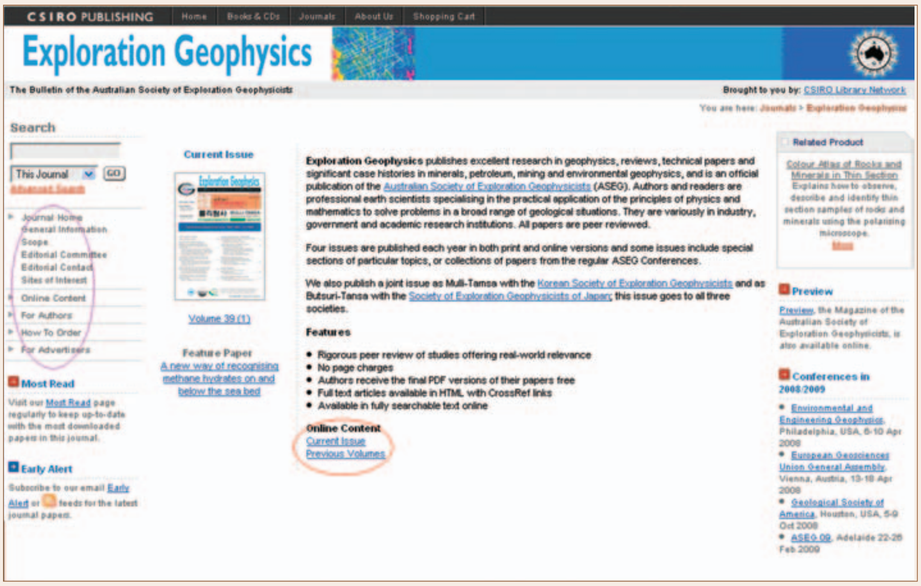
ASEG members of course can view the full contents of ASEG publications. The 'back door' link to *Exploration Geophysics*' content is found on the ASEG's own website, www.aseg.org.au, in the Members Only section. Non-members can choose to subscribe to the journal, pay-per-view for an individual article, or just join the ASEG.

Being online we can monitor the usage of materials, and we have a good, steady usage of the most recent volume, now receiving comfortably over 1000 downloads of per month.

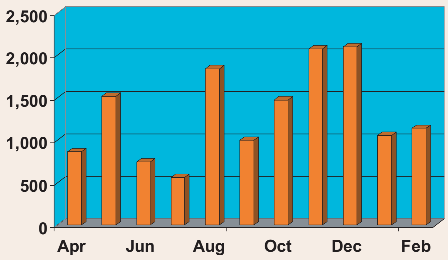
The archive includes all ASEG material from 1970. This feature thus supersedes the older CD set of material. Again, we can see how well used the ASEG's older material is used.

Being online simplifies dissemination of the materials to indexers, and thereby raises the profile of the ASEG. *Exploration Geophysics* is now available through GeoRef and AusGeoRef from the American Geological Institute. We're coming nearer to completing work for the American Institute of Physics, which is the engine behind the SEG's Digital Cumulative Index, and with NASA's Astrophysical Database. These activities raise the profile of *Exploration Geophysics* across the largest organisations of earth scientists and geophysicists. Of course, more suggestions and recommendations for indexers are welcomed.

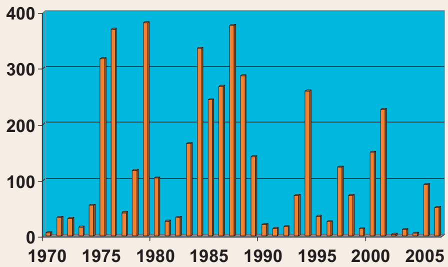
We believe this year should see a startling expansion in *Exploration Geophysics* and consequently the ASEG will become more visible to a wider and increasingly international audience.



Exploration Geophysics website. Navigation and links are found on the left side (circled pink), or go directly to the current issue and archive (circled red).



Downloads of Exploration Geophysics Vol. 38.



Downloads of the Exploration Geophysics archive during 2007.

Richard Hecker
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Secretary: Cathy Higgs
Tel: (08) 9427 0801
Email: cathy@casm.com.au

New members

The ASEG welcomes the following new members to the Society. Their membership was approved at the Federal Executive meetings held on 30 January and 27 February 2008.

Surname	Organisation	State
Takao Aizawa	Suncoh Consultants	Tokyo, Japan
Hayley Jane Anderson	Curtin University	WA
David William Annetts	CSIRO DPR	NSW
Gregory John Ball	Chevron	WA
Charles Bennett Bass	ESI Inc.	WA
Stephen Busuttil	GRS Pty Ltd	Qld
Michael Benedict Clennell	CSIRO Petroleum	WA
Michelle D'Alessio	Curtin University	WA
Long Tan Dang	BHP Billiton Petroleum	WA
Petro Du Pisani	Anglo American	South Africa
Daniel James Eberhard	CGG Veritas	WA
Fiona Jane Eddison	Fugro Airborne Surveys Pty Ltd	WA
Peter James Facci	?	SA
Pierre Gaucher	Instrumentation GDD Inc.	Canada
Daniel Ian Gray	Marmota Energy	SA
Peter Griffiths	Woodside Energy	WA
Marcos Hexsel Grochau	Curtin University	WA
Marshall John Hood	Neon Energy	WA

Surname	Organisation	State
Antonio Jose Huizi-Urich	?	WA
Shunichiro Ito	Suncoh Consultants	Japan
Richard James Jason	Gippsland Offshore Petroleum Ltd	WA
Aki Kakamura	Geoscience Australia	ACT
Andrew Peter Kitts	Global Geophysical Services	Florida, USA
Richard Arthur Krahenbuhl	Colorado School of Mines	Colorado, USA
Yusen Ley-Cooper	RMIT	Vic
Alex Low	Fugro	WA
Jim Mc Rae	Global Geophysical	New Zealand
Michael Francis Middleton	BPC Ltd Group	WA
Brett Robert Rose	Zonge Engineering	SA
Alan Sansome	PIRSA	SA
William Adam Scott	Neon Energy	WA
Nalin Shah	?	Mongolia
Hasan Sidi	Fugro Jason Australia	WA
Dirk Jacob Verschmir	Delft University of Technology	Netherlands
Andrea Viezzoli	University of Aarhus	Denmark
Fu-Pang Yang	E-Sci Co. Ltd	Taiwan

ASEG News

Western Australia

Reece Foster takes over from Megan Evans

2007 was a jammed packed year for the WA Branch with many technical nights, workshops, social events and, of course, the ASEG/PESA conference. The year started off with a number of extremely well attended technical nights including:

- Falcon: heli-borne system results and 3D interpretation case study from the West Musgraves, presented by Anna Dyke
- A novel magnetic gradiometer: description, design issues and trial results, presented by Andrew Sutherland
- BHP Billiton Orion Operations – Stuart Shelf Falcon survey results, presented by Geoff Peters
- How you can build an extraordinary team in a tight labour market, presented by Tabitha Wellman
- Bayesian based fluid and lithology prediction using seismic inversion, prior geologic knowledge and stochastic rock physics model, presented by Matt Lamont and Troy Thompson
- CO_2 geosequestration in Australia as applied to monitoring measurement and verification in the Otway Basin Pilot Project, Victoria, presented by Kevin Dodds
- The SkyTEM helicopter electromagnetic system – Australian examples, presented by James Reid
- Borehole radar applications for exploration and mine planning, presented by Carina Simmat
- Deepwater geohazard identification, presented by Ian Hobbs
- CRiSP Marine Seismic Refraction System, presented by Jim Anderson

The 2007 Distinguished Lecturer Short Course was held in April, with Biondo Biondi, from Stanford University presenting his course – Concepts and applications in 3D seismic imaging – to a sell out audience.

A full day workshop was held in September on Borehole/Seismic Sonic, presented by Leon Dahlhaus, Sergei Tcherkashnev and Frazer Barclay. More than 40 geoscientists that attended this event greatly appreciated the efforts of the presenters, who donated their time and energy to putting this event together.

The annual student night talks were held in October, with four of the best students from Curtin University presenting their Honours projects. The students' talks are scored by members of the audience, and the best speaker is chosen to receive a prize from the ASEG. The best WA student presenter for 2007 was Sean Philips with his project on the 'Feasibility of Deep ocean electromagnetic exploration in Australia's offshore oil and gas basins'.

November of course was the ASEG/PESA Conference held in Perth with over 800 delegates attending from across Australia and the world. The conclusion of the conference was celebrated with a sailing regatta and ASEG/PESA golf day.

The year was then concluded with the ASEG WA AGM held in the city with drinks and nibbles to celebrate the start to the silly season. The formalities concluded with the election of our new WA State President Reece Foster from Geoforce.

I would like to thank all the presenters who donated their time and efforts to putting on our technical nights and workshops, and the members who attend. I would also like to extend a large thank you to the WA Branch Committee Members who volunteered their time providing many events, both technical and social, to our members each year.

I take this opportunity to also hand over the reins to your new State President and thank everyone for their support during my tenure as President.

Stay happy and healthy

Megan Evans
Former WA Branch President

Outgoing WA Branch President, Megan Evans.

Handing over the reins – Megan Evans hands over the WA Branch Presidency to Reece Foster from Geoforce.

2007 PESA/ASEG Golf Tournament

The annual Perth PESA/ASEG Golf Tournament for 2007 was held at the Araluen Country Club and coincided with the 19th International Geophysics Conference. The 41 degree heat didn't stop any of the players from taking the field and venturing through all 18 holes on a golf course where hiking boots are recommended.

Congratulations go out to all the players (as no one buckled under the pressure and gave up the fight) for making the day a much remembered event by all who attended. The final team placements were:

1. Viking II (CGGVeritas) – Tony Weatherall, Brendan Lahey, John Cant and Mark Newman
2. Fugro Allstars (Fugro Seismic Imaging) – Simon Stewart, Toby Bridle, Mick Curran and Jeff Pidhirnyi
3. Igneous-Noramus (ENI Australia) – Aaron Bond, Brad Brown, Sean Breadsell and Paul Sheppey

Special mentions also go out to the last placed team IBM2 (IBM), consisting of Shane Hancock, Paul Abbott and Wayne Skeggs, as well as winners of the varying hole prizes Richard Darwent, Brendan Lahey, Toby Bridle, Aaron Bond, Phil Middleton, Marshall Hood and Andrew Kitts. Justin Anning received the 'Worst Shot' award donated and presented by Andy Cairns from CGGVeritas for having a golf club go further than the golf ball (of course sunscreen and sweat were given as the reason).

I would like to thank the sponsors who contributed to the event, ensuring everyone had a great time:

- Principal sponsor – CGGVeritas
- Gold sponsor – PGS Australia
- Silver sponsors – DownUnder Geosolutions, Geoforce, Task Geoscience and IBM Australia
- Bronze sponsors – RPS Energy, Halliburton, Dynamic Satellite Surveys,

The winning team from CGG Veritas: (left to right) Brendan Lahey, Mark Newman, Tony Weatherall and John Cant.

Andy Cairns (background) presenting the Worst Shot Award to Justin Anning (foreground) as mentioned in the text.

BHP Billiton, UTS Geophysics and Ophir Energy
- Hole sponsors – Fugro Seismic Imaging, Halliburton, E & P IT Solutions, RPS Energy and Helix RDS

My final thanks go to all those who contributed throughout the year to help organise the event and to those who assisted on the day, with special thanks to Megan Evans and Suzanne DelRosso.

I look forward to seeing everyone again at this year's tournament to be held at Burswood Resort.

Reece Foster
ASEG WA President

New South Wales

The NSW Branch held the first meeting of the year and its AGM in February. Mark Lackie was elected as President, Bin Guo was elected as Secretary, Roger Henderson was elected as Treasurer and Peter Gidley continues as Webmaster. Gee! That group looks very familiar. The 2007 President's and Treasurer's Reports are available from the Branch website.

The President wishes to thank the Secretary Bin Guo and the Treasurer Roger Henderson and the Webmaster Peter Gidley for the effort they made in 2007 – it makes life a lot easier.

In February, Bob Whiteley from Coffey Geotechnics presented results from a number of case studies that looked at the application of geophysics to engineering and environmental problems. Bob discussed data from some of our capital cities, revealing how difficult and how innovative you need to be to acquire useful data.

An invitation to attend NSW Branch meetings is extended to interstate and international visitors who happen to be in town at that time. Meetings are held on the third Wednesday of each month from 5:30 pm at the Rugby Club in the Sydney CBD. Meeting notices, addresses and relevant contact details can be found at the NSW Branch website.

Mark Lackie
NSW Branch President

Editor in Chief
Exploration Geophysics

ASEG is seeking expressions of interest from members for the position of Editor in Chief for *Exploration Geophysics*. This position attracts an honorarium and financial assistance to attend ASEG conferences and exhibitions.

Interested persons are encouraged to contact either of the current editor, Lindsay Thomas (lindsayt@unimelb.edu.au), or ASEG Publications Chairman Phil Schmidt (phil.schmidt@csiro.au).

AuScope and national transects

The AuScope initiative, funded under the National Collaborative Infrastructure Strategy (NCRIS), includes funding for Earth Imaging, including the establishment of data infrastructure through transects across regions of major scientific interest.

The 2003 National Strategic Plan for the Earth Sciences advocated:

> *That the nation invest in a major geotransect study to gain fundamental information about the Australian plate, from its basic structure and evolution through to its mineral and petroleum systems and surficial processes.*

In 2003, the necessary resources needed to undertake even a fraction of such a Geotransect program were not available, but subsequent investment by the Australian Government means that, with suitable coordination, we can make significant progress. The Onshore Energy Security Program at Geoscience Australia will be making a major investment in seismic reflection profiling, of the order of 2500 line-km, with the aim of an improved understanding of energy resources in less explored areas. The AuScope Earth Imaging funding should be sufficient for three 200 km seismic reflection segments, with associated collection of other classes of geophysical information.

Through the National Committee for Earth Sciences, a Geotransect Working Group has been established with Prof. Brian Kennett (ANU) as the Chair. The aim is to develop a unified national concept and take best advantage of the available opportunities. This working group has endorsed the concept of designating a suite of corridors that cross the continent's major geological features, as a basis for planning (Figure 1). The aim is that, collectively, the results from such corridors will provide major insight into both the scientific issues associated with the structure and evolution of the continent, and also the associated potential resources. Within each corridor a full range of geophysical, geological, geochemical and geochronological information should be assembled to provide a genuine Geotransect in each of the corridors.

These corridors are of the order of a couple of hundred kilometres across, but certainly nothing should exclude taking in nearby information. It is convenient to be able to identify the corridors and so names have been attached, as used in the discussions of the Working Group. It is hoped that the identification of the corridors will help to focus activity, in particular the framing of important geological questions and the coordination of existing information of all types.

A trial AuScope transect of 200 km of reflection profiling was carried out in July 2007 in conjunction with a major investment by Geoscience Australia and the Geological Survey of Queensland who conducted 1250 km of reflection work on three lines from Cloncurry to near Croydon, across the Georgetown Inlier and from Mt Surprise through Charters Towers (see Figure 2). The AuScope component from just south of Mareeba to Mt Surprise adds a further crossing of the expected location of the Tasman Line and hence improves three-dimensional coverage in this area.

In July 2007, the Earth Imaging component of AuScope issued a call for proposals for data infrastructure in the form of acquisition of data along transect segments during the next three years. The proposals were to be directed to major issues that should help to elucidate the structure and evolution of the continent. A total of six detailed proposals were submitted and all were carefully reviewed for both scientific and technical merit. A number of priority projects can be now identified (Figure 3).

The highest priority has been given to a profile across the northern edge of the Gawler Craton into the Musgrave Block crossing from South Australia into the Northern Territory (Gawler–Musgrave in Figure 3), and to a profile from the Pilbara to the northern edge of the Yilgarn Craton in Western Australia (Capricorn in Figure 3). At the next level is a profile across the Newer Volcanic Province and the Delamerian Orogen connecting from near Stawell in Victoria to Mt Gambier in South

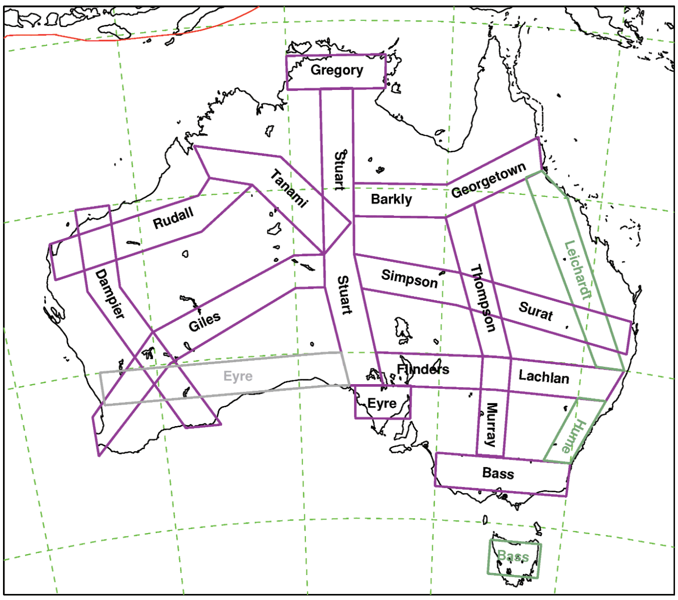


Fig. 1. *Configuration of Geotransect corridors across the Australian continent.*

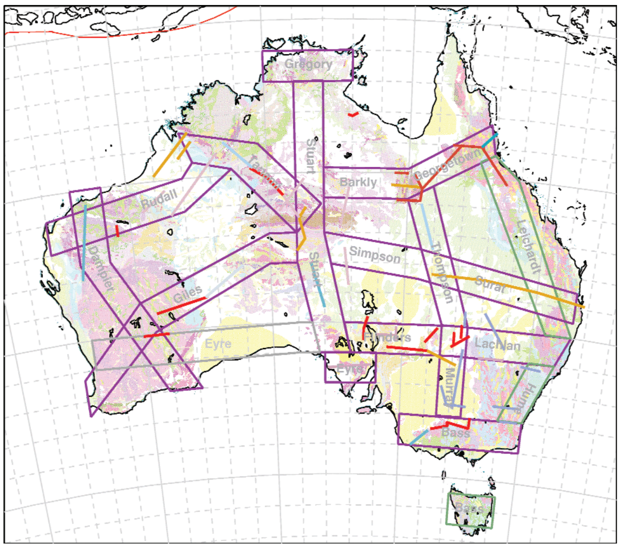


Fig. 2. *Current and potential reflection profiling. Orange lines indicated data acquired with explosive sources and red lines data acquired using vibrators. The dark red lines show lines acquired using the OESP program, together with the trial AuScope segment in north Queensland (dark green). The remaining segments represent concepts from OESP (pink), AuScope (turquoise) and NSW (light blue).*

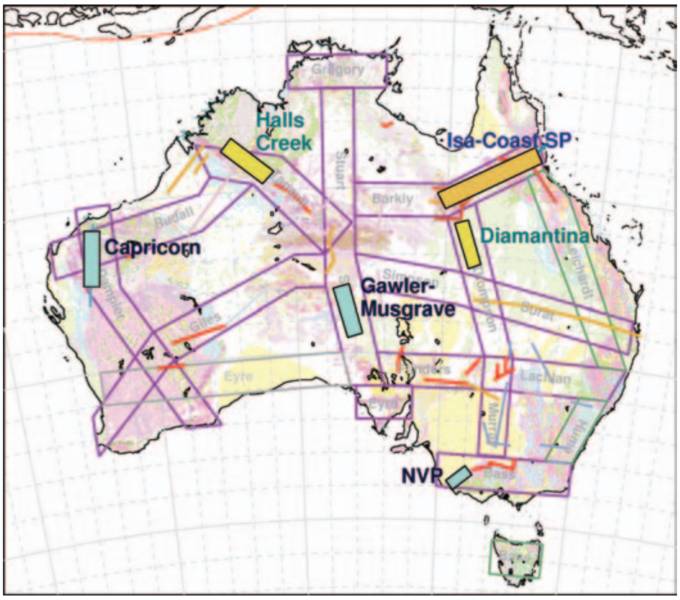


Fig. 3. *Endorsed transect projects from AuScope Earth Imaging. Most data infrastructure projects are larger than can be funded directly by AuScope and so co-investment will be needed to gain the maximum benefit.*

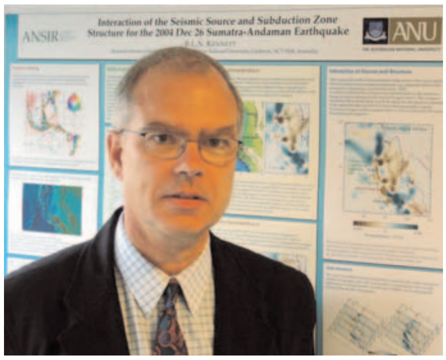
Australia (NVP in Figure 3). Other endorsed projects are the installation of passive seismic recording around the recent reflection profiles in Northern Queensland (Isa-Coast SP in Figure 3), a profile across the southern edge of the Mt Isa block into the Thompson Orogen (Diamantina in Figure 3), and a profile through the Halls Creek fold belt in the Kimberley Block (Halls Creek in Figure 3).

Current planning is based on linking the AuScope experiment in northern South Australia with work under the Onshore Energy Security Program during 2008 and thereby minimising the mobilisation costs for the survey. The data from the different aspects of the AuScope transect will be made freely available as rapidly as possible after the completion of the field programs.

The actual configuration of transects to be undertaken by AuScope Earth Imaging in 2009–2011 will depend on the availability of seismic reflection crews and sufficient co-investment in funding to enable the scientific objectives to be fully met.

A challenge for each of the transects is how we can organise the full range of complementary studies (geophysical, geological, geochemical and geochronological) needed for each geotransect, and the necessary co-investment required to make this happen.

The Geotransect Working Group invites expressions of interest aimed at forming Project Definition Groups for each of the priority transects. These groups should then work towards formulating work plans and specific proposals for funding from ARC, or wherever else might be appropriate.



Brian L N Kennett FAA FRS
Director of the ANSIR National Research Facility
Director, Research School of Earth Sciences, ANU Canberra, ACT 0200
Email: brian.kennett@anu.edu.au

ARC Geoscience Grants for 2008[1]

Discovery Grants

Some of the successful exploration-related projects are listed below. Out of the 878 Discovery Grants awarded only 33 were grouped under the Earth Science heading and only two listed under the 'Geophysics' subheading. So the geophysics outcomes are not impressive. However, as you might expect, there are several successful projects on climate change and CO_2 sequestration.

One surprise is that the ARC funded 31 Medical and Health research projects, when there is a National Health and Medical Research Council with funding about the same as the ARC established just to support medical research. The Discovery Projects relating to exploration are listed below.

Testing the Australian Megatsunami Hypothesis

Researchers: D Dominey-Howes; JF Nott; J Goff.

Funding: 2008: $107 650; 2009: $122 000; 2010: $59 000.

Administering Institution: Macquarie University.

Project Summary: More than 300 000 lives and property worth more than $150 billion on the NSW coast are vulnerable to large tsunamis but at present we do not have a clear idea about how often such tsunamis occur and how big they might be. This project will identify and date evidence for past tsunamis on the coasts of NSW and west New Zealand which will help us understand regional tsunami risk. This will provide knowledge that will guide tsunami risk management practice in vulnerable areas of NSW and help underpin the developing Australian Tsunami Warning System.

Large-scale three dimensional deformation of the lithosphere by subduction and mantle flow

Researchers: LN Moresi; DR Stegman; A Lenardic.

Funding: 2008: $185 000; 2009: $99 000; 2010: $99 000.

Administering Institution: Monash University.

[1]Continued from page 14 of the February 2008 Preview.

Project Summary: We will be modelling of the dynamics of the Earth's crust and shallow lithosphere in response to the huge stresses created by plate motions. For Australia these stresses are transmitted from the distant plate boundaries, but they have a direct controlling influence on the evolution of the petroleum rich basins of Australia. These basins have reached maturity; further exploration will be in deep water where geophysical prospecting methods are unreliable. Model-driven 'exploration geodynamics' methods such as those we are developing will be needed to support traditional exploration techniques in these areas.

Tectonic mode switches and the nature of orogenesis

Researchers: GS Lister; MA Forster; S Richards.

Funding: 2008: $245 000; 2009: $224 000; 2010: $219 000; 2011: $120 000; 2012: $110 000.

Administering Institution: The Australian National University.

Project Summary: Tectonic mode switches coincide with short periods of time during which base and precious metals, as well as diamond-bearing kimberlites are emplaced into the continental crust. Our research is aimed at uncovering why this should be so, thereby perhaps solving a riddle that is at the present little more than an oddity in respect to mineral exploration. If we can understand the underlying science we may be able to provide practical benefits to mineral explorers. The project uses modelling and simulation research infrastructure provided by the AuScope NCRIS initiative, and benefits the community by returning data to this organization.

Present-day stress and tectonics of deltas and deepwater fold-thrust belts

Researchers: RR Hillis; MR Tingay; CK Morley; KR McClay; B Müller.

Funding: 2008: $100 000; 2009: $90 000; 2010: $90 000.

Administering Institution: The University of Adelaide.

Project Summary: The key benefit of the project will be to advance our understanding of the geological processes that control the development of deltas, and of the fold-thrust belts located in deepwater adjacent to deltas, by analysis of five examples worldwide. Global hydrocarbon exploration is successfully moving to deepwater fold-thrust belts. One of Australia's key under-explored frontier petroleum provinces is the Australian Bight Basin. The prospective parts of this basin comprise delta/deepwater fold-thrust belt systems and analysis of more data-rich systems worldwide will help provide the geological knowledge required to help re-invigorate exploration in the Bight Basin.

Compressional deformation and uplift of Australia's passive southern margin

Researchers: RR Hillis; SP Holford; P Green; MS Stoker.

Funding: 2008: $130 000; 2009: $104 000; 2010: $99 000; 2011: $80 000.

Administering Institution: The University of Adelaide.

Project Summary: The key project benefit will be to advance our understanding of the processes which cause active deformation of continental margins that are predicted by plate tectonic theory to be passive. We will analyse Australia's 'passive' southern margin because it is an ideal natural laboratory in which to investigate the causes of the deformation of 'passive' continental margins. Hydrocarbon exploration interest and investment has waned along much of Australia's southern margin because of lack of understanding of the relative age of the formation of potentially hydrocarbon-bearing structures and the timing of hydrocarbon charge. This project will clarify their relative ages.

The role of supercontinents in Earth's dynamic evolution

Researcher: CJ O'Neill.

Funding: 2008: $114 995; 2009: $111 772; 2010: $111 272.

Administering Institution: Macquarie University.

Project Summary: By better understanding the dynamic and volcanic evolution of continents, the project will contribute to our understanding of the long-term evolution and construction of the Australian plate, leading to better models for Australia's deep-Earth resources (NRP 1.6), and the impact of large-scale dynamics on ore-deposit formation. The geodynamic modelling capabilities implemented in this project will keep Australian at the cutting edge of Geoinformatics (NRP 3.2). The project will strengthen ties between the mantle convection modelling and lithospheric dating communities, enhancing our understanding of complex Earth-system interactions, and promote international collaboration between Australia and the USA.

The seismic signature of crustal fluids

Researchers: I Jackson; D Schmitt.

Funding: 2008: $45 000; 2009: $34 000; 2010: $29 000.

Administering Institution: The Australian National University.

Project Summary: Fluids are expected to profoundly modify the seismic properties of the cracked rocks of Earth's upper crust (to depths of about 15 km) but there are so far few relevant laboratory measurements. Through the development and application of novel experimental techniques we plan to build a better laboratory-based understanding of the seismic properties of fluid-saturated crustal rocks. The outcome will be an improved capacity to monitor the presence of fluids in diverse situations ranging from geothermal power generation and waste disposal to earthquake fault zones.

Accessory REE-phosphates as tracers of heat and fluids in time and space

Researcher: B Rasmussen.

Funding: 2008: $115 000; 2009: $114 000; 2010: $109 000.

Administering Institution: The University of Western Australia.

Project Summary: This project will provide fundamental information vital for the widespread application of a new and developing technique for dating rocks and ore bodies that formed at geologically low temperatures. The technique will benefit the Australian mining industry by improving models for the formation of ore deposits, thereby reducing the financial risk involved in discovering new resources. Results will highlight the value of another Australian invention – the SHRIMP – in resolving both fundamental and applied geological problems, encouraging the uptake of this technology overseas. Outcomes from this project will enhance Australia's scientific reputation as a world leader in geochronology and economic geology.

Crustal-scale fluid flow in deep intracontinental settings: conditions, sources and deformational responses

Researcher: CF Clark.

Funding: 2008: $64 889; 2009: $75 136; 2010: $67 586.

Administering Institution: Curtin University of Technology.

Project Summary: Fluids are important agents of heat and mass transport in the Earth's crust. They play a key role in the mobilisation of metals and as such play a crucial role in the generation of ore deposits. The outcomes of this project will result in a greater understanding of the mechanisms and sources of fluid generation and mobilisation in deep-crustal settings. These outcomes can be related directly to the understanding of the controls on the transport and deposition of metals and hence the formation of mineral resources which are vital to maintaining a strong Australian economy.

Characteristics of organic matter formed in toxic, sulphide-rich modern and ancient environments

Researchers: K Grice; RE Summons; RJ Twitchett.

Funding: 2008: $140 000; 2009: $190 000; 2010: $170 000; 2011: $85 000; 2012: $75 000.

Administering Institution: Curtin University of Technology.

Project Summary: This project will help scientists understand past climate changes and understand the mechanisms of global warming. This in turn will improve our ability to forecast future climate change, and help Australia manage current threats to its biodiversity. Furthermore, this research involving Australia's major petroleum rocks will increase the ability to identify crude oil sources, to the benefit of petroleum exploration in Australia and world-wide. Importantly, this project will enable students and young professionals to be trained in state-of-the-art technologies, leading to quality scientists ready for employment in geoscience industries, and raising the profile of science careers in Australia.

The geochemistry of the platinum group elements, copper, rhenium and gold in granitic rocks

Researchers: IH Campbell; E Nakamura; SM Kay.

Funding: 2008: $90 000; 2009: $84 000; 2010: $79 000.

Administering Institution: The Australian National University.

Project Summary: Many of the World's largest copper and gold deposits derive their ore fluids from crystallising granitic magmas. These elements, together with the platinum group elements, are sequestered by immiscible sulfide melts, which when they precipitate from a magma, control the subsequent evolution of these elements. The proposed study takes advantage of platinum's remarkable affinity for sulfides to identify onset of sulfide saturation and then monitor its effect on the subsequent evolution of copper and gold in the evolving magma. It is expected to provide new insights into chemistry of copper and gold in crystallizing granitic melts and explain why some granitic systems are ore bearing and other are not.

The geochemistry of tellurium in hydrothermal environments and the gold-tellurium association

Researchers: PV Grander; A Prang; P Spry; Casey; L Helm.

Funding: 2008: $145 000; 2009: $129 000; 2010: $114 000.

Administering Institution: The University of Adelaide.

Project Summary: Gold and base metal mining are some of Australia's principal export earners. Thus, improving the country's mining and geological exploration capabilities will be a considerable economic benefit to the whole community. The results of the project will yield information concerning how gold deposits form, improved techniques for gold exploration, and more environmentally friendly techniques for the processing of gold-telluride ores.

Linkage Projects

Linkage projects are funded under the umbrella of the National Competitive Grants Program, which is managed by the Australian Research Grants Commission. Linkage projects are all about brokering research partnerships within the Australian innovation system and capturing the economic, social and cultural benefits of research. The main aim is to encourage excellent collaborative research within universities and across the innovation system.

The total funding for new Linkage Projects starting in 2008 is $62.3 million to support 202 projects. The success rate of 48% is much better than for Discovery Projects. However, the total of the partner organisations have committed $95 million for these projects, and these funds may have encouraged the granters to be more generous.

It definitely pays to link with your colleagues and work together. The successful exploration related projects are listed below.

Information content of order flows in the foreign exchange and commodities markets

Researchers: J Wang; FD Foster; L Yang; M Yang; I Geninson.

Funding: 2008: $40 000; 2009: $35 000; 2010: $35 000.

Collaborating/Partner Organisation(s): Commonwealth Bank of Australia.

Administering Organisation: The University of New South Wales.

Project Summary: The Australian economy depends heavily on resources and commodities markets. The Australian dollar is the sixth most actively traded currency in the world and is more volatile than all other major currencies except the Japanese yen. The proposed study seeks to improve volatility forecasts and hedging effectiveness for foreign exchange and commodity risks, which will create significant benefits for the Australian economy, corporations and investors. In addition, the project will enhance investment performance and risk management practice of financial institutions, improving the overall safety of our financial system. It will also foster research culture and increase research capacity of Australian financial institutions.

Unearthing the marginal terranes of the South Australian Craton: keystone of Proterozoic Australia

Researchers: PG Betts; D Giles; G Baines; M Fairclough; BF Schaefer.

News

Funding: 2008: $140 000; 2009: $200 000; 2010: $90 000.

Collaborating/Partner Organisation(s): Primary Industry and Resources South Australia.

Administering Organisation: Monash University.

Project Summary: This project will investigate the buried geology of vast regions of northern South Australia that is likely to be compatible with rocks that host enormous mineral wealth including the giant Broken Hill and Olympic Dam deposits. We will access these buried rocks using a program of on-shore scientific drilling that will provide the ground truth for multi-million dollar federal and state government funded geophysical data acquisition. Results will help identify prospective mineral belts and determine the processes responsible for their formation.

Controls on gold mineralisation in Central Victoria: towards new exploration models

Researchers: CJ Wilson; D Phillips; J Miller; MA Kendrick.

Funding: 2008: $130 000; 2009: $140 000; 2010: $140 000.

Collaborating/Partner Organisation(s): GeoScience Victoria, Department of Primary Industries, Perseverance Corporation Limited, Ballarat Goldfields (Lihir Gold Limited), Bendigo Mining NL.

Administering Organisation: The University of Melbourne.

Project Summary: The proposed project will develop and evaluate new exploration models with implications for gold exploration and mining/investment in Victoria. The frontier research techniques to be employed will ensure that Australian geoscience remains at the forefront of international research. This project will also provide unprecedented research training opportunities for the next generation of Australian Earth Scientists. As prospective gold terranes are located in regional Australia, enhanced exploration and mining activity in future years may have significant economic and infrastructure benefits for rural and regional communities.

Impacts of climate change on coastal floodplain wetland biogeochemistry and surface water quality

Researchers: RT Bush; P Slavich; SG Johnston; LA Sullivan; ED Burton.

Funding: 2008: $80 000; 2009: $84 000; 2010: $82 000.

Collaborating/Partner Organisation(s): NSW DPI, Richmond River County Council, Northern Rivers Catchment Management Authority.

Administering Organisation: Southern Cross University.

Project Summary: The most vulnerable Australian landscapes to global warming driven sea-level rise are our low-lying coastal floodplains. Seawater inundation dramatically affects soil chemistry and water quality. Over 74 000 km^2 of the low-lying coastal floodplains of Australia contain acid sulfate soils. For these soils, seawater inundation has the potential to greatly enhance the release of acidity, with a high capacity to severely degrade wetlands, estuaries and farmland. This project will directly contribute to our national capacity to assess and manage impacts from climate change, providing greater protection of our coastal floodplains resources.

Flue gas and CO_2 geosequestration in Surat and Bowen Basin Coals

Researchers: V Rudolph; P Massarotto; SD Golding; M Gasparon; SK Bhatia.

Funding: 2008: $247 327; 2009: $308 095; 2010: $229 799.

Collaborating/Partner Organisation(s): Stanwell Corporation Limited, Institute of Geology, Geochemistry of Petroleum & Coal of University of Aachen, Origin Energy Ltd, Santos, Thiess Pty Ltd.

Administering Organisation: The University of Queensland.

Project Summary: Climate change considerations require that CO_2 emissions to atmosphere be severely reduced. This is best done in the short term by permanently storing the CO_2 underground. Amongst the cheapest and safest options are to use coal seams, which then release valuable methane. The market value of this extra methane is ~$9 billion and this reduces the cost of sequestration from ~$56 to $25/t CO_2. Coal has a very strong affinity for CO_2, so flue gas stream from power stations can be injected directly, eliminating the need for equipment to capture the CO_2, providing savings of ~$500 million for each large power station.

ASEG Research Foundation

The ASEG Research Foundation has been supporting students in all facets of Applied Geophysics at the BSc (Honours), MSc and PhD (or equivalent levels) for 17 years. In this issue of *Preview* we provide two summaries of research projects undertaken at the Curtin University of Technology.

The Virtual Source Method – verifying the concept using numerical and physical modelling

Student: Matthew Saul

Supervisors: Brian Evans and Bruce Hartley

Funding support: $4950

See the Extended Abstract: *The Virtual Source Method – Verifying the concept using numerical and physical modelling* by Matthew J. Saul, Bruce Hartley and Brian Evans in the proceedings of the 19th ASEG Conference held in Perth, November 2007. Matthew is now employed in the exploration industry.

Project Summary: The Virtual Source Method (VSM) has been proposed for removing the effects caused by heterogeneities in the near surface. The method involves acquisition geometries similar to that of VSP, with receivers below the most troublesome part of the overburden. The time reversal principle is utilised to focus down-going energy through the overburden into useful primary energy at the virtual source location. The time reversal process is performed during data processing and requires no knowledge of the velocity model between sources and sub-surface receivers. The result is a downward continued-dataset with virtual sources at the sub-surface receiver locations. The concept is verified using numerical and physical modelling, which demonstrates that the method can be used to accurately detect reflectors at depth, where conventional seismic fails.

VSI as proposed by Bakulin and Calvert (2004) can be regarded as a very powerful way to generate high quality data using conventional VSP-type acquisition in areas with heterogeneous overburden. We verified the concept using numerical and physical modelling, and confirmed that the more complex the overburden the better the resulting virtual source records due to the increased effective aperture. It was also verified that cross-correlating the windowed direct arrival with the total recorded wavefield at each subsurface receiver and summing over all surface sources, produced optimal results.

The method has great potential to increase the quality of conventional seismic acquisition in areas of highly heterogeneous overburden such as salt, karst topography and near-surface basalts. It also poses as a method to eliminate the majority of problems resulting in the reduced accuracy of 4D seismic by placing fixed receivers in the sub-surface below the time-varying, complex near surface. The increased accuracy of repeated seismic surveys should result in improved mapping of fluid flow anomalies and potentially increase the production of a hydrocarbon field.

Feasibility of the marine controlled source electromagnetic methods for hydrocarbon exploration; Western Australia

Student: Sean Phillips

Supervisor: Brett Harris

Funding support: $2007

Sean has since graduated with BSc (Hons) from Curtin University of Technology and is currently employed in the USA with Schlumberger's Marine CSEM team. Sean's project focused on both suitability Marine CSEM methods and optimising survey parameters for Marine CSEM, for hydrocarbon exploration for a number of locations off the coastline of Western Australia.

Project Summary: Recently in the petroleum exploration industry there has been a surge of interest in the marine controlled-source electromagnetic (CSEM) method. This exploration method can detect the presence of deep thin hydrocarbon reservoirs and other electrically resistive structures such as salt bodies and gas hydrates below the seabed. Electrical properties derived from a marine CSEM survey typically have a more direct relationship with reservoir fluids than seismic methods. CSEM measurements respond directly to increases in hydrocarbon saturation and reservoir thickness. Commercial application of the marine CSEM method was first seen in about 2002 and until recently no offshore surveys had been completed in Western Australia. There is potential for widespread application of the marine CSEM in the Northwest Shelf; however, the feasibility of the method must firstly be evaluated to determine if it is an appropriate exploration tool.

Critical geological factors and survey parameters should be considered prior to design of a marine CSEM survey. Geological factors include water depth, bathymetry, target depth, saturation and thickness, host formation resistivity and the effect of shallow resistive formations. Survey parameters investigated in this research include: (a) transmission frequency and harmonic content, (b) required offsets and (c) the components of the electromagnetic field that need to be measured. Target reservoir detect-ability is determined through the use a forward modelling code capable of numerically simulating the response from a 3D resistive body embedded in a layered earth. Layered earth (1D) modelling helps to develop an intuitive feel for how controlled-source electromagnetic fields interact with the sub seafloor and can ultimately determine if a target is detectable or not. 1D sensitivity analysis provides good approximations to the frequencies and offsets required for a given target. The results of modelling can then be used for survey design to ensure the optimal response from the target reservoir.

For areas of the Northwest Shelf including the Scarborough Gas Field and the Browse Basin; 1D models were built from geophysical bore-hole logs and seismic data. Scarborough Gas Field is deep; however it is a laterally extensive deposit in a deep water setting. Forward modelling results indicate that this commercial scale deposit is detectable. In Browse Basin the issue is water depth which is seen as the main problem with the CSEM method. Reservoirs located at North Scott Reef, Walkley and Caswell appear to have sufficient water depth to be detectable with current CSEM technology. However closer to the shore, on the Yampi Shelf, the water is too shallow relative to target reservoir depth and it is highly unlikely that current typical CSEM technology would be an effective exploration method in this setting.

The marine CSEM method works best in areas where:

(a) the large scale resistivity of the background sediments is relatively uniform,
(b) there are high reservoir resistivities,
(c) there exists well defined field edges, and
(d) there is a smooth seafloor.

The method is not well suited to areas:

(a) where the reservoir is in close proximity to crystalline basement,
(b) below salt structures,
(c) in very shallow water, or
(d) at a depth much greater than the water depth.

Vertical electric field sensors may provide the additional information required to move exploration into shallower water. In general, all components of the electromagnetic field should be acquired along with MT data to move the marine CSEM method into areas currently considered unsuitable.

Curtin partners with Rio Tinto

It is interesting to note that Curtin University of Technology is continuing attract research funding from the exploration industry and, in March 2008, entered into a $10.5 million partnership Rio Tinto to develop a world class innovation centre for strategic research and development in materials and sensing in mining.

The new Centre for Materials and Sensing in Mining will be based at Curtin's Bentley campus. Vladimir Golovanevskiy will lead the Centre, which will provide greater knowledge of rock properties and hopefully result in improved logistics for processes such as mining sequence, equipment deployment, ore/waste discrimination and subsequent processing steps.

Global mineral exploration sets record in 2007

The Metals Economics Group, in a special report for the PDAC 2008 in Toronto (see http://www.metalseconomics.com/default.htm), indicated that in 2007 worldwide nonferrous exploration totalled $10.5 billion[1], up from $7.5 billion in 2006 – which was also a record year. The MEG surveyed 1821 companies with a budget of over $100 000 to compile these numbers. As can been seen in Figure 1, the increases since 2002 have been huge and largely driven by the high prices for most mineral commodities. Furthermore these numbers do not include uranium exploration, which amounted to $936 million for 2007. Of the $10.5 billion, Junior explorers accounted for more than 50% and Majors a little over 30%. In 2002, the situation was reversed with Majors accounting for more than 50% and Juniors just over 30%.

Figure 2 shows how each major region of the world fared in 2007. The only changes to the 2006 numbers are the increase in Australia (up 1% to 12%), which was balanced by a decrease of 1% for the Rest of the World, down to 17%. Once again Canada (19% and ~$2 billion) dominated, followed by Australia (12%), The United States (8%), Russia (6%), Mexico (6%) and Peru (5%) – no wonder PDAC is held in Toronto every year!

Gold still attracts the highest investment, as shown in Figure 3. However, base metals are catching up. In 2004 gold accounted for 50% of exploration expenditure and base metals only 26%, so there is an increased interest in base metals – maybe lead for batteries rather than gold for jewellery!

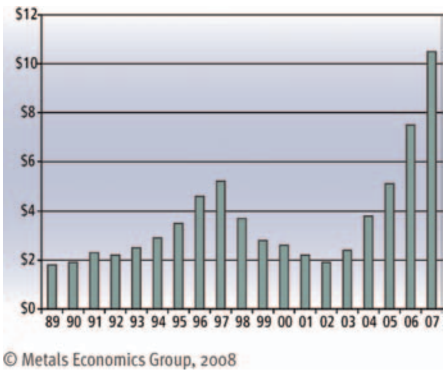


Fig. 1. *Estimated total worldwide non-ferrous mineral exploration budgets in US$ billions, not adjusted for inflation.*

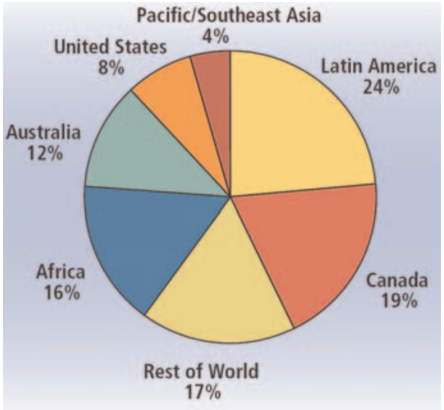


Fig. 2. *Worldwide Exploration Budgets by Region, 2007. The percentages are very similar to the 2006 numbers.*

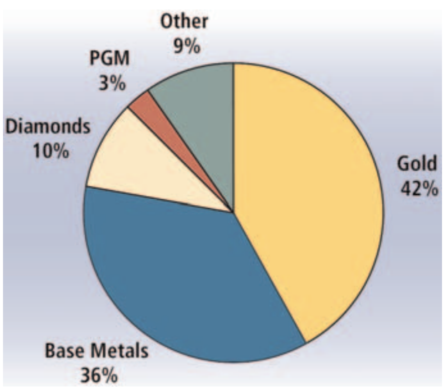


Fig. 3. *Exploration expenditure by commodity.*

Geodynamics tests flow rates

Geodynamics announced on 25 March 2008 that the open flow test from Habanero 3, with reinjection at Habanero 1, sustained a circulating production of 20 kg/s at a flowing pressure of 27.5 MPa (4000 psi) through a 14-mm fixed choke. The flowing temperature is 212°C with a bottom-hole temperature of 244°C.

The company is pleased with these results which are in line with its expectations and will allow it to proceed with the building of its 1 MW pilot power station for commissioning by the end of the year. The cover picture shows steam and water discharging from the steam separator at Habanero 3.

So it is good news for Geodynamics which raised $37.4 M in new capital in February earlier this year.

Xstrata acquires Jubilee Mines

On 1 February 2008, Xstrata acquired majority ownership of Jubilee and it became part of Xstrata Nickel. Jubilee Mines NL is a mining and exploration company with a primary focus on high grade nickel sulfides. Jubilee owns and operates the Cosmos Nickel Project in the North Eastern Goldfields of Western Australia as well the Acra and Sinclair nickel projects. Jubilee Mines had a market capital of about A$2 billion at the time of the acquisition. On 21 February Xtrata acquired the remainder of the shares and the takeover is now complete.

[1]All monies are in US$ and have not been adjusted for inflation.

Oxiana and Zinifex merge

Oxiana Ltd and Zinifex Ltd have agreed to merge their businesses in March 2008, creating a new major diversified base and precious metals mining company with global capability. The merged company will be renamed and will remain headquartered in Melbourne, Australia.

Both companies are of similar size and at the time of writing Zinifex had a market capital of ~A$5.0 billion, Oxiana ~A$5.2 billion and the renaming had not been done. The new company will focus on zinc and copper.

After the merger, Barry Cusack, Chairman of Oxiana, will remain Chairman and Andrew Michelmore, current Chief Executive Officer and Managing Director of Zinifex, will be CEO of the merged entity. All the current directors of both companies will form the Board of the merged entity.

ABARE forecasts record export earnings for commodities

Australia's commodity export earnings are forecast to increase by 30% to a record $189 billion in 2008–09. This and other commodity projections out to 2012–13 are contained in the March quarter issue of *Australian Commodities* released today by Phillip Glyde, Executive Director, ABARE.

'The growth in export earnings forecast for 2008–09 mainly reflects increased shipments of iron ore, coal, gold, LNG, grains and oilseeds in response to strong demand in overseas markets,' Mr Glyde said.

The total value of Australia's minerals and energy exports is forecast to rise by 33% to a record $153 billion in 2008–09, following a forecast rise of 7% to $115 billion in 2007–08.

In 2008–09, iron ore is forecast to be Australia's largest export commodity (in value terms), followed by metallurgical coal, thermal coal, gold and crude oil. Australia's largest agricultural export commodity (in value terms) is wheat, ranked 10th overall in commodity export earnings.

Let's hope the forecast is right.

Continued from p. 3

> the National Library of Medicine's PubMed Central an electronic version of their final *peer-reviewed manuscripts upon acceptance for publication* to be made publicly available no later than 12 months after the official date of publication: Provided that the NIH shall implement the public access policy in a manner consistent with copyright law.

Let us now look at the European Research Council's guidelines:

1. All *peer-reviewed publications* from ERC-funded research projects be deposited on publication into an appropriate research repository where available, such as PubMed Central, ArXiv or an institutional repository, and subsequently made Open Access within 6 months of publication.
2. The ERC considers essential that primary data – which in the life sciences, for example, could comprise data such as nucleotide/protein sequences, macromolecular atomic coordinates and anonymised epidemiological data – are deposited to the relevant databases as soon as possible, preferably immediately after publication and in any case not later than 6 months after the date of publication.

Now let us examine some of Dr Hecker's arguments and see how they stack up against the law in the US and the guidelines in the EU.

Standards: He says that OA removes editorial quality control.

Firstly, all the researchers bid competitively for grants under some of the most competitive grant awarding schemes and, secondly, all the papers will have been peer-reviewed. So the standards will be high and the publications will be available quickly. Quality control is not an issue.

Fairness: He says the OA model is unfair because it depends on the ability to pay.

This is clearly not correct now and will not be correct under an OA regime, good quality papers will be published now and in the future, whatever the regime.

Libraries: He states that funds will be diverted from libraries to researchers.

There is never going to be enough money for researchers or libraries. However, under the OA regime more papers will be accessed through the internet, thus reducing the operating costs for libraries and speeding up access to results for researchers. I would have thought this should be commended.

Societies: He argues that OA eliminates the benefits of publications to its members.

Well if all researchers can access research results through the internet, there should be cost savings to societies such as the ASEG. The question here is what sort of publications do members of societies want?

Peer-review: He argues that OA papers may not be peer-reviewed.

That is not correct (see the US Law and the ERC guidelines above).

Industry: I am not sure what Hecker's argument is here.

Industry pays taxes the same as anyone else, why should it not benefit accordingly?

Publishers: He argues that it will be harder for publishers under an OA regime.

This is probably correct, if we are just looking at the standard publishing model that has been developed over the last 100 years. However, we are moving into a new era of electronic publishing that makes results available more rapidly and we probably need new publishing models.

Sustainability: He argues that the Public Library of Science is required to increase its publishing fees.

I am not sure how this works or how its funding problems affect the general OA principle.

Primary data

I should point out that the ERC guidelines include reference to basic information acquired during research projects. I believe that this is a very important point. Too often one would like to go back to the original observations, particularly in the Earth Sciences, for activities such as age dating or geochemical analysis. Parameters such as the locations of the rock samples and the geochemical analyses can be crucial and should be preserved. So it is not just in the Life Sciences that basic data are important.

I rest my case and I am not yet breathless.

Eristicus

Aeromagnetic interpretation and petroleum prospectivity of the offshore Canning Basin

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New aeromagnetic data acquired by Geoscience Australia over offshore Acreage Release Areas W07-12 to W07-15 in the Canning Basin was released through the online data delivery system (GADDS) in October 2007 (see *Preview* issue 130, October 2007).

These data have subsequently been interpreted and integrated with other data sets, particularly seismic and gravity, under contract to Encom Technology Pty Limited. The magnetic interpretation was undertaken by Clive Foss, the seismic by Vic Ziolkowski (Oil Exploration Consultants) with project management and interpretation review by Wayne Stasinowsky.

The interpretation report (71 pp. and 78 figures) and associated 3D model of this part of the Canning Basin was released to the public in February 2008, via Geoscience Australia's Oil & Gas website (www.ga.gov.au/oceans). The short time-frame between acquiring the data and releasing the report was necessary to ensure the interpretation was available to companies contemplating bidding on the blocks, in advance of the closing date of 17 April 2008.

The expectation of the magnetic study was that anomalies would be predominately sourced from basement, thus defining the basin architecture away from areas where it is reliably imaged on seismic. However, it has transpired that the majority of magnetic anomalies are caused by intrusives, located at or below the Late Permian Bedout unconformity, at depths of between 1000 m and 4000 m.

Dolerites had previously been intersected in the Perindi-1 and Wamac-1 Wells but their full areal extent was not known. It is now apparent that these occur over much more of the release areas than previously recognised and mask the magnetic response from deeper basement. However, in some locations, mainly in the western part of the survey area, basement magnetic sources are evident at depths up to 11 km (Figure 1).

A 3D view of basin structure (Figure 2), plus magnetic sources and interpreted seismic horizons can be manipulated in Encom's PA Viewer (free download from www.encom.com.au).

Despite the widespread occurrence of intrusives in the section, the presence of active hydrocarbon systems (as verified in Perindi-1 and nearby onshore wells) and the variety of play types identified and mapped on seismic sections, suggest there is good exploration potential in this largely under-explored region. Tectonic events in the Late Permian (Bedout unconformity), Late Triassic (Fitzroy Movement) and Late

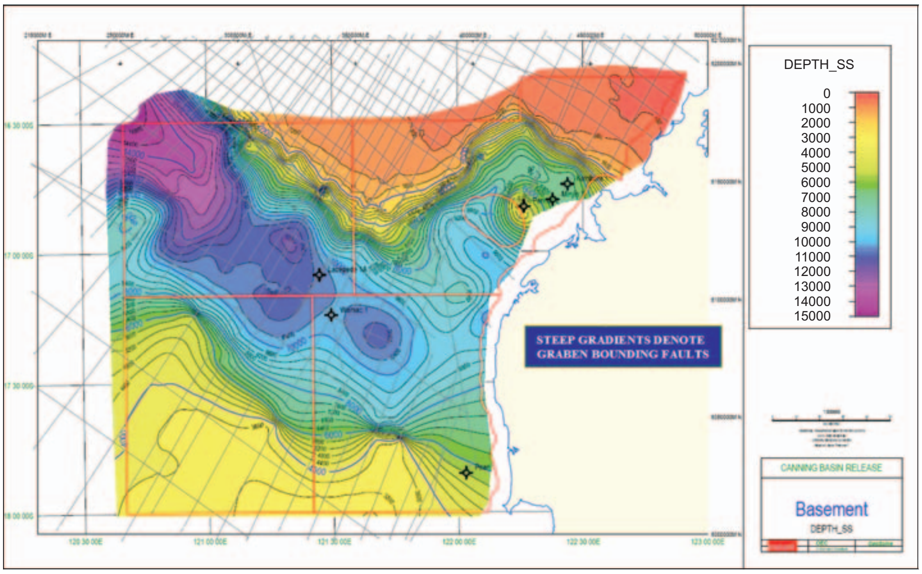

Fig. 1. *Basement depth structure map showing offshore acreage release areas (red) and location of exploration wells.*

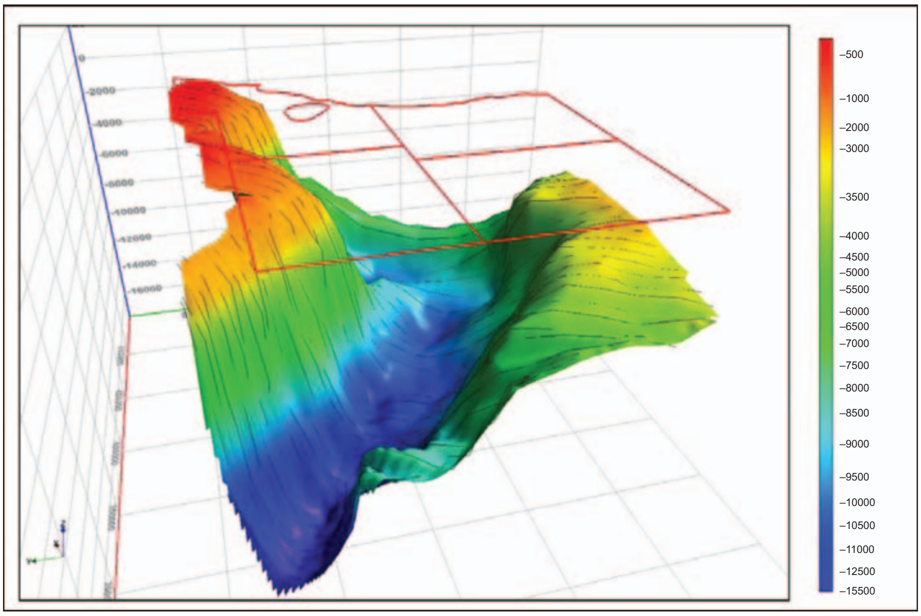

Fig. 2. *3D image of basement depth surface (looking east towards the coast), showing the west to north-west trending depocentre and location of offshore acreage release areas (red).*


Edward A. Bowen


John M. Kennard

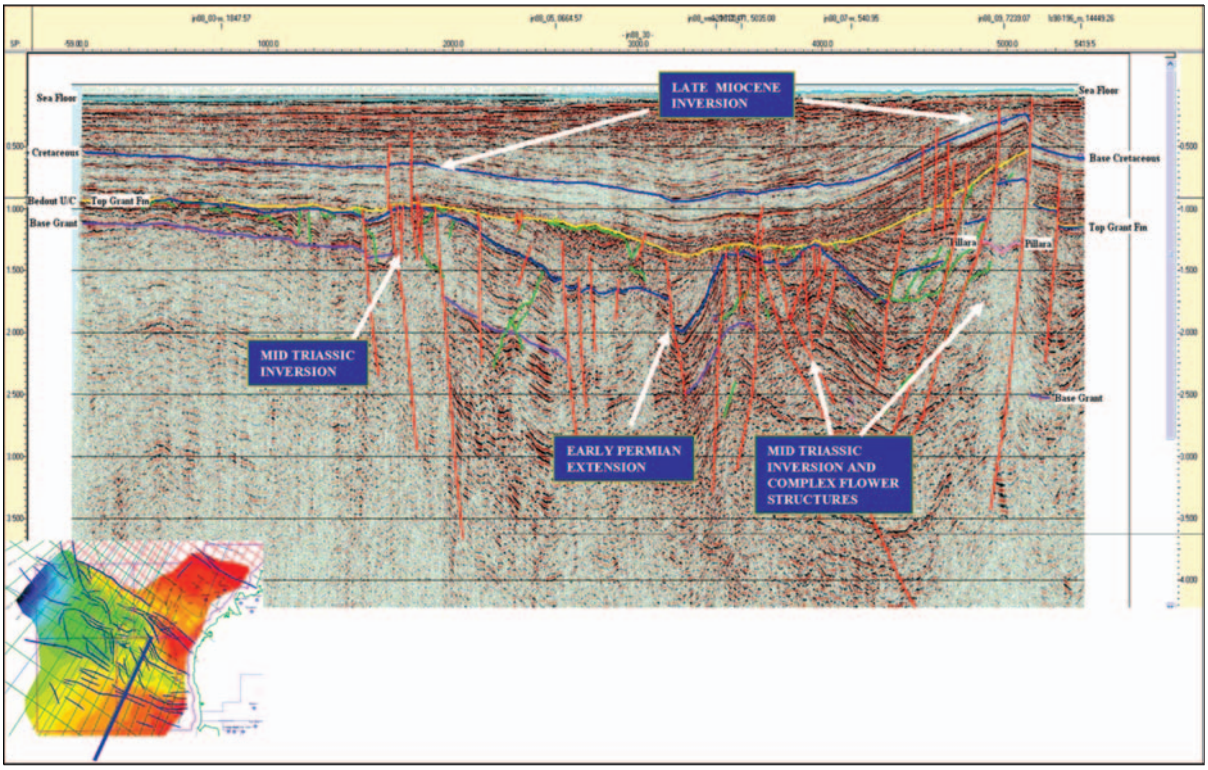

Fig. 3. *Southwest-northeast seismic section (Line JN88-28S) showing Early Permian-Mid Triassic inversion and transpression, and Late Miocene compression.Late Permian intrusives shown in green.*

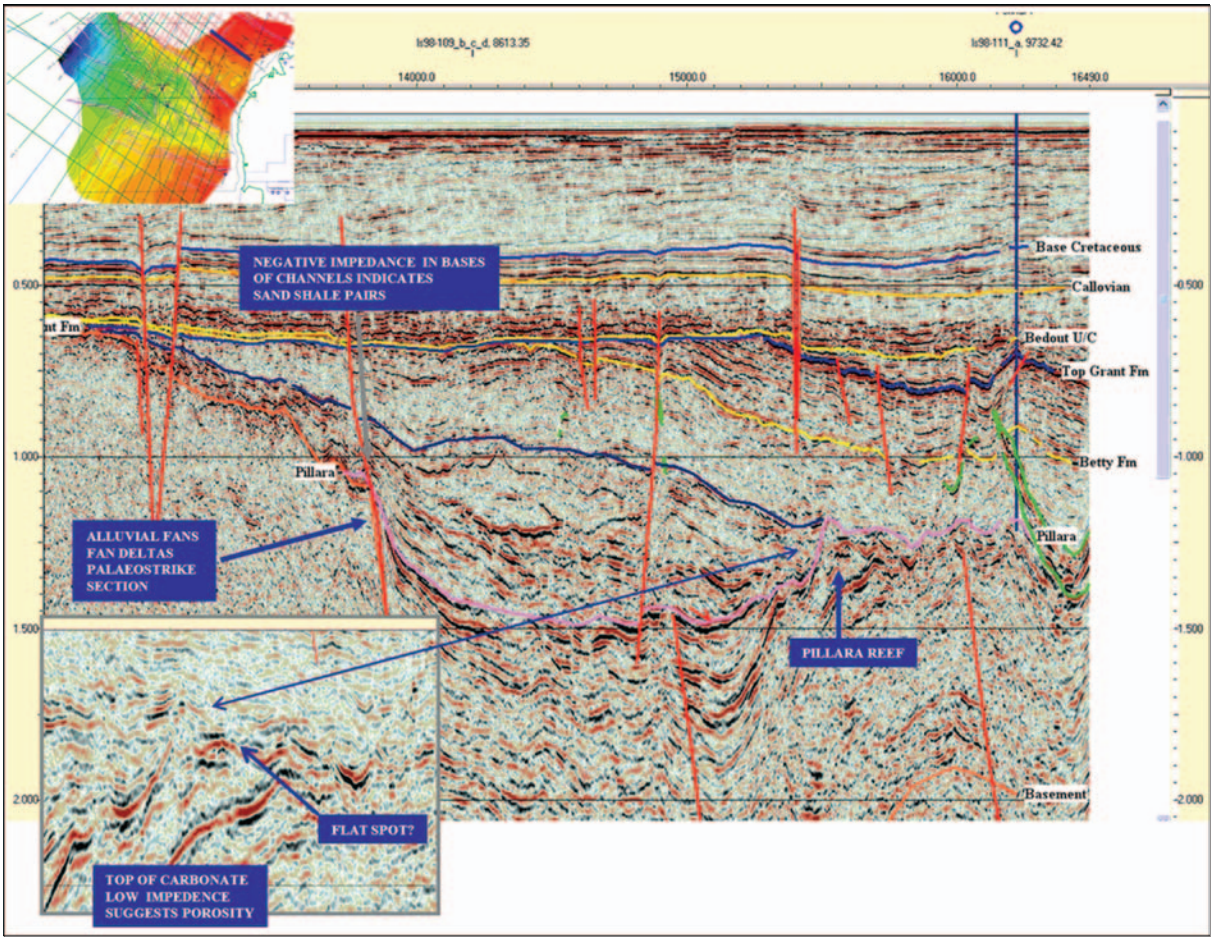

Fig. 4. *Northwest-southeast seismic section (Line LS98-198) showing Devonian reef and alluvial fan delta adjacent to northern margin of the depocentre.*

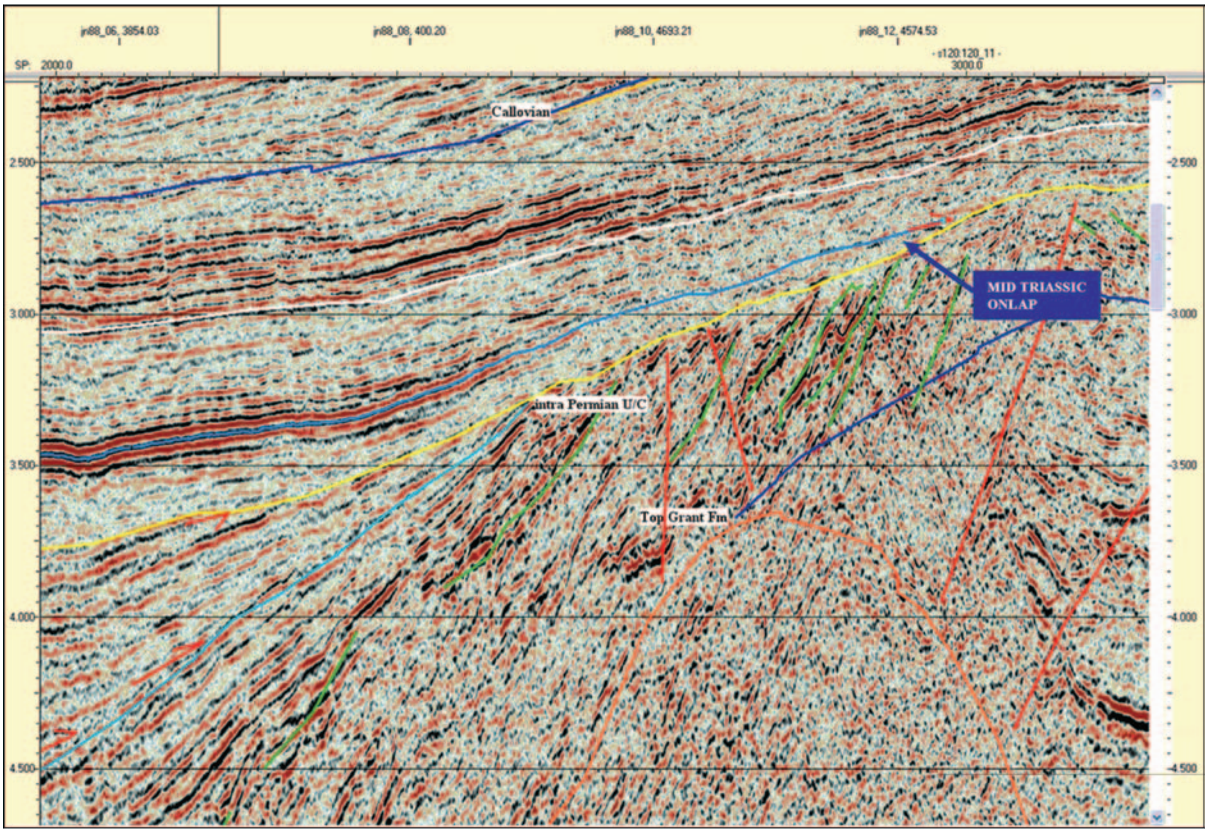

Fig. 5. *Triassic–Jurassic onlap and pinchout (Line S120;120-11) onto the Bedout unconformity (yellow horizon).*

Miocene have resulted in large scale folding, inversion and wrenching of Early Permian/Late Carboniferous clastics and Devonian carbonates above the main depocentre (Figure 3).

Around the margins of the depocentre, Devonian carbonate reefs and siliciclastic alluvial fans are in evidence (Figure 4).

In the outboard areas, onlapping Triassic–Jurassic strata (Figure 5) and possible Early Cretaceous submarine fans provide opportunities for stratigraphic plays.

Together, the new magnetic data and interpreted seismic sections provide a good indication of the structures within the release areas, and interpretation of the two data sets has proven to complement the evaluation of the petroleum potential of the release areas.

Update on geophysical survey progress of Queensland, Western Australia, Northern Territory, Tasmania and Geoscience Australia (Information current at 11 March 2008)

Tables 1–3 show the continuing acquisition by the States, the Northern Territory and Geoscience Australia of new gravity, magnetic, airborne EM and radiometric data over the Australian continent. There are two new magnetic and radiometric surveys, two new airborne EM surveys and three new gravity surveys. All the surveys are being managed by Geoscience Australia.

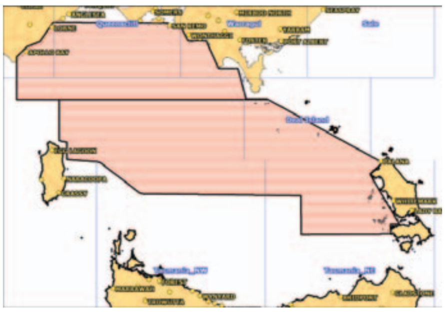

Fig. 6. *Updated Bass Strait aeromagnetic survey; the area near the Victorian coast has now been added (see Table 1).*

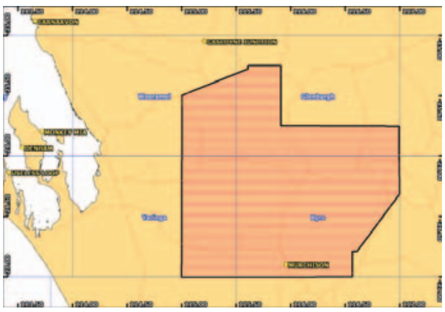

Fig. 7. *Location of the Byro aeromagnetic and radiometric survey (see Table 1).*

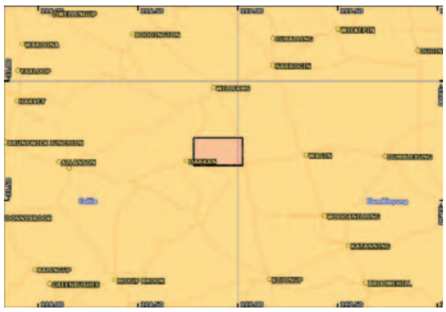

Fig. 8. *Location of the South-West Catchment Council: Darkan–Wagin airborne EM survey (see Table 2).*

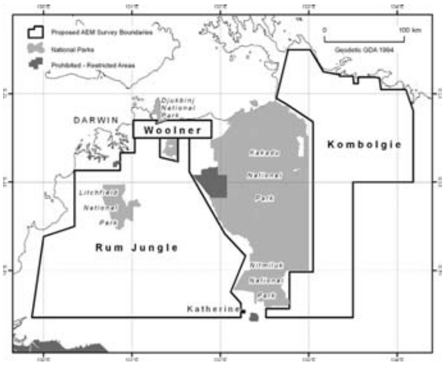

Fig. 9. *Location of the Pine Creek Airborne EM survey (see Table 2).*

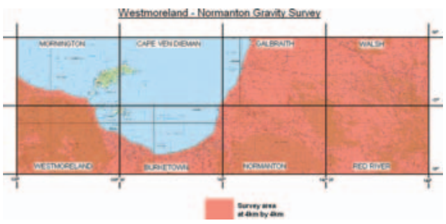

Fig. 10. *Location of Westmoreland–Normanton gravity survey (see Table 3).*

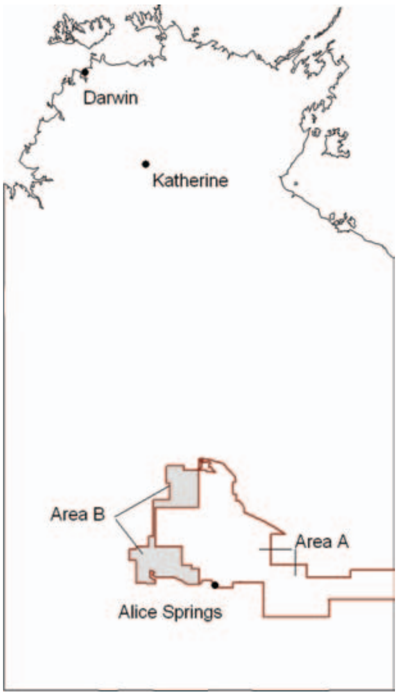

Fig. 11. *Location of the Central Arunta gravity survey (see Table 3).*

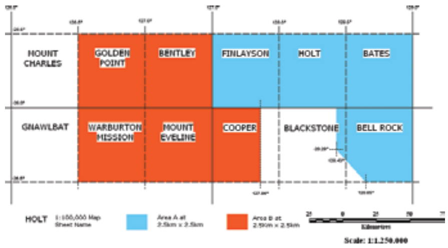

Fig. 12. *Location of the West Musgrave gravity survey (see Table 3).*

Locality diagrams for the Byro airborne magnetic and radiometric survey, the Pine Creek and South-West Catchment Council: Darkan–Wagin Airborne EM surveys, and the Westmoreland–Normanton, Central Arunta and West Musgrave gravity surveys are shown in Figures 6–12.

For more information on any of the above surveys contact Tony Meixner of Geoscience Australia at: tony.meixner@ga.gov.au

Table 1. Airborne magnetic and radiometric surveys

Survey Name	Client	Contractor	Start Flying	Line (km)	Spacing AGL Dir	Area (km²)	End Flying	Final Data to GA	Locality Diagram (Preview)	GADDS release
AWAGS2	GA	UTS	29 Mar 07	145 300	75 m 80 m N/S	7 659 861	Completed @ 14 Dec 07	TBA	124 – Oct 06, p. 15	TBA
Croydon	GSQ	UTS	2 Jun 07	100 320	400 m 80 m E/W	335 310	Completed @ 21 Sep 07	10 Jan 07	127 – Apr 07, p. 27	8 Feb 08
South Kimberley	GSWA	GPX	24 Jan 08	163 000	400 m 60 m N/S	57 920	16.7% complete @ 10 Mar 08	TBA	128 – Jun 07, p. 26	~ Dec 08
Westmoreland	GSQ	Fugro	2 Sep 07	59 753	400 km 60 m N/S	21 010	Completed @7 Dec 07	TBA	129 – Aug 07, p. 33	TBA
Cooper Basin East	GSQ	UTS	8 Jan 08	214 352	400 m 60 m N/S	76 980	8.0% complete @ 10 Mar 08	TBA	130 – Oct 07, p. 29	TBA
Canning Basin West	GSQ	Fugro	8 Nov 07	N–S lines 161 088 E–W lines 47 993	400 m 60 m N/S & E/W	N–S lines 57 700 E–W lines 16 710	33.9% complete @ 10 Mar 08	TBA	130 – Oct 07, p. 29	TBA
Normanton	GSQ	TBA	Apr 08	114 487	400 m 80 m E/W	74 410	TBA	TBA	132 – Feb 08, p. 23	TBA
Bass Strait	MRT	Thomson	28 Jan 08	70 856	800 m 90 m E/W	44 325	Completed @ 10 Mar 08	TBA	132 – Feb 08, p. 23 and this issue	TBA
Offshore NW Tas	GA	Fugro	21 Jan 08	43 824	800 m 90 m E/W	27 512	50% complete @ 10 Mar 08	TBA	132 – Feb 08, p. 24	TBA
Offshore SW Tas	MRT	Fugro	15 Jan 08	26 554	800 m 90 m E/W	16 745	Complete @ 3 Mar 08	TBA	132 – Feb 08, p. 24	TBA
South-West Catchment Council – Dumbleyung	GSWA, DAFWA and SWCC	Fugro	7 Mar 08	74 360 total (67 583 @ 100 m spacing and 6777 @ 400 m spacing)	100 m 30 m N/S and 400 m 60 m N/S	7783 total (100 m lines: 5948; 400 m lines: 1835)	TBA	TBA	132 – Feb 08, p. 24	~July 08
Byro	GSWA	TBA	TBA	82 855	400 m 60 m E/W	29 750	TBA	TBA	This issue	TBA

TBA: To be advised

News

Table 2. Airborne EM surveys

Survey Name	Client	Contractor	Start Flying	Line (km)	Spacing AGL Dir	Area (km²)	End Flying	Final Data to GA	Locality Diagram (Preview)	GADDS release
Paterson	GA	Fugro	8 Sep 07	28 367	1000 & 2000 m for GA 200 m – 666 m company infill; 120 m; E/W & SW/NE North & South, respectively of theRudall River NP	33 950	32% complete @ 30 Nov 07 demobilised for the summer to restart in first week of April 08	TBA	130 – Oct 07, p. 30	~Oct 08
South-West Catchment Council: Darkan–Wagin	GSWA, DAFWA and SWCC	TBA	Apr 08	1127	300 m N–S	288.6	TBA	TBA	This issue	TBA
Pine Creek	GA	TBA	TBA	29 058	1666 & 5000 m for GA: 200 m – 1000 m company infill; E/W flight lines; Flying height to be confirmed	72 412	TBA	TBA	This issue	TBA

TBA: To be advised

Table 3. Gravity surveys

Survey Name	Client	Contractor	Start Survey	No. of stations	Station Spacing (km)	Area (km²)	End Survey	Final Data to GA	Locality Diagram (Preview)	GADDS release
Charters Towers	GSQ	Fugro	22 Aug 07	15 310	2 and 4 regular	133 950	Survey 92.7% Complete @ 6 Dec 07	TBA	128 – Jun 07, p. 26	TBA
Cooper Basin South	GSQ	ATLAS Geophysics	17 Oct 07	9170	4 regular	146 700	23 Nov 07	TBA	130 – Oct 07, p. 30	8 Feb 08
Westmoreland–Normanton	GSQ	TBA	TBA	5977	4 regular	95 620	TBA	TBA	This issue	TBA
Central Arunta	NT	TBA	TBA	9958 in Area A & a possible 1128 in Area B	4 regular with selected areas for infill at 500 m to 2 km	97 600	TBA	TBA	This issue	TBA
West Musgrave	GSWA	TBA	May 08	1674 in Area A & a possible 2277 in Area B	2.5 km regular	24 340	TBA	TBA	This issue	~Aug 08

TBA: To be advised

Seismic surveys

As part of the Onshore Energy Security Program and in conjunction with the New South Wales Department of Primary Industries, Geoscience Australia has undertaken a deep crustal seismic reflection survey in the Rankin Springs and Yathong troughs of the Darling Basin. The survey area is interpreted as an extensive sediment-filled structural low, a large part of which attains basements depths in excess of 3500 m and has been identified as having high petroleum prospectivity within the Darling Basin. Seismic coverage in these troughs is virtually non-existent and this survey will provide important data on the basin architecture across the region.

Two traverse lines totalling around 234 km of high resolution reflection seismic data are being acquired by Terrex Seismic (Figure 13). At the time of writing 107 km of excellent quality data had been acquired along the traverse located south of Cobra and the crew were preparing to relocate to Hillston to start the second traverse, of approximately 124 km. It is anticipated that the survey will be completed 22 March 2008.

For more information contact:
Jenny Maher +61 2 62499896 or
jenny.maher@ga.gov.au

Fig. 13. *Rankin Springs seismic survey traverse line location map.*

Western Australian programs

Because half the minerals exploration effort is carried out in Western Australia we have included a map showing where the surveys being carried out in that state are taking place or planned.

Download final data releases from the Geoscience Australia Data Delivery System at www.ga.gov.au/gadds. Download preliminary and final grids and images from the Regional Geophysical Surveys page of the GSWA website (www.doir.wa.gov.au/GSWA).

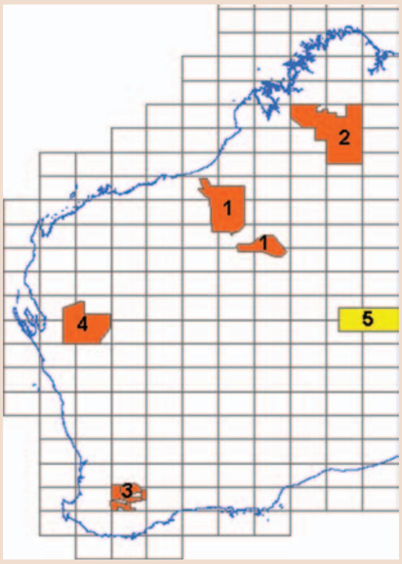

Fig. 14. *Locations of surveys being undertaken or planned in Western Australia. The codes are as follows: 1, Paterson 2007; 2, South Kimberley 2007; 3, Dumbleyung 2008; 4, Byro 2008 and 5, West Musgrave 2008.*

Subscribe to the GSWA mailing list (on the News and Events page of the above website) to keep informed of preliminary and final data release dates. Contact David Howard (david.howard@doir.wa.gov.au) for more information.

New PACE gravity survey for South Australia

As part of the Government's Plan For Accelerating Exploration (PACE) Initiative, Primary Industries and Resources South Australia (PIRSA) has completed one of the largest gravity surveys ever undertaken in the southern hemisphere. The survey area covers the highly prospective Northern Olympic Domain along the north-eastern margin of the Gawler Craton (Figure 1).

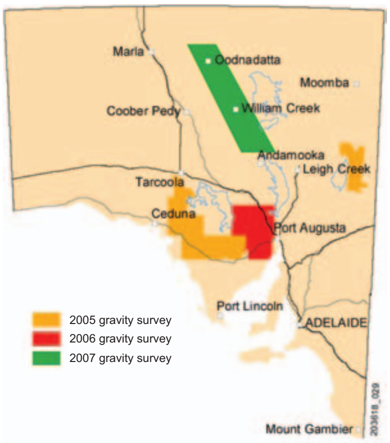

Fig. 1. *Locations of recent gravity surveys in South Australia.*

The PACE Gravity Survey 2007 was also supported by contributions from three exploration companies operating in South Australia – Barrick Gold of Australia, Metex Resources and Copper Range. The survey comprised 14 550 new stations at a spacing of 1.5 km × 1.5 km, with infill to 750 metres funded by contributions from the three participating companies. The survey was conducted by Atlas Geophysics using helicopter support from May to September 2007.

The new PACE Gravity Survey dataset was released in October 2007 (see www.minerals.pir.sa.gov.au for free download). The infill datasets are scheduled for release in late 2008.

A Bouguer Anomaly map (2.67 t/m^3) of the new PACE Gravity dataset is shown in Figure 2.

Data were collected over 32 000 km^2 covering the largely covered northern limits of the Olympic Domain, which hosts numerous IOCG+/–U (or related) prospects and deposits, including Olympic Dam, Carrapateena, Prominent Hill, Punt Hill and Moonta in the south. The northern limits of this Archean–Mesoproterozoic Domain are transitional into other Domains in the survey area, and the data will allow delineation of extensions to the prospective geology further north. Geophysical exploration has been a critical aspect of the discovery of mineral deposits in this region and numerous targets are revealed which were not apparent in pre-existing ~7 km spaced gravity stations. Barrick has already commenced drilling of targets, and numerous other targets are discernable for other tenement holders and interested explorationists.

A solid geology interpretation is shown in Figure 3 and the detailed map (at A0 size) can be obtained from PIRSA. The area covers the Torrens Hinge Zone, a broad structural belt of multiple structural reactivation ranging from the Palaeoproterozoic to Mesoproterozoic, with later variable down-faulting and subsequent uplift on the margins of the Neoproterozoic Adelaide Geosyncline to the east. In combination with aeromagnetic data, important northwest and east-northeast striking conjugate structures active in the early Mesoproterozoic ('Olympic Dam-time') can be assessed relative to broadly coincident gravity and magnetic highs. In conjunction with structural and lithological targeting criteria, valuable depth to basement information may also be obtained from the new data, providing exploration companies with a range of new information to increase chances of exploration success.

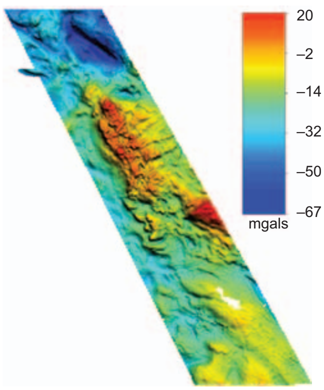

Fig. 2 *Bouguer Anomaly image of the area surveyed in 2007.*

Fig. 3 *Solid geology interpretation of area covered by gravity survey. The A0 sized map can be obtained from PIRSA.*

Comparing airborne electromagnetic systems[1]

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Summary

AEM systems are essential tools for a wide range of mineral exploration and geological or environmental mapping applications. The product of peak dipole moment and the Liu waveform factor provides a quantitative estimate of the effective signal strength of a TEM system at a specific base frequency and can be used to 'compare' systems operating at similar base-frequencies. Given also the noise levels of an AEM system and its frequency or time sampling, it is easy to predict the capabilities and resolution of the system.

These predictions were compared with survey results from the fixed-wing TEMPEST and the helicopter VTEM systems over a survey line in the Tanami desert, Australia. The much larger effective dipole moment of the VTEM system allowed it to detect deeper conductors, and its higher signal/noise ratio facilitated separation of distinct layers in a CDI section.

The most challenging development required of AEM is the development of systems operating at 5 Hz or less to penetrate conductive cover and assist in the discrimination of very conductive copper/nickel sulfide deposits. Altimeter errors provide the main limitations in depth resolution of shallow environmental targets. 2D and 3D imaging and inversion strategies are not yet reliable or fast enough for routine application.

Introduction

AEM systems are essential tools for a wide range of mineral exploration and geological or environmental mapping applications. Worldwide, the time-domain helicopter EM (HTEM) systems have captured the bulk of the mineral exploration market, with VTEM the dominant global system. However, there are a number of other HTEM systems with varied dipole moment, waveform and other characteristics operating, such as the Aerotem, HeliGEOTEM, Hoistem, Reptem, SkyTEM, Seatem, THEM and Newtem systems.

James Macnae

A few time-domain fixed wing systems continue to operate, namely Spectrem, MEGATEM, GEOTEM and TEMPEST, and the first three of these have the largest peak dipole moments of any AEM systems. As a result they have been marketed as having the greatest depth penetration. Frequency domain systems are dominated by the RESOLVE HEM systems, but older systems such as DIGHEM, Hummingbird and some wing-tip systems continue to operate (Figure 1).

In choosing an AEM survey, there is a need to balance availability and cost against the conductivity mapping and target detection capabilities. To date, there has been no easy way to quickly compare the capabilities of available systems. Numerical modelling (e.g. Raiche, 2001) is the only way to compare predicted signals for specific targets using different system geometries. Forward numerical modelling is rarely attempted in practice however, due to the limited availability of robust, relevant and flexible EM modelling codes, coupled with incomplete documentation of (often changing) EM system parameters.

This paper discusses two very simple tools that permit a quick comparison of different AEM systems for sounding and for target detection. To allow for differences in receiver electronics and processing algorithms between different systems and facilitate the use of 'case history' material, I will propose that each system be characterised by its peak dipole moment, its Liu Waveform Factor (related to duty cycle), and a 'maximum depth penetration', based on detection of a conductive layer under resistive cover in otherwise ideal conditions.

Target detection comparison

The RMS current and the peak dipole moments, sometimes quoted in AEM system comparisons, are mainly measures of the heat dissipated in the transmitter loop, and cannot be simply related to EM induction. Liu (1998) investigated the effects of repetitive

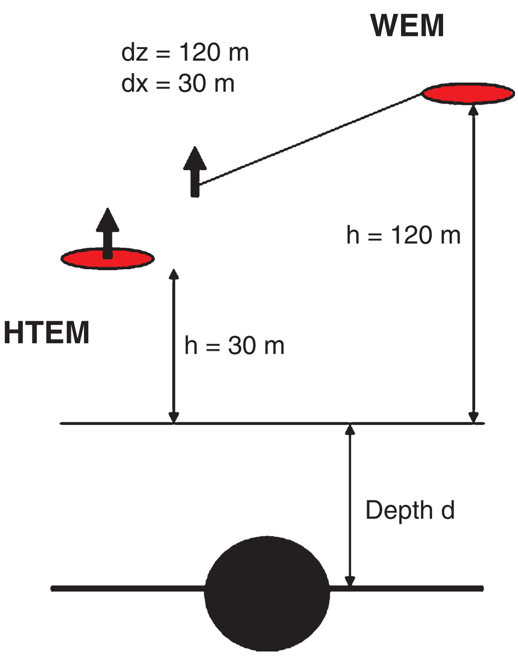

Fig. 1. *Geometry for comparison of fixed wing (WEM) and helicopter (HTEM) system, showing a thin target layer and a target sphere each at a depth d below surface.*

[1]This paper is based on the presentation 'Airborne Electromagnetic Systems' given by James Macnae at the Perth ASEG Conference in November 2007.

Table 1. Airborne TEM system dipole moments as found in Sattel (2006) and on the internet in late 2007, which when multiplied by the Liu (1998) waveform factor provide an effective dipole moment that can be used to compare secondary signals from a target (identically coupled at the same distance from the transmitter, with a common base frequency)

System	Peak dipole moment (MAm^2)	Liu waveform factor (LWF)	Effective moment (MAm^2)	Base frequency range (Hz)	Notes
Spectrem	>0.5	1.9	>1.0	25–125	100% duty cycle
MEGATEM	>2	0.6	1.2	25–90	
GEOTEM	0.6–1	0.3	0.4–0.6	12.5–125	4 ms pulse, 25% duty cycle
VTEM	0.63	0.8	0.5	25–200	10 ms pulse, 25 Hz
High signal (above)					
SkyTEM	0.12–0.45	1	0.12–0.45	25–500	50% duty cycle
Low signal (below)					
TEMPEST	0.055	1.5	0.08	25	LWF for actual waveform with 100% duty cycle
Aerotem II	0.04	0.3–0.5	0.01–0.02	30–150	Triangular, 30–50% duty cycle
Hoistem	0.12	0.5	0.06	25	25% duty cycle
Newtem	0.08	1	0.08	25–30	50% duty cycle
HeliGEOTEM	0.23 (0.5?)	0.3	0.07 (0.15?)	30–90	4 ms pulse, 25% duty cycle
THEM	0.2	0.3	0.06	30	4 ms pulse, 25% duty cycle

With the exception of Skytem, AEM systems fall into a high signal group (>0.5 MAm^2) and a low signal group, with an order of magnitude less effective moment.

transmitter waveform shapes on the off-time secondary signal from a confined target of 'long time-constant τ', which effectively means $\tau > 0.2\ T$ (T being the half-period). He concluded that half-sine (e.g. GEOTEM, MEGATEM) current waveform excitation produced at most 64% of the secondary signal in the off-time, as would be produced by a square pulse. A triangular current (e.g. Aerotem) waveform would produce at most 50% of the square pulse signal. Any exponential turn-on and/or ramp turn-off in the current also reduced the amplitude of the secondary response as measured in the off-time. The amplitude of the secondary was determined by Liu to be roughly proportional to the area under the curve in a plot of current vs. time. It is also easy to extend Liu's analysis to 100% duty cycle waveforms such as those of Spectrem and TEMPEST, as it is roughly double the waveform factor for a 50% duty cycle of the same shape in the on-time.

For good conductor detection, we can thus approximate the 'effective moment' of any AEM system, measuring to delay time T, with the product of the peak dipole moment and waveform efficiency (Table 1). The waveform factor used is that of Liu (1998), namely the area under the current pulse compared to 50% duty cycle square wave.

The analysis of received signal strength for any system in practice contains an additional element: that of geometry. Signal strength should be considered with reference to specific targets of interest as well as to system geometry. For example, the helicopter-slung VTEM system flies significantly lower than the MEGATEM and Spectrem fixed wing systems, so that the actual VTEM secondary signal from a finite target (falling off with distance as the inverse cube or greater power) will probably be the largest of the four high power systems, even though its effective dipole moment is the smallest.

Geometrical comparisons can be made with simple EM models, for example a spherical target at depth-to-centre d and a horizontal thin sheet. The ratio of secondary fields as a function of geometry can be calculated using the first moment of a sphere (Smith and Lee, 2002) or the inductive limit of a thin sheet (Macnae et al., 1998).

In the case of the red curves in Figure 2, approximating the MEGATEM and VTEM geometries and effective dipole moments, the helicopter TEM system is significantly better for large conductors up to depths of 200 m, and significantly better for small conductors to depths of 500 m. The limit in response at any depth always exceeds the ratio of effective moments, due to the lower altitude assumed for the HTEM system, and the ratio is of the order of 2 at depths of 1 km.

The layer and sphere responses are simple enough to code in Microsoft Excel, making the comparison shown trivial for different systems.

Sounding comparison

The next topic we will investigate is the effect of depth resolution and penetration. Most systems have an associated 'maximum penetration depth' that is available via the grapevine, through case histories or contractor literature. However, as well as this maximum, the location of time windows and/or frequencies

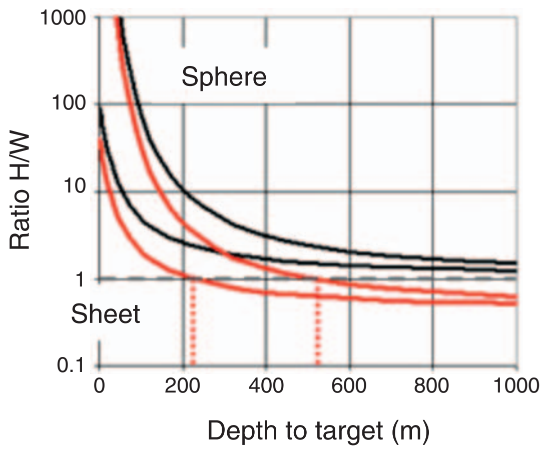

Fig. 2. *Ratio (black) between signals from an identical transmitter operated in H helicopter (concentric, altitude 30 m) and W fixed-wing (Tx height 120 m, Rx displaced 120 m back, 30 m below) mode. Shown are the limiting cases of a compact sphere and an infinite horizontal sheet. The red curves show the ratios if the fixed wing system had 2.4 times the effective dipole moment of the helicopter system.*

affects the depth resolution in AEM sounding, as each channel 'sees' to a different (but conductivity structure dependent) depth. In conductive environments, the maximum depth of penetration is controlled more by the base-frequency of the EM system than its inherent geometrical depth resolution.

Using the Maxwell receding image algorithm that is the basis for program EMFlow (Macnae et al., 1998), a very quick AEM forward modelling algorithm was developed that can simulate a three-layer earth with variable depth and conductivity of each of the layers. The results of this forward modelling then have some noise imposed. Rather than attempt to account for AEM system differences in waveform, sampling, noise reduction etc, it is possible to characterise noise in terms of a "maximum depth of penetration", based on the maximum depth at which a conductive layer in a resistive background can be reliably detected.

Figure 3 shows a forward model optimised to show the characteristics of AEM systems in a very favourable environment, where the aim is to map a roughly 300 mS/m layer, tens of metres thick, lying under a varying thickness of resistive cover. The basement is moderately conductive. Each of the layer thicknesses and conductivities is allowed to vary harmonically. Underneath the section showing the model are two images, a CDI for the 6-frequency RESOLVE system, and one for the 5-frequency Hummingbird system. The 'discrete' depths of penetration at each frequency are shown in profiles. Note that Hummingbird has effectively 3 (the coplanar coils frequencies) rather than 5 frequencies, as the two coaxial coils are operated at almost identical frequencies to two of the coplanar frequencies.

The CDI algorithm used assumes approximately uniform conductivity between the depths fitted at each frequency. This implies that the conductivity from surface to the first fitted depth (at the highest frequency) is an average. With a resistive layer near surface, the first frequency in this case has penetrated into the second layer, leading to poor characterisation of the conductivity of the near-surface resistor.

Figure 4 shows equivalent results for some time domain EM systems. The uppermost AEM system is the fixed-wing TEMPEST system, which has provided a good image of the true section. The profiles within this section are the fitted depths at each delay time. As the first delay time (at 26 μs) has already penetrated some distance into layer 2, this means that the conductivity of layer 1 is less well resolved than the RESOLVE system seen in Figure 3. Both the VTEM B field system and the Aerotem II systems provide good CDI images of this conductor. In each of these cases, the limited range of delay times at a base frequency of 25/125 Hz respectively has limited the depth of penetration at the latest sampled delay time. In resistive ground, with an effective dipole moment about 30 times greater, VTEM has a 'maximum depth penetration' about three times greater than Aerotem II.

The conductivity sections seen in Figures 3 and 4 are optimistic, in that the thicknesses and layers were chosen to provide confidence in the modelling approach. Figure 5 provides a more typical example in laterite terrain, where conductivities of the three layers are in the 1 to 100 mS/m range. Again, the middle layer (saprolite) is expected to be the most conductive. In this case, the expected CDI responses from GEOTEM (which does not have early time samples) and DIGHEM are shown. Clearly, both AEM systems have responses that reflect some aspects of the actual model, but quantitative mapping of this moderately conductive geology would not be reliable with either of these systems.

One simple conclusion that can be drawn for simple models such as those shown is that no AEM systems currently operates at low-

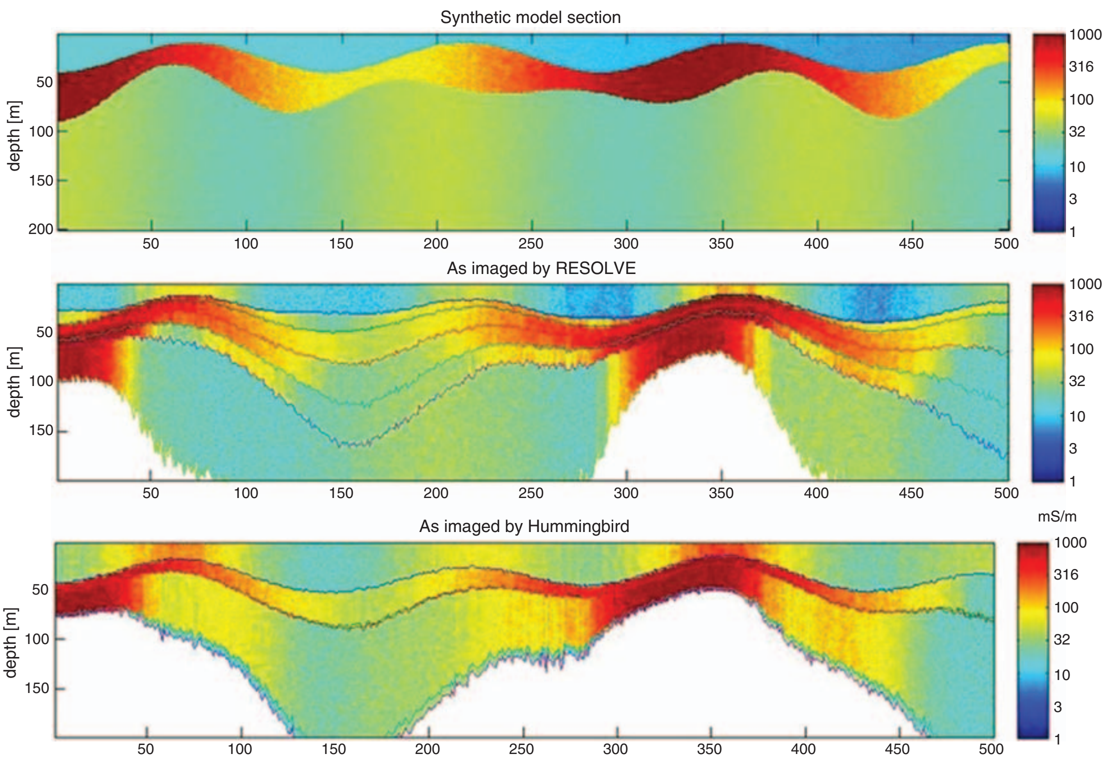

Fig. 3. *(Top) Model with simple harmonic variations in layer conductivities and depths. (Middle) Corresponding CDI section from the resolve system showing the fitted depth of penetration of each independent frequency. (Bottom) Response of the 5 frequency Hummingbird EM system with essentially 3 independent frequencies that do not allow much vertical resolution.*

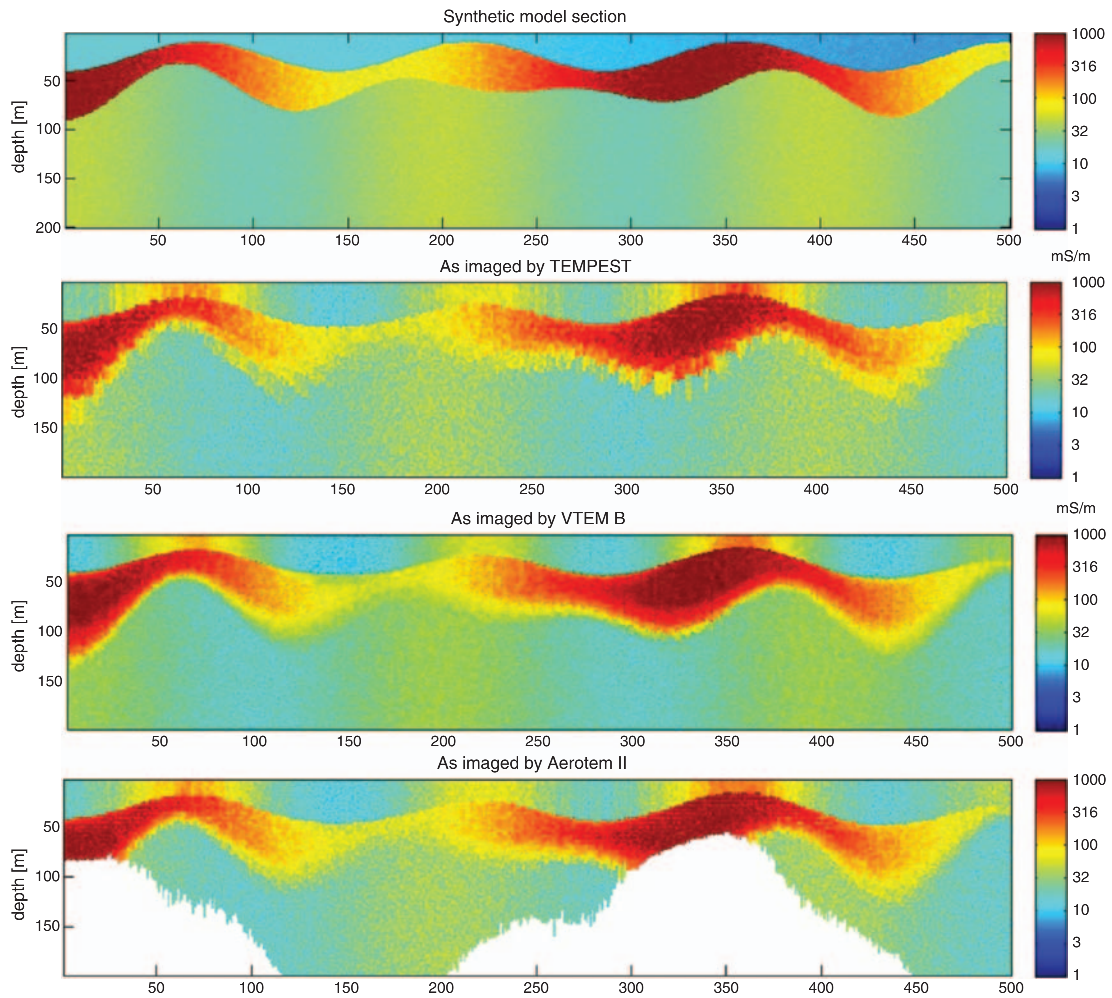

Fig. 4. *(Top) Model with simple harmonic variations in layer conductivities and depths. (Next) Corresponding CDI section from the TEMPEST system. (Next) CDI from the VTEM system. (Bottom) Response of the Aerotem II system.*

enough base frequency to penetrate conductive overburden exceeding about 10 or 20 S in conductance.

Example: VTEM and TEMPEST

Figure 6 shows a line of low-moment fixed-wing TEMPEST data flown in 2007, with x and z components. The data were collected in the Tanami desert, Australia. Above the data, which has been processed to derive the B field square-wave response in each component, I present a CDI section from EMFlow processing. A subhorizontal layer is clearly depicted, which is thought to be a shaly unit within a sandstone sequence or the sandstone–basement uncomformity (G. Beckitt, Cameco Australia Pty Ltd, pers. comm.). Dashed black lines have been drawn to show the extent of the high conductivity. To the right of symbol A, a yellow band shows the conductive response apparently dipping to the left.

Figure 7 shows VTEM data and an EMFlow CDI section from the same approximate location as the Tanami TEMPEST line and also flown in 2007. The VTEM system has over 5 times the effective dipole moment (Table 1) of TEMPEST and tows its transmitter and receiver at lower altitudes than the TEMPEST transmitter and receiver. It is therefore not surprising that the response appears less noisy. The dashed black lines on the VTEM CDI, copied from the TEMPEST data interpretation, show that the VTEM system has mapped the same shallow layer, and for the eastern part of the survey line, the mapped conductor location is virtually identical. However, the VTEM CDI section appears to map a more resistive facies within the thin layer as extending continuously to the west (above symbol A) and under a high ridge. Further, as predicted from dipole moment considerations, the VTEM system, with its lower altitude and higher moment, is capable of mapping a second layer; sub-parallel to the first and at a depth of about 300 to 500 m below surface. This layer is shown with a dashed white line, repeated on Figure 6 (TEMPEST CDI) for comparison. Little evidence for this deeper conductor can be seen in the TEMPEST CDI section. Between the two thin conductors, the VTEM section is more resistive that the TEMPEST section, possibly indicating the effects of filtering in TEMPEST data processing. The conductor to the right of A appears quite distinct from the shallow clay layer, from which it may be inferred that the TEMPEST section exhibits an edge effect, connecting the response of the deep conductor to a conductivity change in the near-surface conductive layer. It is well known that coincident-loop systems such as VTEM have fewer artefacts in data and CDI sections than do fixed wing AEM systems with their asymmetric geometry.

While this CDI comparison favours VTEM, as might be expected from simple dipole moment and geometry considerations, it is worth pointing out that the waveform

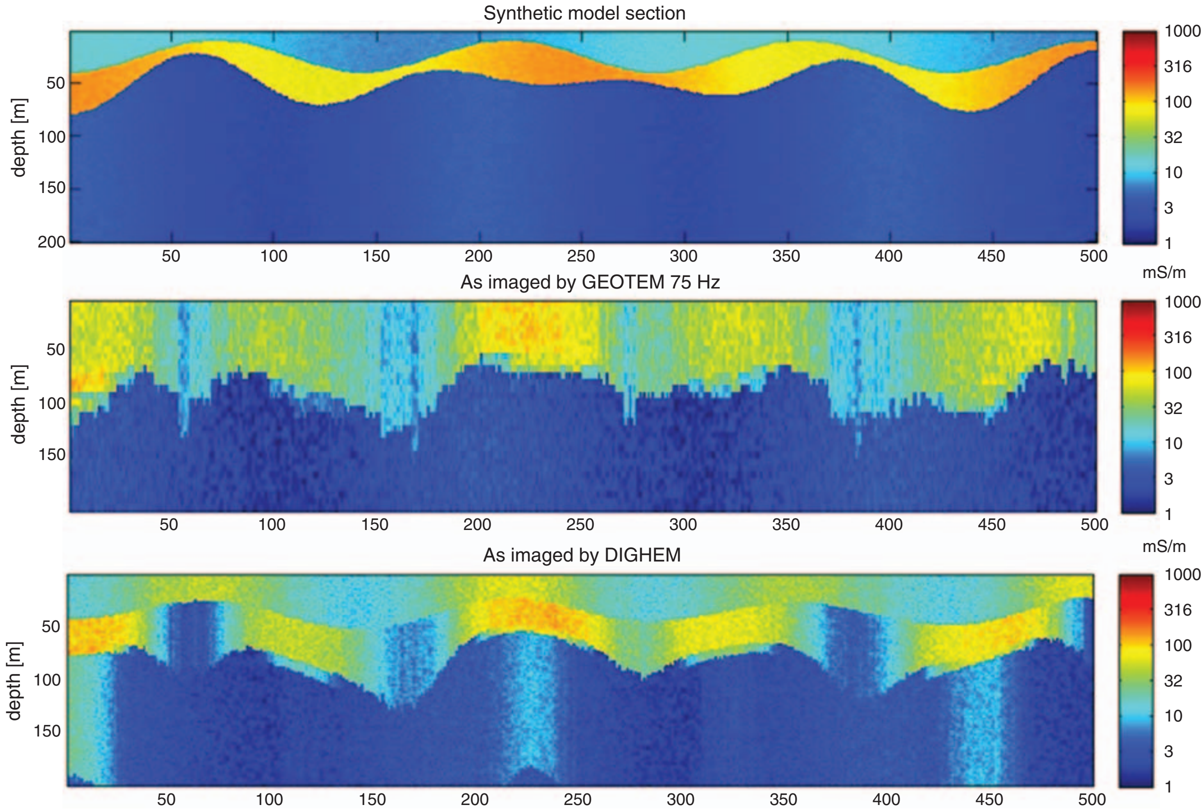

Fig. 5. *(Top) Laterite geology model with simple harmonic variations in layer conductivities and depths. (Middle) Corresponding CDI section calculated for a GEOTEM system showing the fitted depth of penetration of each delay time. Because the first channel has a delay over 200 μs from the turn-off, resolution in the near-surface is restricted. (Bottom) Calculated response of the 5 frequency DIGHEM system.*

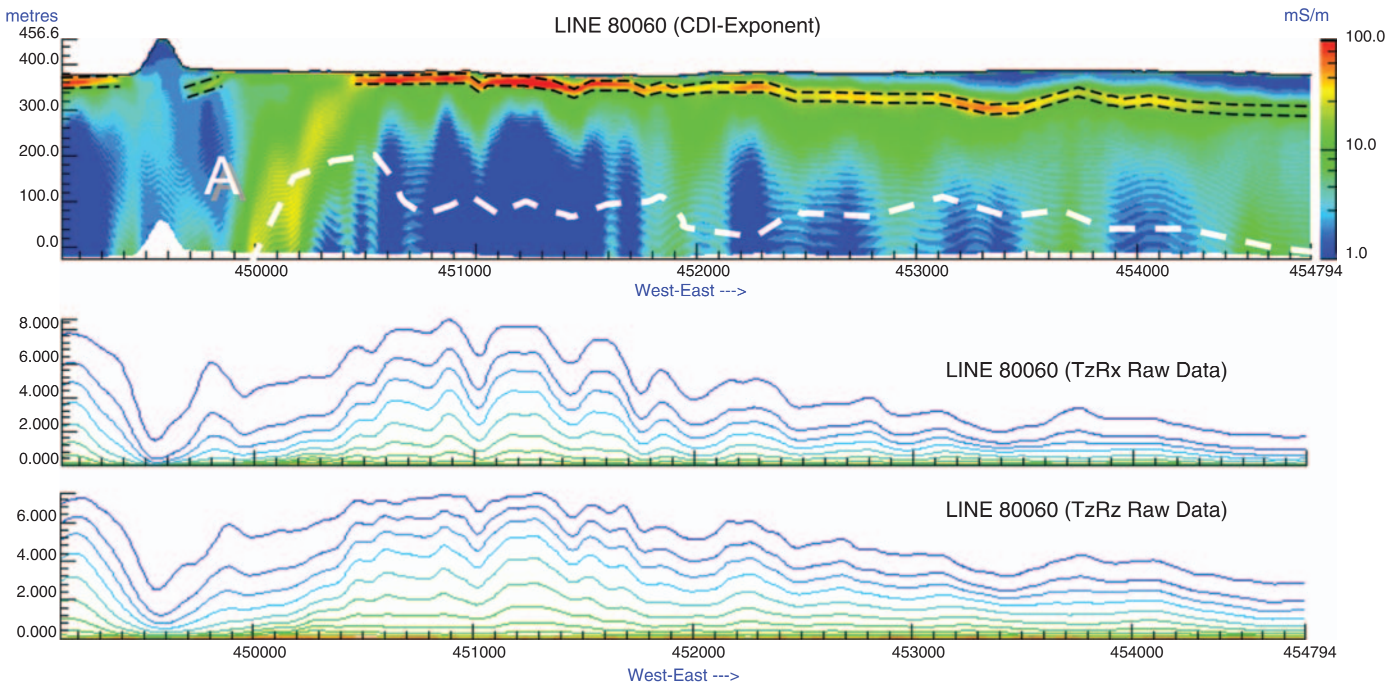

Fig. 6. *TEMPEST data and derived EMFlow CDI from flight line in the Tanami. The dashed black lines define the interpreted location/depth of a thin shale conductor, with conductivity variations within the layer. The image was calculated to a depth of 400 m. A conductor with apparent dip about 45° appears to the right of symbol A. The dashed white line is derived from VTEM data shown in Figure 7.*

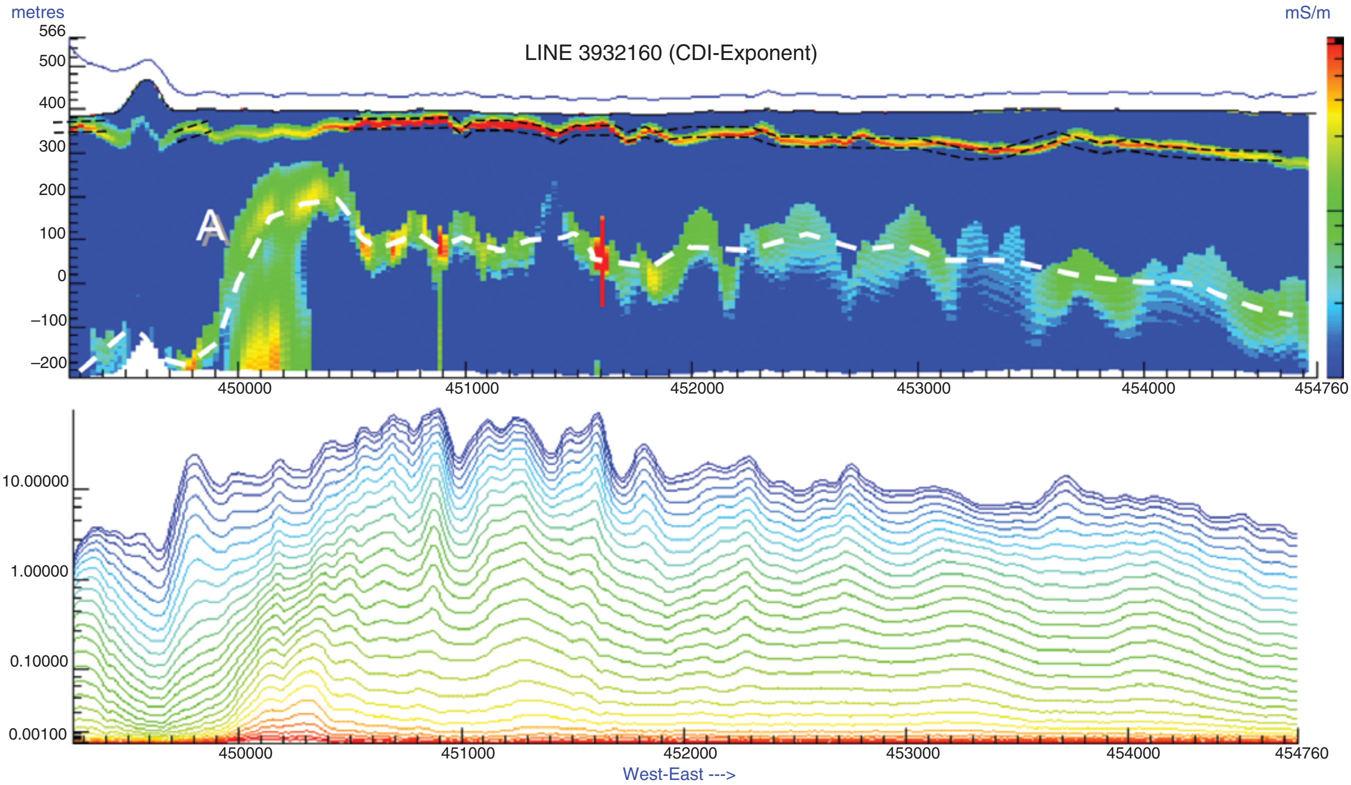

Fig. 7. *VTEM dB/dt data and derived EMFlow CDI section over the Tanami flight line. The CDI section extends 600 m below surface. The interpretation of the shallow clay layer from the TEMPEST CDI is shown with black dashed lines. VTEM imaging of this layer agrees almost perfectly east of 450500, but VTEM appears to show a more continuous clay layer above symbol A, and under the topographic high towards the west. A deeper conductor, sub-parallel to the clay layer, is evident in the VTEM data and its trace connected with a dashed white line.*

deconvolution and geometrical control processes of Fugro mean that the TEMPEST data is invariably a calibrated, quantitative, two-component step response. EMFlow processing almost always gives stable and reliable CDI sections 'first time' with TEMPEST data. VTEM on the other hand has a system waveform that varies from year-to-year and system-to-system, has a variable number and variable timing of delivered time-gates. As a result, it is more time-consuming to set up parameters for CDI processing, and there is a greater scope for error. A surprising aspect of the CDI sections is that, while TEMPEST delivers three earlier time-gates than VTEM, the shallow VTEM response of the more resistive facies of the shallow layer is clearer (to the west of the survey lines). The VTEM CDI section also shows higher contrast between the conductors (red-yellow) and the background (blue-green). The reason for this is not clear; it may be better signal/noise or the effect of less temporal averaging in VTEM. This effect is not seen in the synthetic data of Figure 4.

Conclusions

Simple models which are programmable as Excel spreadsheets or MATLAB executables provide an easy answer to the hypothetical question as to whether any specific AEM system is likely to see a geological target in a specific background with known physical property ranges. Such predictions are borne out in practice as seen in CDI sections from two different systems flown in the Tanami desert. In conductive terrain however, there is a definite need for AEM systems operating at lower base frequencies than commercially available.

Acknowledgements

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Gravity gradiometer systems – advances and challenges

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Summary

Gravity gradiometry has been heralded as one of the top five developments in advancing airborne geophysics in the past decade (Thomson, 2007). There are presently nine deployed gradiometer systems operating in various configurations (partial tensor and full tensor) on various platforms in support of global exploration activities. There are also numerous development programs underway with an aim of producing lower noise gradient measurements. A review is provided of the broad scope of developments in gravity gradient instrumentation, with a view towards how the projected improved performance will require greater attention to other error sources. It is easy to see how improved gradient data will benefit the explorationist, yet lower noise sensors alone do not provide the answer. Improved operational capability will need to come from lower sensor and system noise, as well as addressing the external error sources associated with terrain and geology. A wide range of technologies and operational scenarios under development to achieve a robust gravity gradient measurement are briefly examined and identified here. The significant challenges associated with improved gravity gradiometer operational capability including vehicle dynamic noise, terrain noise, geological noise and other noise sources are also a key focus of this paper.

Introduction

The past few years have witnessed significant advances and unparalleled interest in gravity gradiometer instrument technology as well as new deployment scenarios for various applications. Gravity gradiometry is now routinely considered as a viable component for resource exploration activities as well as being deployed for global information gathering. Since the introduction of the torsion balance in the 1890s (see Figure 1), it has been recognised that gravity gradient information is valuable yet difficult and time-consuming to obtain. Baron Lorand von Eötvös developed the first fieldable torsion balance instrument with an accuracy of 10^{-9} per sec^2 (this CGS unit ultimately received the name Eötvös or E). The only problem was that the measurements were very time consuming, requiring about 25 minutes per reading with five readings needed per station. Improvements in torsion balance design led to the introduction of the Oertling gravity gradiometer in the 1920s, with similar accuracy as Eötvös' early instrument, only smaller in size. This paper will summarise advances in gradient sensor development, and will also look at deployment scenarios and gradiometer systems that have been successfully fielded. Finally, we will briefly address the most significant challenges associated with improved gravity gradiometer operational capability. These challenges include instrument and system intrinsic noise, vehicle dynamic noise, terrain noise, geological noise and other noise sources.

Dan DiFrancesco

Gravity gradient sensors

A rapid increase in the development of new technologies for measuring gravity gradients has occurred over the past few years, spurred in part by rising oil, gas and commodity prices, as well as a renewed commitment to basic gravity gradiometry research. A brief overview of these technologies is provided below:

Lockheed Martin Rotating Accelerometer Gravity Gradiometer

The Lockheed Martin gravity gradiometer, which incorporates high-precision, room-temperature accelerometers, has been operationally deployed for more than 25 years (Metzger, 1982; Hofmeyer, 1994). Recent improvements to this instrument concept include the digitisation of critical signals to provide for lower noise and higher reliability. An additional benefit of this digital design is the reduction in size and weight of the installed system, making helicopter surveys possible (Lee et al., 2006). Gradiometers developed by Lockheed Martin have been deployed in commercial systems used by BHP Billiton (FALCON™; a partial tensor system with 8 accelerometers);

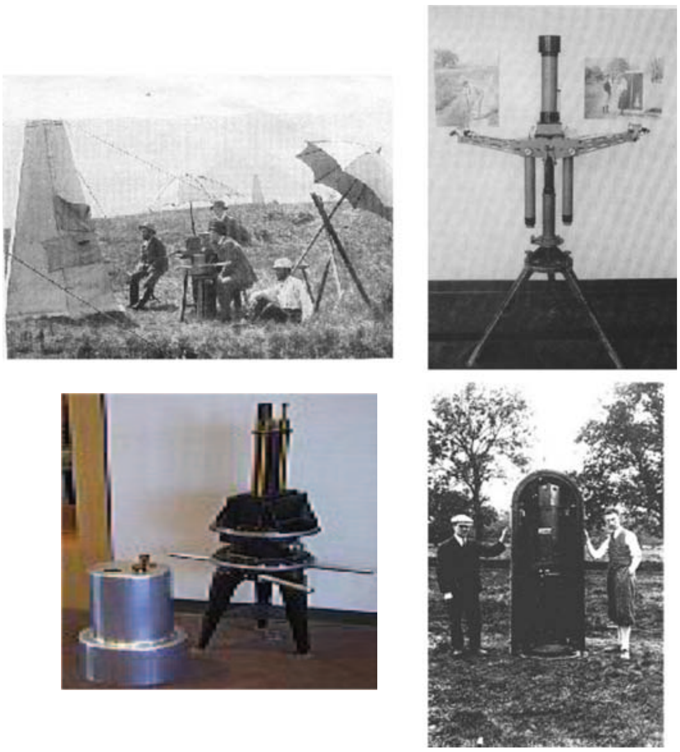


Fig. 1. *Early gravity gradiometers. Clockwise from top left: Baron Lorand von Eötvös conducting early field measurements at Ság Hill in Transdanubia (1891); Torsion balance instrument (c. 1902); British Geological Survey field measurements (1927); The Oertling gravity gradiometer (c. 1920). Photo credits: SEG; Lorand von Eötvös Virtual Museum.*

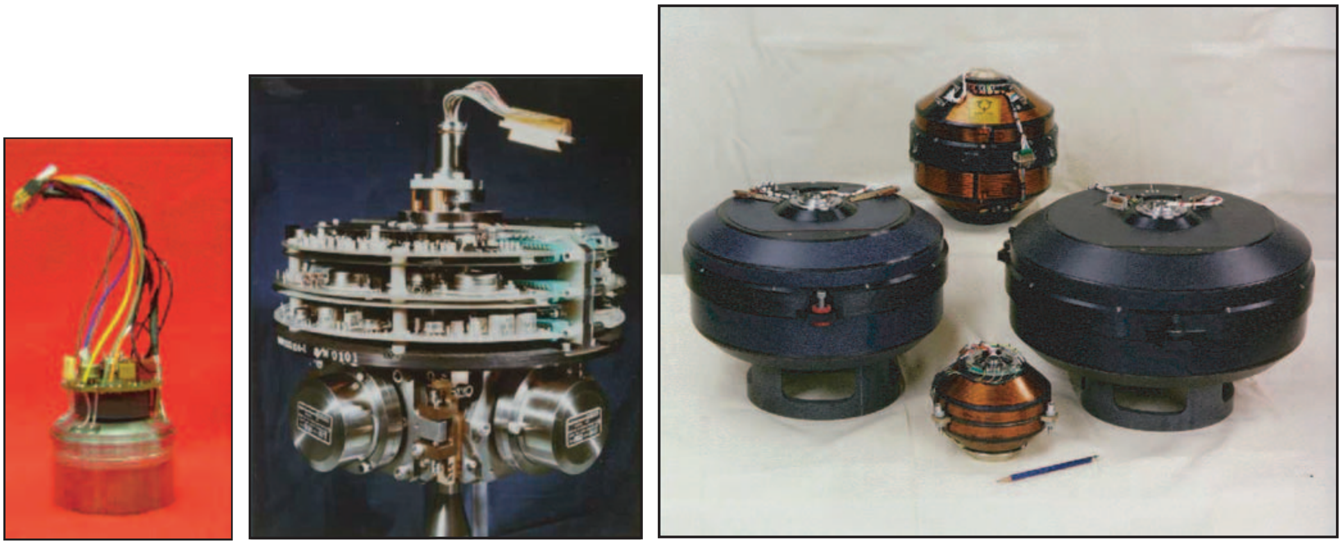


Fig. 2. *Lockheed Martin gravity gradiometer use precision accelerometers (left) as core sensing elements. Multiple accelerometers are mounted onto a rotating structure (centre), with fielded instruments depicted (right).*

Bell Geospace Inc. (Full Tensor Gradiometer – FTG) and by ARKeX Ltd (also using an FTG system). Figure 2 depicts Lockheed Martin gravity gradiometer configurations.

ARKeX Exploration Gravity Gradiometer (EGG)

ARKeX, a UK company, is in the advanced stages of testing a superconducting gravity gradiometer (Lumley, 2001). The EGG uses two key principles of superconductivity to deliver impressive performance: the 'Meissner Effect', which provides levitation of the EGG proof masses and 'flux quantisation', which gives the EGG its inherent stability. The EGG has been specifically designed for high dynamic survey environments. The EGG operates at four degrees above absolute zero (–269°C) and is maintained vertical by a state-of-the-art stabilised platform. Figure 3 shows components of the EGG.

The EGG performance is specified to be:

- Resolution: 1E/√Hz (target sensitivity)
- Bandwidth: 200 m–60 km
- Measurements: Vertical gravity gradient (Tzz)

Gravitec ribbon sensor

Gravitec Instruments Ltd, a UK company with research operations based in Perth, Australia, has developed a novel concept for measuring gravity gradients. The Gravitec gravity gradiometer sensor comprises a single sensing element (a ribbon) that responds to gravity gradient forces (see Figure 4). External electronics provide control, measurement and modulation functions (Veryaskin, 2000). The sensor is versatile in that the sensing element can be configured for airborne, ground, static, or borehole deployment. Specifications for the sensor are as follows:

- Dimensions: 400 × 30 × 30 mm
- Weight: 500 g, bandwidth: DC – 1 Hz
- Target sensitivity: 5 E√Hz flat response
- Gradients measured: Txy, Tyx, Txz, Tzx, Tyz, Tzy
- Modulation frequency: 5–10 Hz.

Stanford University Atomic Interferometer (AI) Gravity Gradiometer

The atomic interferometer gravity gradiometer uses the fundamental principle of position measurement of free-falling

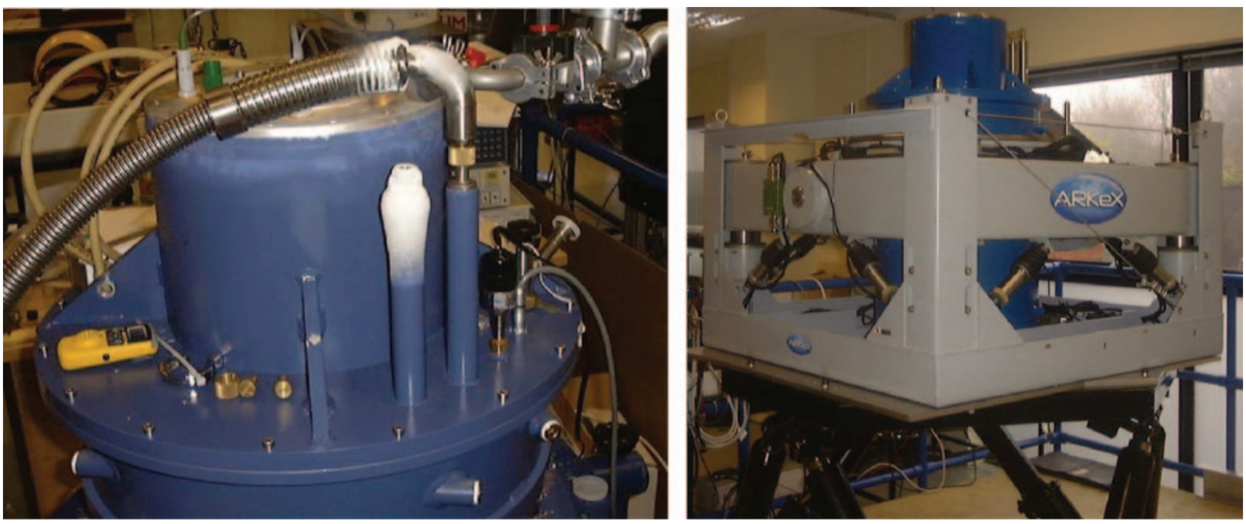


Fig. 3. *ARKeX Exploration Gravity Gradiometer (EGG). Cryostat housing superconducting sensors (left) and stabilised platform (right). Photo credit: ARKeX Ltd.*

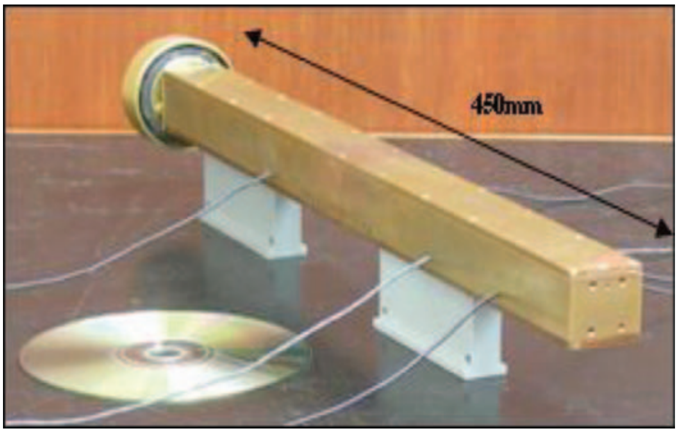


Fig. 4. *Gravitec ribbon sensor housing. Elongated form factor houses ribbon element. Photo credit: www.gravitec.co.nz.*

objects, with the unique aspect of having atomic particles serving as the test masses. Atom trajectories are interrogated by coherent laser pulses to derive the necessary inertial information. Combining two sensors provides the basis for a gravity gradient measurement. This concept is enabled by laser cooling techniques to achieve the required velocity (wavelength) control for the atom source (1997 Nobel Prise in Physics) and by the production of bright, coherent atomic sources (2001 Nobel Prise in Physics). Figure 5 depicts the Stanford AI gradiometer concept and prototype.

Jet Propulsion Laboratory Quantum Gravity Gradiometer (QGG)

In a similar fashion to Stanford's AI gradiometer, the Jet Propulsion Laboratory (JPL) at the California Institute of Technology has embarked on the development of a gradiometer system for space. In this process, called the Quantum Gravity Gradiometer (seen in Figure 6), a single laser interrogates two separate atom clouds generated in the Magneto-Optical Trap (MOT). The phase shift difference in the atom interferometers is measured to determine the gravity gradient.

Università di Firenze (Florence) MAGIA

The Misura Accurata di G mediante Interferometria Atomica (MAGIA) program at the University of Florence, Italy has been developed with the goal of determining values of the gravitational constant, G. In this concept, stable isotopes of Rubidium atoms (as opposed to Cesium atoms used by Stanford and JPL) are processed for Bose–Einstein condensation and measurement. The concept is shown in Figure 7.

Gedex High-Definition Airborne Gravity Gradiometer (HD-AGG™)

Gedex, a Canadian company based outside of Toronto, is integrating a high-performance gravity gradiometer with an active six-degree-of-freedom isolation system to minimise vehicle dynamic inputs resulting in a robust system for exploration. High precision angular accelerometers are incorporated as the sensing elements. The gradiometer design also uses superconducting components to achieve low instrument quiescent noise. Laboratory tests indicate that noise levels of 0.3 Eötvös at 3 Hz have been achieved (Main, 2006). Figure 8 shows a schematic of the angular accelerometer used in the HD-AGG™.

University of Western Australia (UWA) Gravity Gradiometer

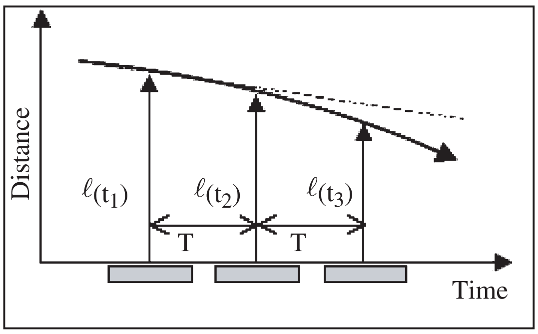
The UWA Gravity Gradiometer uses an orthogonal quadrupole responder (OQR) design based on pairs of microflexure supported balance beams (Tryggvason, 2003). Performance from this gradiometer is anticipated to be better than 1 E/√Hz. Figure 9 shows the gradiometer and system concept.

European Space Agency's Gravity Field and Steady-State Ocean Circulation Explorer (GOCE)

The European Space Agency anticipates deployment of the GOCE satellite in 2008. The system includes a high-precision gravity gradiometer configured to measure all gradient tensors. The mutually orthogonal axes are comprised of two accelerometers each, with a baseline of 50 cm. The low-earth orbiting satellite (250 km) will attempt to determine the earth's gravity field with an accuracy of 1 μGal at 100 km half-wavelength and the geoid height within 1 to 2 cm. Figure 10 shows the GOCE gradiometer schematic.

Gradiometer system deployments

Gravity gradient measurements have been conducted using a wide variety of survey scenarios, from very simple static collection to the use of satellites. Figures 11–17 depict system deployments conducted in recent years. Each of the examples identified has a common element of being viable to take measurements in 'real world' applications. This is the result of significant effort focused



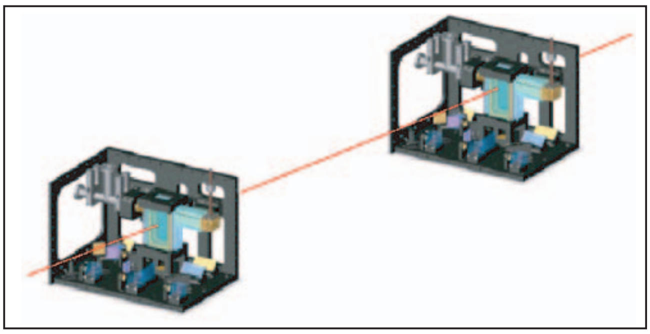


Fig. 5. *Stanford Atomic Interferometer gradiometer concept. Picture at left depicts free-falling atom cloud under sequential interrogation resulting in localised acceleration measurement. View at right shows two separate atom chambers with a coherent laser inspecting the atom clouds to produce a gradient measurement. Photo credit: DARPA.*

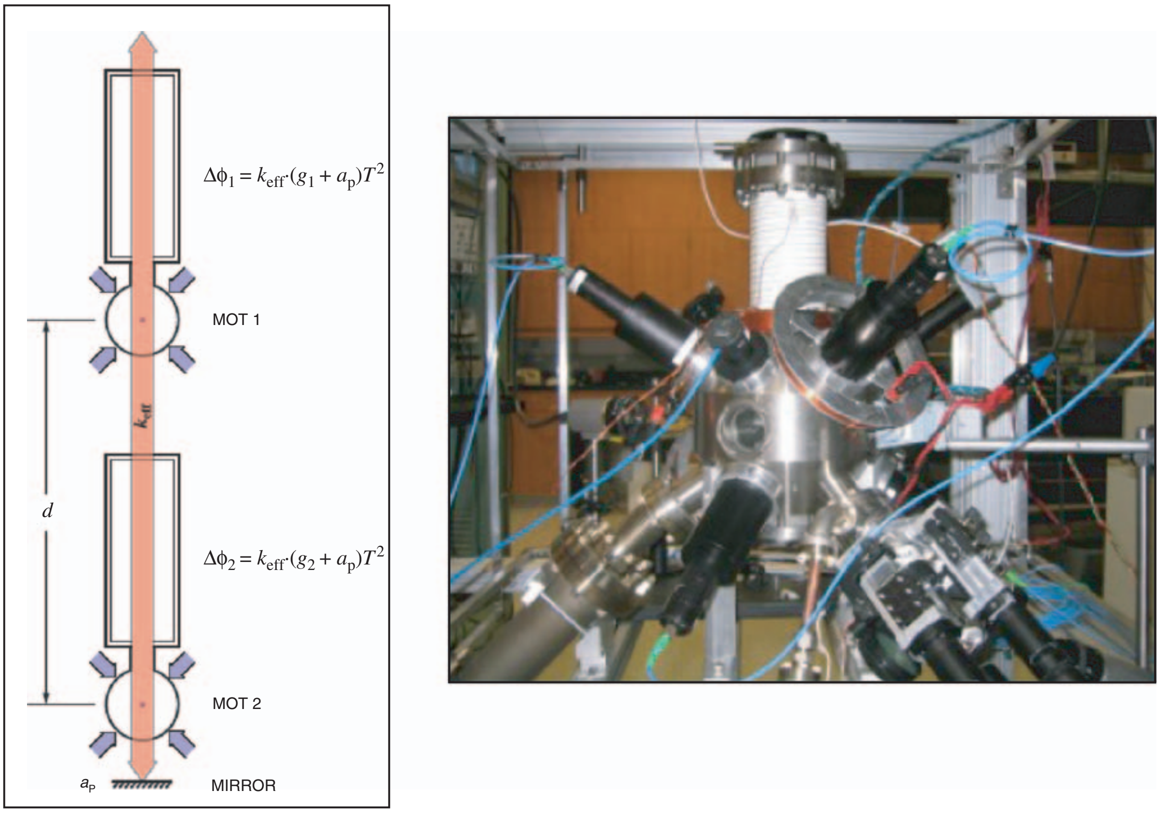


Fig. 6. *The Jet Propulsion Laboratory at Cal Tech has also developed an atom interferometer gradiometer concept. At left is the schematic of linear atom cloud chambers with a single interrogating laser. The measurement differential over 'd' yields a gradient. The prototype assembly is seen at right. Photo credit: NASA/JPL.*

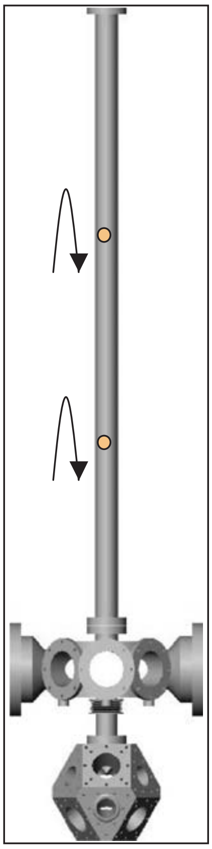


Fig. 7. *The MAGIA project at the Università di Firenze interrogates Rubidium atom clouds in the process of testing to determine the gravitational constant, G. Photo credit: Università di Firenze.*

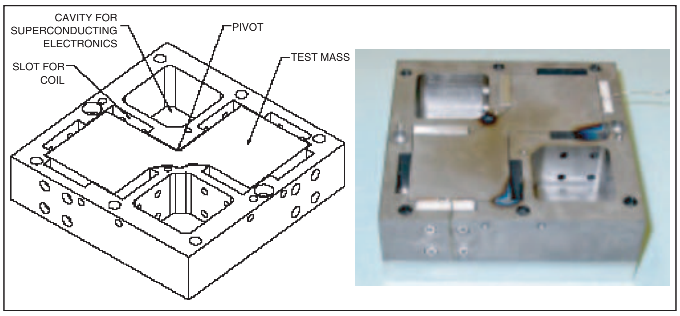


Fig. 8. *Gedex's High-Definition Airborne Gravity Gradiometer (HD-AGG™) employs an angular accelerometer with central pivot as depicted above. Photo credit: GEDEX.*

on the development of stabilised platform systems to isolate the gradiometers from vehicle dynamics, as well as intricate system engineering activity to integrate the gradiometers with their host vehicle.

Challenges for today – and beyond

Gravity gradiometers don't discriminate – they 'see' everything and 'measure' everything. This fact has both positive and negative ramifications. While the intrinsic noise levels of gradient sensors steadily improve, the relative sensitivity of the measurement to other noise factors correspondingly increases. For example, as the resolution of a gradient measurement improves by a factor of ten (say from 1 E to 0.1 E), the influence of disturbing sources (e.g. terrain and subsurface geology) also increases by the same amount. Liken it to now seeing the trees instead of the forest, yet

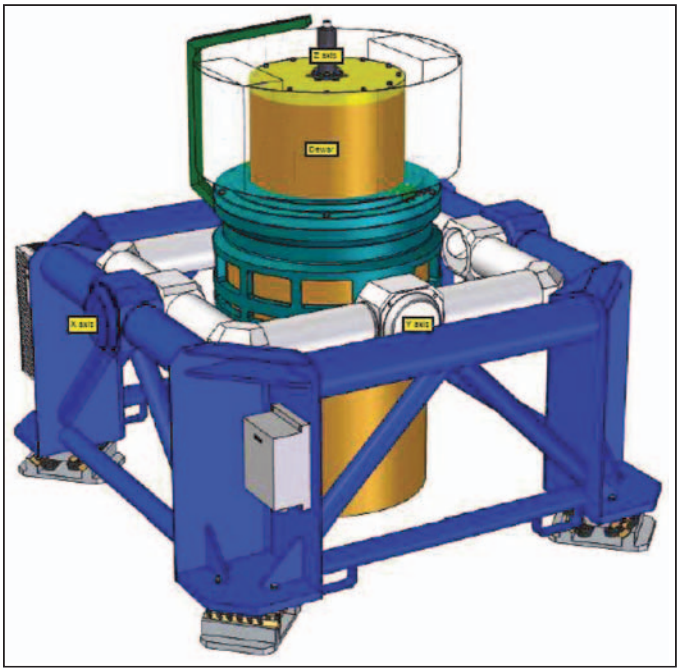


Fig. 9. *University of Western Australia's Orthogonal Quadrupole Responder (OQR) gradiometer system concept. Diagram depicts gradiometer housed within stabilised platform structure. Photo credit: Rio Tinto.*

trying to identify individual timbers in the group. Many of the gravity gradient sensors under development promise lower intrinsic noise. Performance claims of better than 1E/√Hz for the ARKeX EGG, Stanford AI, Gedex HD-AGG™ and UWA OQR sensors point to the need for better measurement of terrain as well as a way of dealing with the subsurface variations that will now be observable. Figure 18 illustrates the concept of 'stripping away' layers of noise combined with the signal measured by the gradiometer, with the top layer indicating the total measured

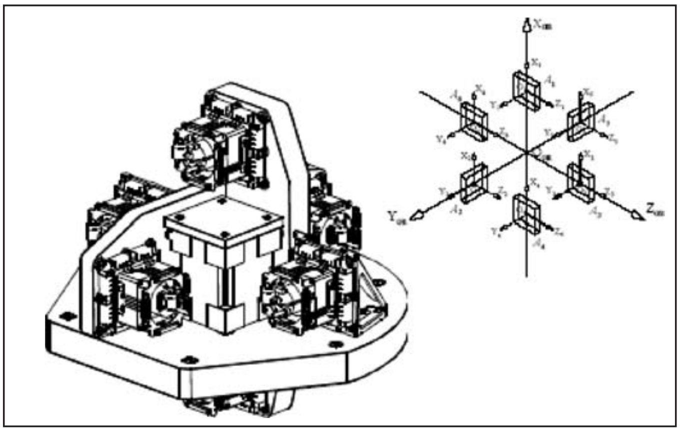


Fig. 10. *The GOCE gravity gradiometer employs six accelerometers on mutually orthogonal axes to measure all tensor components of the gravity field. Photo credit: ESA.*

Fig. 11. *Gravity Sensors System (GSS) installed on US Navy Trident submarine (1987).*

Fig. 12. *US Air Force Geophysics Laboratory (AFGL) Gravity Gradiometer Survey System (1989). The full tensor gradiometer is installed in the 'recreational vehicle', and in the extreme case, driven onto a C-130 for airborne tests.*

Fig. 13. *Cessna Grand Caravan (Model 208B) aircraft used by the BHP Billiton FALCON™ system, the Bell Geospace Full Tensor Gradiometer (Air-FTG®) system, and the ARKeX FTGeX.*

Fig. 14. *Surface ships (e.g. Northella) used by Bell Geospace for marine FTG surveys in the Gulf of Mexico and North and Barents Seas.*

Fig. 15. *Eurocopter AS350-B3 used by BHP Billiton for FALCON™ surveys. The upgraded Digital AGG system (smaller and lighter) is installed in this scenario.*

Fig. 16. *Bassler BT-67 (upgraded DC-3) is becoming a popular platform for airborne geophysical surveying. Bell Geospace has deployed FTG systems in these aircraft with good success.*

Fig. 17. *Zeppelin airship used by Bell Geospace and DeBeers for FTG surveys in Africa.*

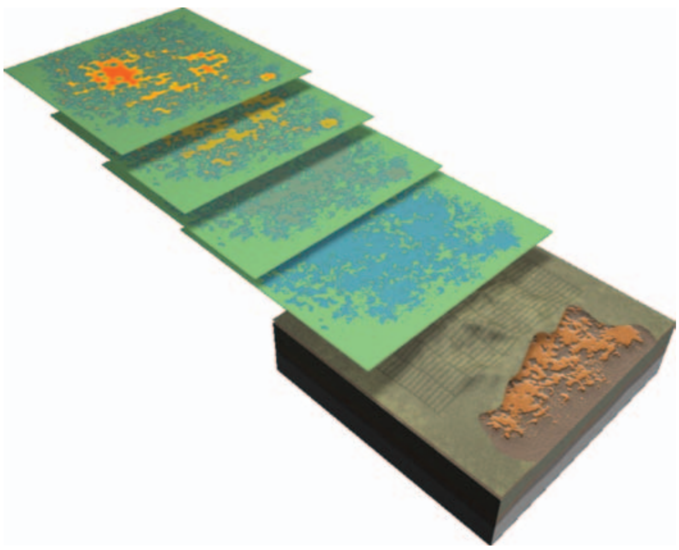


Fig. 18. *Gravity gradiometer sensors cannot separate the effect of terrain or geological variations from the total measured signal. The figure illustrates this thematically: the top layer is the total measured signal; the next layer would represent the influence from instrument and system noise; the subsequent layer the effect from terrain and elevation; the next layer geologic noise and finally, when all are removed, the signal of interest becomes evident.*

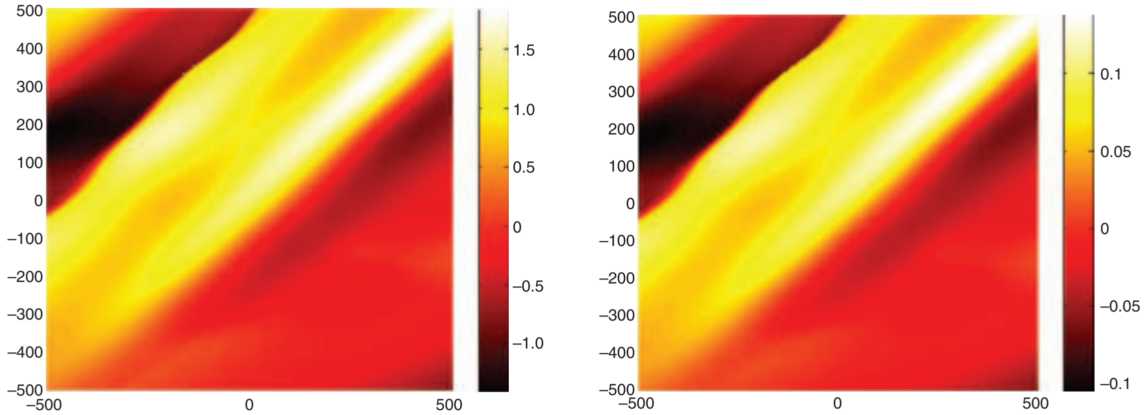


Fig. 19. *Terrain and elevation uncertainty of ±75 cm yields a 2.5 E gradient error (left). If the uncertainty is reduced to ±5 cm (right plot), the gradient error is lowered to ±0.1 E.*

gradient, and subsequent lower layers indicative of the instrument/system, terrain, subsurface and other noise sources. Ultimately, the signal of interest lies beneath all of the disruptive noise sources and the data processing challenge is to filter out the noise to detect the signal of interest within the host geologic structure.

Terrain and elevation errors

The magnitude of this challenge is demonstrated by the plots in Figure 19 where a 1 km square survey area is viewed. The plot shows the horizontal curvature gravity gradient signal resulting from a ±75 cm combined uncertainty in terrain and vehicle elevation. In this example, the resulting gradient variation is approximately 2.5 E, which would 'swamp' the benefits achieved from a higher resolution gradiometer sensor. The same 1 km square area with a terrain and elevation uncertainty of only ±5 cm, which yields a gradient error of about 0.2 E, is shown for comparison. So it can be readily seen that accurate knowledge and compensation of terrain and survey vehicle elevation is a key requirement for high accuracy surveys.

Geological variability errors

Another key area to address with regard to making high resolution gravity gradient measurements is the variability in the host geology of a potential target. The simulations in Figures 20–22 depict a 500 m square area with a density variation (Gaussian) of 2500 kg/m^3 ± 100 kg/m^3. Figure 20 (noisy) shows the contribution of this geological variation to a survey conducted with a 1E RMS

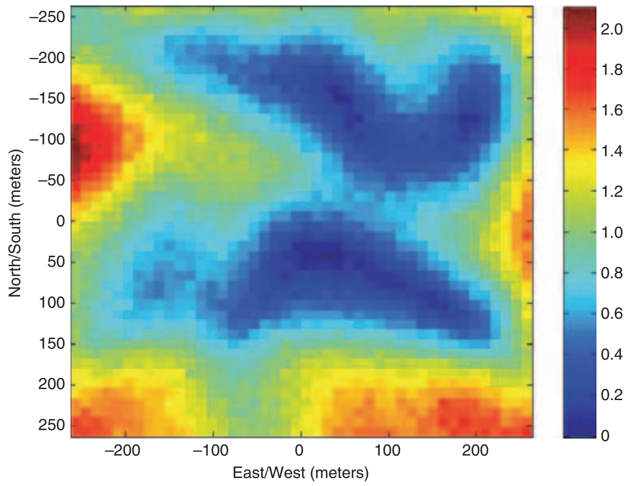


Fig. 21. *Improved signal from lower gradiometer noise (0.1 E RMS) and slower survey (30 m/s).*

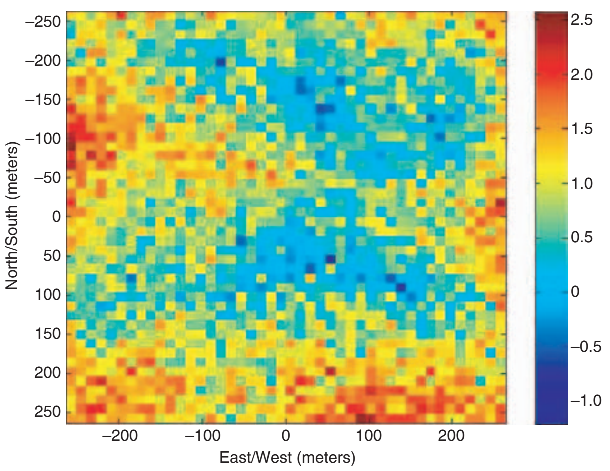


Fig. 20. *Noisy signal from 1 E RMS gradiometer at 60 m/s survey speed.*

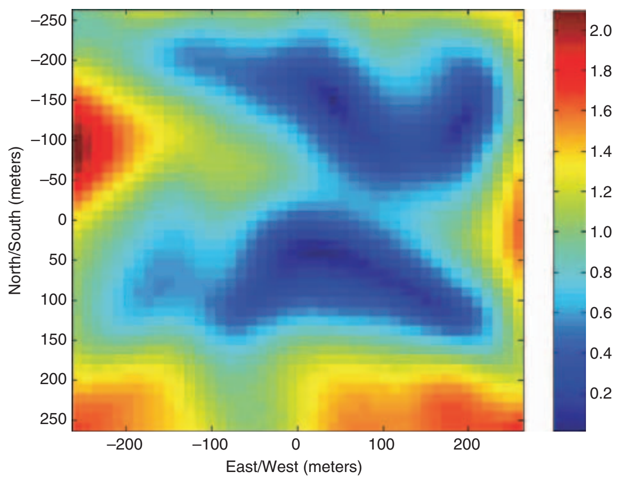


Fig. 22. *'No Noise' gradiometer surveying at slow speed (30 m/s).*

Continued on p. 39

Inferring soil chemical and physical mobility using 256-channel NaI radiometric data[1]

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Summary

The 228Ac gamma ray decay emission at ~900 keV from the thorium-232 decay series is produced approximately 1.9 years (half-life) before the formation of 208Tl and the 2614 keV (standard thorium) gamma ray decay emission. Because the difference between the daughter products is relatively small, it has been assumed that the two decay energies are in equilibrium. However, when 228Ac gamma ray energy at ~900 keV was isolated from standard 256-channel, high resolution radiometric data using a multispectral processing technique, a difference in the spatial distribution of the 228Ac ~900 keV and 208Tl 2614 keV was observed. This case study describes how the difference between the 228Ac ~900 keV and 208Tl 2614 keV was resolved and considers how the spatial differences may be used to infer and monitor soil chemical and physical mobility and identify potential radiometric disequilibrium conditions.

Introduction

The standard processing methodology for 256-channel sodium-iodide (NaI) radiometric data (IAEA, 2003) was developed to calculate the equivalent ground concentration of parent radionuclides potassium-40, thorium-232 and uranium-238. Thus historically, mapping studies using radiometric data have focused on the contribution and distribution of these radio-elements in order to interpret soil or regolith units. By modifying the manner through which 256-channel radiometric data is processed, this study demonstrates that it is possible to isolate gamma ray energies whose physical relationships can be used to map soil and regolith characteristics, specifically soil chemical and physical mobility as a function of thorium decay products.

Kirsty Beckett

Multispectral processing

In order to extract additional information from the standard radiometric data, an alternative multispectral processing methodology was established. The objective of the multispectral processing technique was not to create an alternative method for calculating ground concentration of radionuclides but to isolate individual gamma-ray peaks in order to assess whether a spatial relationship existed between the activity of the peak and soil type, soil properties and/or environmental conditions.

In order to separate the unwanted Compton scattered and x-ray energies from the direct emissions, a smooth spectral 'hull' representing the bulk of the undesirable Compton scattered and x-ray energies was calculated and removed from the data, similar to the technique applied in multispectral satellite remote sensing. In this case study, the hull was defined using a simple series of constantly decreasing negative gradients bound by local lows in the spectrum. The hull for each sampled data point was determined independently and then subtracted to create a 'peak' spectrum that emphasized the energy peaks (Figure 1).

Thorium distribution case study

The ^{228}Ac gamma ray decay emission at ~900 keV from the thorium-232 decay series is produced approximately 1.9 years (half-life) before the formation of ^{208}Tl and the 2614 keV (standard thorium) gamma ray decay emission. Because the difference between the daughter products is relatively small, it is usually assumed that the two decay energies are in equilibrium.

However, when ^{228}Ac gamma ray energy at ~900 keV was isolated from standard 256-channel, high resolution radiometric data using a multispectral processing technique (shown below), a difference in the spatial distribution of the ^{228}Ac ~900 keV and ^{208}Tl 2614 keV was observed. This could indicate that thorium daughter products are leached further into the soil profile, away from the detector prior the production of ^{208}Tl, thus increasing ^{208}Tl attenuation. Alternatively, the thorium source may be recently transported to the area, within less than 2 years, such that equilibrium is yet to be fully established.

As with standard radiometric interpretations, the patterns expressed by the soil units can assist in interpreting soil characteristics, such as texture, horizon changes and homogeneity in the top 40 cm. In the study below, the pattern generated by the thorium responses in the gravel soil unit in the lower half of the image are confined to discrete areas with uniform response. This suggests that the thorium source is constrained by a local material, such as thorium-rich laterite gravel or near-surface bedrock with shallow overburden (subcrop with colluvium). In the clay soil unit in the top half of Figure 2, the pattern generated by the thorium channels is speckled and flecked with red. This suggests that the source of the thorium is dispersed evenly throughout the unit, such that the unit is likely to have isotropic soil characteristics.

Consequently, spatial differences between thorium decay energies can be used to infer and monitor soil chemical and physical mobility and identify potential radiometric disequilibrium conditions.

Inferring mobility through thorium response

^{228}Ac and ^{208}Tl may be displaced due to the loss of gaseous daughter product ^{220}Rn between the production of ^{228}Ac and the

[1]This contribution is based on the poster presentation by Kirsty Beckett, which won the Best Poster Award at the 19th ASEG Conference in Perth in November 2007.

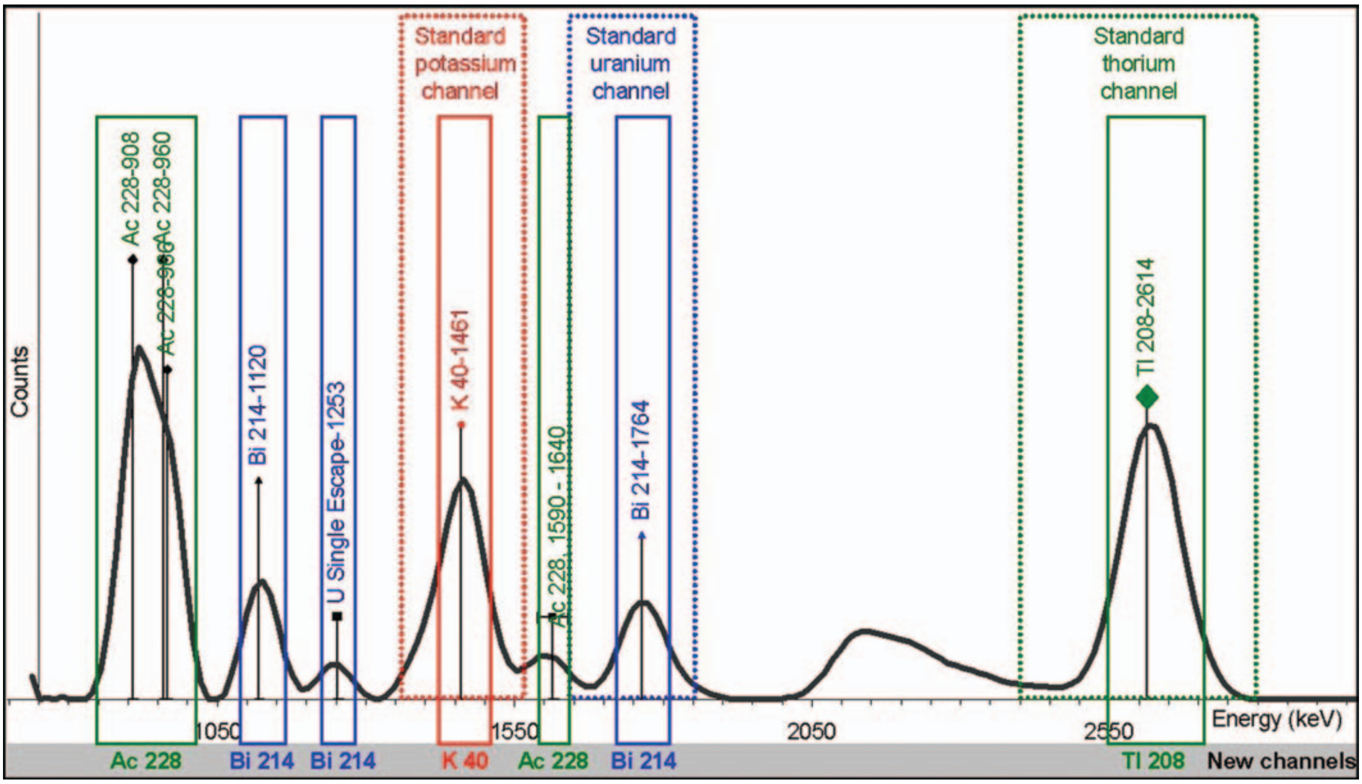

Fig. 1. *New radiometric channels isolated using the multispectral processing methodology.*

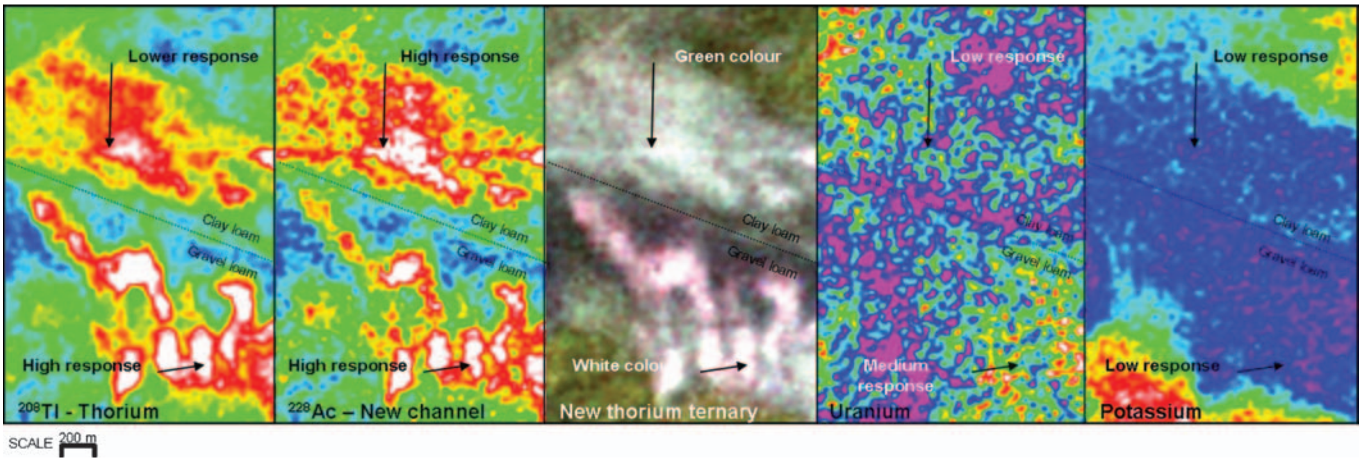

Fig. 2. *Thorium ^{208}Tl response is slightly lower in the clay soil than the gravel, while the two units show similar response ^{228}Ac response. When the three thorium channels are combined in a ternary image ^{208}Tl [red], ^{228}Ac 1590–1640 keV [blue], and combined ^{228}Ac ~950 keV [green] the soil units are clearly differentiated by colour and texture – clay in green tones and gravel in white/red. The uranium and potassium images demonstrate that the thorium differences are not a result of contamination from other radiometric sources.*

production of ^{208}Tl or through the reactivity of other intermediary daughter products within the soil.

For example, with the increased solubility of the intermediate daughter product ^{228}Ra (half life of 5.75 years) it is possible for the ^{228}Ra to be dissolved or adsorbed to fine fractions in the soil and leached through the soil profile. The deposited ^{228}Ra will decay to ^{228}Ac (the half life of ^{228}Ac is 6.13 hours). However, once the ^{228}Ra source is exhausted, detectable gamma radiation in the area of deposition will be confined to the ^{228}Th decay series for the remainder of the cycle.

Alternatively the observed difference between the ^{228}Ac and ^{208}Tl peaks may simply be a function of the displacement of ^{208}Tl further up or down the soil profile. Nevertheless, the change in the peak response ratio provides a link to changing soil chemistry and water movement.

Implications for standard processing

During standard 256-channel radiometric processing, the contribution of Compton scatter and daughter decay emission from the thorium-232 decay series in the potassium and uranium channels is calculated as a percentage of the ^{208}Tl 2614 keV count rate from a known concentration of thorium-232 decay in equilibrium and subtracted from the total channel count. However, the relative contribution of thorium to the potassium and

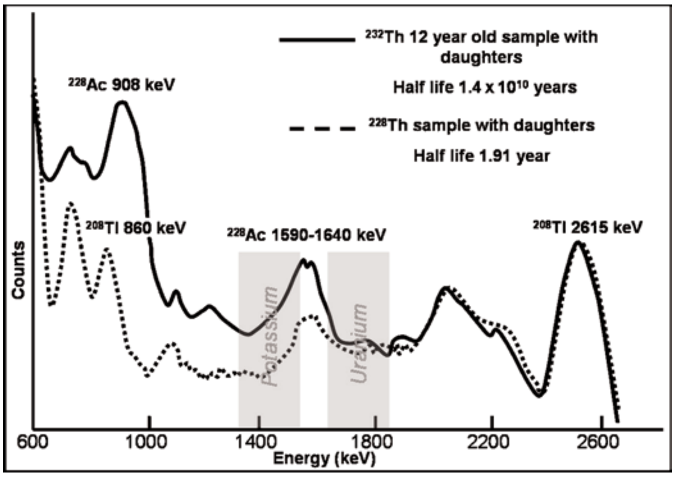

Fig. 3. *Gamma ray response of ^{232}Th and daughter product ^{228}Th for a NaI spectrometer. The fraction of thorium within the potassium and uranium channels relative to ^{208}Tl 2615 keV is different for the two thorium decay sequences.*

uranium windows would change if the ^{228}Th daughter product was separate from ^{232}Th (Figure 3). As soil characteristics and local environmental conditions influence thorium gamma ray response, by for example varying ^{228}Ra solubility, the count rate for the ^{208}Tl 2614 keV window will not always accurately represent thorium content in the uranium and potassium windows. This will, in turn, produce inaccuracies in the calculation of equivalent potassium and uranium concentrations using standard processing techniques.

However, by using the ^{208}Tl full energy peak at 2614 keV and combined ^{228}Ac full energy peaks at 908 keV, 960 keV and 966 keV multispectral channels, this case study demonstrates it is possible use the data to differentiate ^{208}Tl and ^{228}Ac distributions and hence identify and rectify disequilibrium conditions.

Acknowledgements

This work was supported by the Co-operative Research Centre for Landscape, Environment and Mineral Exploration (CRC LEME), the Co-operative Research Centre for Plant Based Solutions to Dryland Salinity, and Curtin University of Technology, Bentley, Western Australia. Supervised by Jayson Meyers and Anton Kepic, Curtin University of Technology.

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gravity gradiometer at 100 m flight height and 60 m/s vehicle speed. Figure 21 shows the benefit of improved gradiometer performance (0.1 E RMS) and flying slower (30 m/s). Figure 22 depicts the optimal result with a zero noise gradiometer flying at the practical speed of 30 m/s.

Conclusions

The growing interest in gravity gradiometry as an exploration tool has fostered many new and innovative approaches to developing these instruments. Advances in gradiometer instrumentation will continue to drive the need for better measurement and compensation for naturally occurring error sources associated with terrain and geologic uncertainty. The combination of better sensors and better processing portends a bright future for gradiometry as a key exploration tool.

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The Joint Australian Tsunami Warning Centre: responding to a tsunamigenic earthquake – Puysegur Trench, 30 September 2007

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Introduction

The Joint Australian Tsunami Warning Centre (JATWC) was established in response to the catastrophic Indian Ocean tsunami in 2004. In the wake of the devastation a clear need for an Indian Ocean tsunami warning system was recognised. As part of this ocean-wide system, the JATWC was set up to play a major role (Cummins, 2005).

The JATWC consists of collaboration between Geoscience Australia (GA) and the Australian Bureau of Meteorology. Each organisation has strictly defined roles in the event of a large earthquake in the Australian region that has the potential to generate a tsunami. Real-time seismic data is captured at Geoscience Australia's branch of the JATWC where the earthquake analysis takes place. An initial analysis of the earthquake reveals the origin time, location, depth and magnitude and based on these parameters, preliminary estimates are made as to the potential tsunamigenicity. In the case of large shallow earthquakes, the initial parameters are sent electronically to the Bureau of Meteorology within minutes of the earthquake. The Bureau of Meteorology then automatically generates tsunami travel-time information and selects a precomputed tsunami scenario based on the received earthquake location and magnitude. Appropriate advice for the Australian public is then distributed. Real-time sea level data from tsunameters and sea level gauges are monitored for any indication that a tsunami has been generated. Measurements of wave heights on these instruments can then be used in conjunction with the scenario to allow the JATWC to provide further warning messages or cancellations to coastal areas.

The Australian coastline is surrounded by active plate margins that have the potential for large tsunami generating earthquakes. In recent years several large earthquakes have generated tsunamis which have impacted the Australian coastline (Dominey-Howes, 2007). Potential sources for tsunamigenic earthquakes include the extremely large subduction zone marked by the Sumatra and Java Trenches to Australia's north-west. To the north-east, the South Solomon Trench and New Hebrides Trench mark the convergent boundary between the Australian and New Hebrides Plates. These nearby highly active margins, however, are not the only tsunami threat to Australia. Convergent plate boundaries between the Pacific Plate and regions like the Aleutian Islands and South America pose significant ocean-wide tsunami threats. However, travel-times for tsunamis generated in these regions allow many hours for detection and for adequate preparation of the Australian population. Source regions closer to Australia do not provide this luxury of time and must be identified early. One source region that presents this situation for Australia's southern and eastern coastlines comes from the Puysegur margin south of New Zealand. The Puysegur Trench marks the subduction boundary between the Australian and Pacific oceanic plates. To the north of the Puysegur Trench, the relative plate motion is oblique and enables a transition in the subduction to transform faulting (Lamarche and Lebrun, 2000). A large earthquake located along the Puysegur subduction zone on 30 September 2007 presented a significant full-scale test for the JATWC. This article will examine each stage of analysis and the actions of the JATWC from the origin of the earthquake to the tsunami monitoring and post analysis of the rupture.

Jonathan S. Bathgate

The earthquake analysis

The earthquake occurred at 05:23 UTC on 30 September 2007. It was located by the JATWC at 49.38°S and 164°E, approximately 200 km NW of Auckland Island, New Zealand (Figure 1).

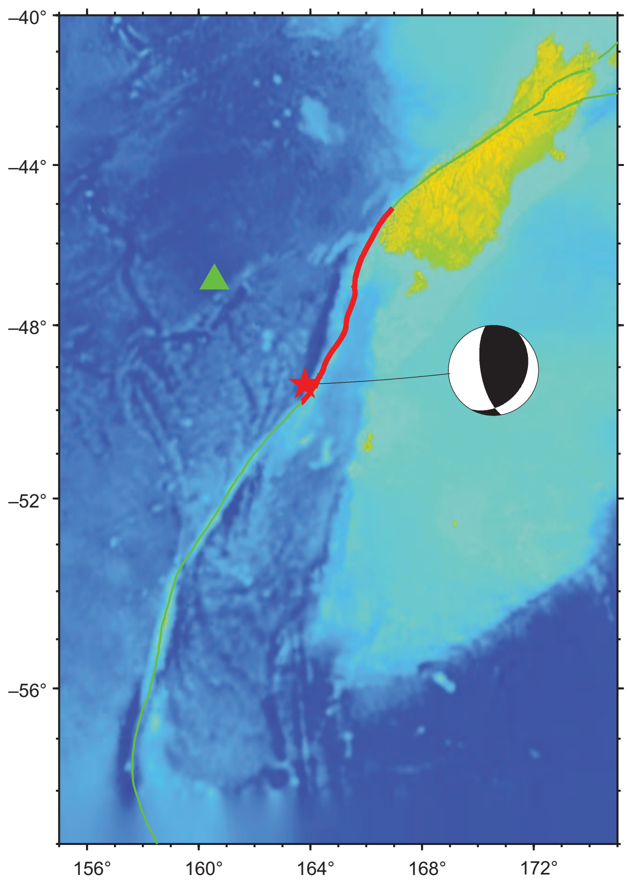

Fig. 1. *Map showing the epicentre of the earthquake (★) that occurred on September 30, 2007. The known subduction zone is shown by the thick red line and the strike-slip faults are shown by the green lines. The green triangle marks the location of the tsunameter operated by the Australian Bureau of Meteorology. The CMT calculated at GA clearly shows a thrust mechanism and it is therefore likely that the earthquake is related to subduction style faulting.*

The earthquake was immediately thought to be potentially tsunamigenic due to its location, shallow depth (10 km), and large magnitude. The final magnitude calculated by Geoscience Australia for this earthquake was 7.4 (M_w). These parameters are recognised as potentially tsunamigenic and, due to the complex nature of this plate boundary, the source mechanism is difficult to predict. Along the boundary of the Australian and Pacific Plate, the faulting transitions from strike-slip in the south at the Macquarie Ridge Complex (Ruff et al., 1989) to subduction-related thrust faulting along the Puysegur Trench and then abruptly back to strike-slip faulting at the southern tip of the South Island of New Zealand where it forms the beginning of the Alpine Fault. The location of the earthquake placed it at the southern end of the known subduction zone. However, large earthquakes with a strike-slip mechanism have been recorded in this area. To understand if this earthquake was related to a transitional zone of faulting or subduction-style faulting, a fault mechanism analysis is required. At GA this analysis is run automatically on large earthquakes by calculating the centroid moment tensor.

M_{wp}

After verifying the earthquake location and depth, various tools can be used to calculate its magnitude. Automatic estimates of magnitude are made, namely the mb and M_s using the P and surface waves, respectively. The mb is calculated using the short-period first arrivals making it a quick estimate of earthquake size. However, its usefulness is limited to smaller earthquakes, less than magnitude 6, that are generally not large enough to be tsunamigenic. Larger earthquakes will saturate the mb scale. The M_s is calculated using the 20 second period surface waves. This scale saturates slightly higher giving a better indication of magnitude for larger earthquakes. However, the surface waves are slower to arrive, making this scale less desirable for tsunami warning. In this case, the mb and M_s were 6.2 and 7.2, respectively, both of which are underestimates for this earthquake. A relatively new method to measure magnitude, which estimates the seismic moment using broadband P waveforms (Tsuboi et al., 1995), is now routinely used as a first estimate of earthquake size. This measure is commonly known as the M_{wp}. The seismograms, in displacement, are integrated to give a moment trace for each station. The peak moment is then used to determine the magnitude (M_{wp}) for the earthquake. The M_{wp} calculated for this earthquake using 24 broadband seismic traces was 7.6.

Centroid moment tensor

A valuable part of the earthquake analysis is the calculation of the centroid moment tensor (CMT). The CMT primarily gives the analyst an indication of the earthquake focal mechanism and size but also gives an independent measure of the hypocentre. Dziewonski et al. (1981) established a way of determining the earthquake focal mechanism and hypocentral coordinates through an iterative procedure using the body wave portions of waveform data. A variation of this method has been installed at GA which uses the long period surface waves (Polet et al., 2006). The system automatically triggers for any earthquake detected that has a magnitude (mb) of 5.5 or above. The initial earthquake hypocentre is automatically calculated from the first arrivals of the body waves and is passed on to the CMT software as a starting point. The results from this analysis are available between 15 and 30 minutes after the earthquake origin. Although the inversion process is very quick, the delay is due mainly to the travel-time of the long period surface waves from the earthquake source to the seismometer. The waveforms acquired from all 3-component broadband seismometers are filtered between 150 and 300 seconds. Now that we have the initial earthquake hypocentre and the centroid location it should also be possible to get an indication of the direction of rupture for very large earthquakes. Although the initial information passed to the Bureau of Meteorology is based on the M_{wp} estimate, the CMT will provide a confirmation of magnitude and additional information on the potential tsunamigenicity of the earthquake within a short period of time. The focal mechanism distinguishes between different faulting styles that caused the earthquake. Thrust and normal faulting are more likely to create a vertical displacement of the ocean floor and therefore are more likely to generate a tsunami. Strike-slip mechanisms are less likely to vertically displace the sea floor and present a lower risk of generating a tsunami.

For the Puysegur earthquake the focal mechanism indicates predominantly thrust-style faulting with the strike aligned in the direction of the Puysegur Trench (Figure 1). It is therefore likely that this earthquake is related to the subduction of the Australian plate beneath New Zealand's South Island rather than the obliquely slipping plate margin immediately to the South that is associated with the Macquarie Ridge complex. From this initial interpretation of the earthquake mechanism it could be said that the potential for tsunami generation was higher than if the source mechanism were strike-slip. The CMT magnitude (M_w 7.4) and focal mechanism agree closely with those calculated by the Global CMT Project (GCMT, http://www.globalcmt.org/CMTsearch.html).

The tsunami

Once the preliminary earthquake analysis has taken place and the alerting thresholds have been met, the Australian Bureau of Meteorology is sent the earthquake hypocentral parameters and magnitude. These parameters are used to select the most appropriate scenario from a pre-existing scenario database for predicting the potential large scale sea level changes (up to an ocean depth of 20 m) caused by the resulting tsunami. A scenario database is a set of tsunami model runs that are calculated ahead of time with the initial conditions carefully selected so that they are likely to represent actual tsunamigenic earthquakes.

The JATWC currently uses the T1 scenario database (Greenslade et al., 2007) which consists of 741 scenarios calculated using the MOST model (Titov and Synolakis, 1998) for a range of magnitudes in the Australian region. Immediately upon receipt of the earthquake parameters, the Bureau of Meteorology matches the hypocentral parameters to the closest possible T1 scenario. This then determines the extent of the warnings to be distributed to the public and emergency management agencies. This will usually occur before the expected tsunami arrival-time at any of the tide gauges or tsunameters. For this earthquake the T1 scenario shown in Figure 2 best matches the parameters that were initially calculated.

It predicts that parts of eastern Tasmania could see maximum offshore tsunami amplitudes between 15 cm and 20 cm and the south-eastern mainland, Victoria to NSW, could see maximum amplitudes of up to 5 cm. Based on this information the JATWC then issued a tsunami bulletin stating that a tsunami threat exists for the south-east mainland coast of Australia and Tasmania and that confirmation of tsunami generation is being sought. The bulletin also includes the expected arrival-times of a tsunami at locations potentially affected if one has in fact been generated.

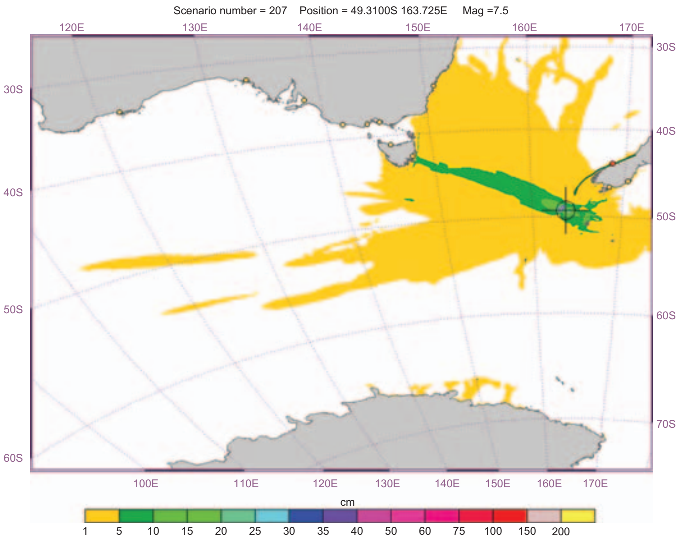

Fig. 2. *This pre-calculated T1 scenario for an earthquake located at 49.31°S and 163.72°E, with a magnitude 7.5 was the closest available scenario to describe the likely sea-level changes expected from the earthquake occurring on 30 September 2007. Maximum tsunami amplitudes up to 50 cm are predicted near the earthquake epicentre and up to 20 cm off the Tasmanian shore.*

To determine if a tsunami is in fact generated, the Australian Bureau of Meteorology will actively monitor tide gauges and tsunameters in the area for any signs of unusual activity. A recently deployed tsunameter operated by the Australian Bureau of Meteorology is located approximately 360 km to the north-west of the earthquake epicentre (Figure 1). At 05:51 UTC, 28 minutes after the earthquake, a large signal on the tsunameter record marks the tsunami arrival (Figure 3). The maximum peak-to-peak value of the wave is 13 cm, giving a wave amplitude of approximately 6.5 cm. Figure 3 also shows a signal prior to the arrival of the tsunami at the tsunameter. This signal coincides with the expected arrival-time of the seismic surface waves. The theoretical arrival-time for the seismic surface wave was 05:25:20 UTC assuming a wave velocity of 3.5 km/sec. At this stage it can be confirmed that a tsunami has been generated and warning messages for the Australian coast can be re-evaluated.

As the wave approaches the shore, variations in local coastal and shallow water bathymetry can have a significant impact on the resulting wave height at the shore. It is these coastal effects that make it difficult to predict the effects of a tsunami along a large stretch of coastline. This was noticed as a result of this tsunami, with discrepancies between observed amplitudes at tide gauges along the coast and the expected offshore amplitudes predicted by the T1 scenario. Interestingly, wave heights measured at Port Kembla (34.47°S, 150.91°E) on the NSW coast were greater than those measured by a tide gauge at Spring Bay (42.54°S, 147.93°E) in Tasmania. As mentioned earlier, offshore sea level changes of up to 20 cm were expected near certain areas of the Tasmanian coast and this was reflected by amplitudes of 10 cm measured by the tide gauge at Spring Bay. However, amplitudes of up to 15 cm were measured at Port Kembla which is higher than that observed at Spring Bay, despite the lower offshore predicted amplitude near Port Kembla (~5 cm) from the scenario. Local bathymetric effects and positioning of the tide gauge can affect these measurements (Allen and Greenslade, submitted).

With confirmation of tide gauge levels and no reports of damage in these areas the JATWC issued a cancellation of the tsunami threat but warned of abnormal currents and tide levels for the next several days.

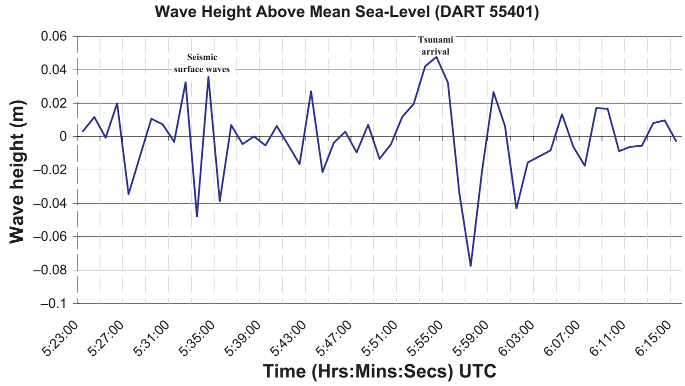

Fig. 3. *Sea level data acquired from the tsunameter located in the Tasman Sea. Tidal effects have been removed and residuals plotted to show the relative wave heights. The distance from the earthquake epicentre to the Dart buoy is 3.32 degrees or approximately 360 km. The epicentre is approximately 1400 km from the Tasmanian coast.*

Rupture and tsunami models

The techniques used here for rupture and tsunami modelling currently form part of the research that is being carried out by the JATWC. The aim is to develop these methods to a level where they can be incorporated into the operational systems of the JATWC. The tentative results below show the potential of these methods for tsunami warning.

In order to estimate the rupture parameters, GA retrieved data from the Incorporated Research Institutes for Seismology's (IRIS) Data Management Center, selecting recordings mainly from high-quality broadband stations of the Global Seismographic Network (GSN) and the Australian National Seismographic Network (ANSN). 18 P and 30 surface waves were selected from seismic traces with the best signal-to-noise ratio. This resulted in a geographic coverage that was sufficient for rupture modelling (Figure 4a). The modelling was based on the results of the GCMT Project for this event, with parameters (Strike:31, Dip:34, Rake:120) for the shallow and (Strike:176, Dip:62, Rake:71) for the steep dipping focal planes, respectively. The method of Thio et al. (2004) was used to invert the seismic waveforms for rupture on the two candidate fault planes. From the two focal mechanisms mentioned above, the steep dipping one was selected for the following reason: The results for this plane show a maximum slip of ~1 m for the steep solution (Figure 4b), whereas for the shallow mechanism the maximum slip is 4 times larger.

As a consequence, the maximum slip distribution from the shallow mechanism resulted in a much larger tsunami (~40 cm) instead of the 13 cm observed at the tsunameter, 360 km NW of the epicentre. This relatively small maximum slip of 1 m was also obtained the by finite fault inversion algorithm for only body waves (Kikuchi and Kanamori, 2003).

The tsunami was modelled by solving equations of the linear shallow-water theory, using a variation of the method of Satake (1987). The global bathymetry model GA-DBDB2 was used, resampled from 2 to 1 arc-minute spacing. A grid search for a number of azimuth-dip pairs close to the GCMT solution was conducted. A variation in the strike to align with the plate boundary (150°–225°) was allowed, while dip varied from 48°–78°. For those pairs with variance reduction >46% the one that best matched the amplitude and the time of the observed tsunami is: strike 220°, dip 58°. The variance reduction for this solution was 48%.

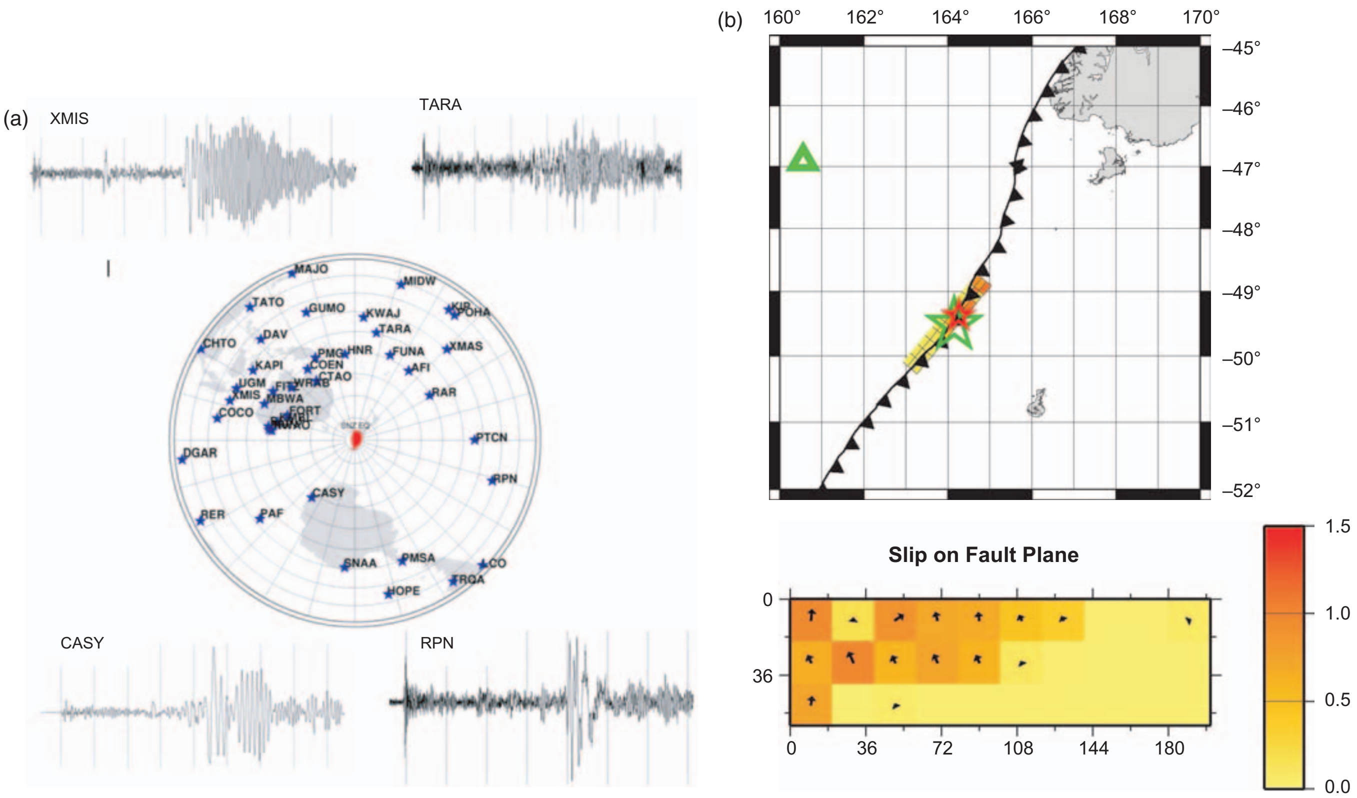

Fig. 4. *(a) Seismic station distribution (stars) used in the inversion. The epicentre of the 30 September 2007 earthquake and its focal mechanism are located in the centre. (b) Cumulative slip distribution on the fault plane during the event. Colour shows the amount of slip and arrows represent the motion of the hanging wall relative to the footwall. The map shows the epicentre (green star) and the centroid location (red star) superimposed on the slip distribution. The green triangle shows the tsunameter location.*

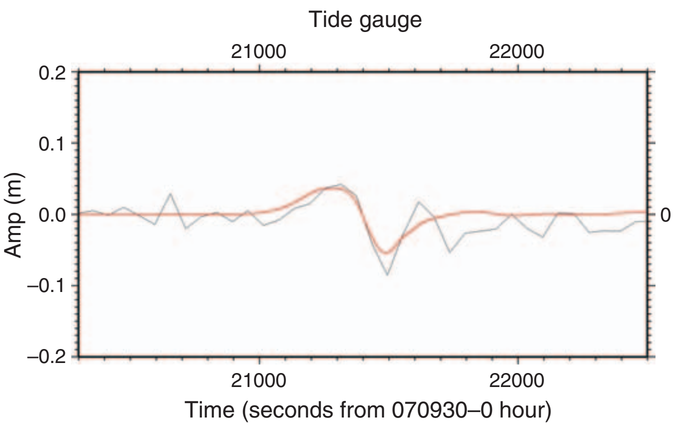

Fig. 5. *Comparison between the calculated (red) and observed (black) tsunami waveforms of the 30 September 2007 earthquake, by a tsunameter in the Tasman Sea.*

An initial peak-to peak time-shift of ~100 s between the predicted and observed time of the tsunami arrival was believed to be due to the hypocentral errors and/or inaccuracies of the bathymetry data. When a slight adjustment was made by moving the hypocenter 0.14° south-east from the initial location, the model-data discrepancy disappeared. The final model can be seen in Figure 5. This result suggests that the efficiency of tsunami generation by an earthquake can depend significantly on the details of rupture, and that detailed analysis is sometimes needed to determine which of the two candidate fault planes of a moment tensor solution actually ruptured in order to accurately model the resulting tsunami.

Discussion

The JATWC has established the infrastructure and the tools to provide fast and accurate warnings for any tsunami threat to the Australian public. Greatly increased seismic coverage has improved seismic monitoring of the region in terms of the speed of the earthquake detection and the accuracy with which it can be located. An increase in processing power has enabled rupture analysis to take place in near real time which provides information that was previously unavailable for many hours after the earthquake. Information such as this aids in decision making and could provide vital clues as to the potential tsunamigenicity of the earthquake. The rupture and tsunami models are not yet real-time operations and presently exist as postevent analysis tools, but they are becoming more routine processes and for each earthquake valuable lessons on the tectonic setting, tsunami generation and propagation are learned.

As improvements in the seismic coverage have aided in earthquake detection, additional sea-level data provided by the deployment of tsunameters has aided in the detection of tsunami. As shown in the case study described here, the ability to confirm the existence of tsunami when still a considerable distance from the shore, gives the warning centre time to respond by revising warning messages for the Australian public. This improves the accuracy with which regional warnings can be applied and will affect the actions taken by emergency services in the affected areas.

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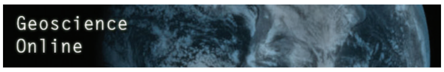
Earth science resources for kids

Predictably perhaps, a Google search on this general topic returned more than seven million hits, the majority apparently US-based. I have attempted to insert some order into the summary below. If you visit the online version of this article at http://www.publish.csiro.au/journals/pv each link should work, thus saving you the tedium of manually copying each address from the hardcopy version of this article.



Within Australia the two largest online educational resources for earth sciences (and sciences in general) are Geoscience Australia and CSIRO at http://www.ga.gov.au/education/index.jsp and http://www.csiro.gov.au/resources/ExploreAndEducate.html, respectively. The Petroleum Exploration Society of Australia (PESA) also hosts a 'Geoscience Online' collection of useful educational links for all ages at http://www.pesa.com.au/rightbar/geoscienceonline.html.

The resource at http://www.kidsgeo.com/ is a reasonable starting point for the general study of 'The earth and her people', including comprehensive sections on both geology and Geography. Likewise, the following links are all good compilations of miscellaneous links presented in an orderly manner to help children understand earth processes and evolution:

- http://www.kidinfo.com/Science/Geology.html
- http://www.kidsolr.com/science/page13.html
- The introductory sets of FAQs at http://www.faqkids.com/idx/4/0/The_Earth.html?lore_sid=c5e5e45737af5c3901f65878169bac41
- Walter McKenzie's surfaquarium at http://surfaquarium.com/IT/CONTENT/earth.htm
- The more adult-focused Earth and Sky at http://www.earthsky.org/
- The student's favourites from Palomar College at http://www.palomar.edu/earthscience/ES_100/Favorite%20Earth%20Science%20Web%20Sites.htm.

For one of the most comprehensive collections of links, visit the kids section of geology.com at http://geology.com/news/category/geology-for-kids.shtml.

As our global attention increasingly focuses upon the environment and ecology, the EcoKids site at http://www.ecokids.ca/pub/index.cfm is recommended, including many games and homework activities. Likewise, North Carolina State University maintains a set of links at http://www.ncsu.edu/imse/1/earth.htm that are focused upon projects suitable for school assignments.

If you want a simple place to start, kids enjoy interactive games, so they will find more stimulating introductions to earth sciences at http://kids.earth.nasa.gov/games/ (try the Pangea Map Game).

NASA have a series of outstanding online resources, including the collection 'For Kids Only' at http://kids.earth.nasa.gov/site.htm.

More structured earth science resources according to school class levels can be found at http://classroom.jc-schools.net/sci-units/earth.htm (Earth and its place in the universe), NASA's sitemap for Educators at http://www.nasa.gov/lb/audience/foreducators/topnav/subjects/earthscience/index.html, the Eclectic Homeschool Online at http://www.eclectichomeschool.org/articles/article.asp?articleid=534&resourceid=108, and the Official Kids Portal for the U.S. Government at http://www.kids.gov/.

Although a login account is required, http://www.iknowthat.com/com/L3?Area=Science%20Lab offers several interactive project activities for different class levels. The Kids resource on AOL also includes a Homework Help for Juniors at http://kids.aol.com/homework-help/junior/earth-science/land. Many explanations are animated, providing appeal. Of interest, the Earth and Space Science page at http://www.learner.org/channel/courses/essential/earthspace/session4/ideas.html allows students to offer structured text answers to a series of questions, and offers hints upon request.

Overall, the web is rich with earth sciences resources for kids. At the end of the day though, what gets their interest like movies of natural hazards such as earthquakes and volcanoes! Begin with the incredible USGS library at http://library.usgs.gov/, justifiably claimed to be 'The largest earth science library in the world' The photographic library will keep you entertained forever. Keep searching at http://www.usgs.gov/ and you will encounter a virtual cornucopia of earth science-related resources. For a quicker fix go to YouTube at http://www.youtube.com/ and dial up a short movie on anything you can think of

Happy surfing

Andrew Long
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Igneous Petrology, 3rd Edition

by Alexander R. McBirney

Publisher: Jones and Bartlett Publishers, 2007, 550 pp.
RRP: $179.50, ISBN-10: 0-7637-3448-9 and ISBN-13:978-0-7637-3448-0

I jumped at the opportunity to review the latest edition of 'Igneous Petrology' by Alexander McBirney. Earlier versions of 'Igneous Petrology' provided infinite assistance during my undergraduate and postgraduate studies and I was keen to see if the rapidly evolving field of igneous petrology was suitably represented in the new edition. In the Preface McBirney states that theories that had seemed so secure 20 years ago are now up for debate, such as do Hawaii's lavas really come from a plume rising from the deep mantle? Although some recent research topics like this were not covered in much detail, this book remains an excellent and up-to-date introduction to the broad and often complex field of igneous petrology for students with an elementary background in petrography and petrology, such as 3rd year undergraduates.

The first five chapters cover elementary concepts in igneous petrology, such as basic thermodynamic relations and the physical properties of magmas, before discussing specific types of magmas and tectonic environments, such as basic intrusions, intra-plate volcanism, magmatism at convergent plate margins. The book concludes with six appendices which contain useful data tables, including atomic and molecular weights and radii and a comprehensive description of mathematic functions of radiogenic isotopes. Particularly useful are the selected references highlighted at the end of each chapter, which each have a by-line justifying their relevance or importance.

Chapter 1 covers the early evolution of the Earth, containing descriptions of the formation of the Earth's core, mantle and crust and providing a useful discourse on the isotopic evolution of the mantle and crust. Furthermore, comprehensible descriptions of the mantle and the mechanism of magma generation are provided. A very useful overview of magmas and igneous rocks is given in Chapter 2 and includes igneous rock nomenclature, the physical properties of magmas (e.g., temperature, viscosity), effects of cooling and crystallisation, the flow of magma in the mantle and crust and convection. Crystal–liquid relations and key thermodynamic concepts are covered in Chapter 3. Chapters 2 and 3 are particularly valuable to readers less familiar with igneous petrology concepts or for specialists that need to review some key concepts. Chapter 4 broadly covers common igneous minerals and the crystallisation thereof and, whilst useful, it should be used in conjunction with other key texts (e.g. 'An introduction to rock forming minerals', Deer, Howie and Zussman). In my view, Chapter 5 is a key section in the book as it describes in clear language and descriptive mathematics the often convoluted area of magmatic differentiation, partial melting and trace element partitioning.

Chapter 6 moves on to give specific examples of differentiation in mafic intrusions, including a comprehensive section outlining the characteristics of the Bushveld Complex (South Africa), the Muskox Intrusion (Canada), the Stillwater Complex (United States) and the Skaergaard Intrusion (Greenland). The mantle origin of basalts and the different magma series (e.g. tholeiitic, alkaline) are covered in detail in Chapter 7, including broad descriptions of the Galapagos Tholeiitic Series and the Tahitian Alkaline Series. Following is a chapter on oceanic magmatism, hotspot volcanism and flood basalts which includes a very interesting narrative on the lunar flood basalts. Chapter 9 describes magmatism at convergent plate boundaries and has excellent basic descriptions of Cascade and Aleutian arc convergent volcanism. There is also a clear description of the role of the subducted crust and the generation and rise of subduction-related magmas. Of concern to me in this chapter is the use of the term of calcalkaline to describe magmatism at convergent plate boundaries. I once used calcalkaline to describe the products of convergent volcanism during a conference presentation and inadvertently found myself at the centre of a heated audience debate (see Arculus, R.J., 2002, Use and abuse of the terms calcalkaline and calcalkalic: J. Petrol., **44** (5), 929–935). Chapter 10 methodically covers the silica-rich granitic plutons and ignimbrites and includes chemical and tectonic classifications, crustal environment, tectonic setting, Archean Trondhjemites, phase relationships and silicic melt generation and crustal ascent. This chapter also contains a discussion on the 'granite problem', that is, are granitic and rhyolitic magmas generated by differentiation of mafic parental magmas or by crustal melting? Finally Chapter 11 deals with magmatism found in continental interiors, including continental rift magmatism, carbonatites, lamprophyres and kimberlites.

The 3rd Edition of 'Igneous Petrology' is certainly equal to or of higher quality than the earlier editions and provides an outstanding introduction to the fascinating but often complex world of igneous petrology. Whilst this book is targeted at undergraduates, and perhaps students starting out in postdoctoral research, I would highly recommend it to all geoscientists, be they igneous petrology specialists or exploration geophysicists, as it provides a wonderful overview of all areas of igneous petrology. I know this edition of 'Igneous Petrology' will have a prime position on my bookshelf for years to come.

Copies can be purchased direct from Elsevier Australia Customer Service: Tel: 1800 263 951, Fax: (02) 9517 2249 or Email: service@elsevier.com

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Mineral processing technology: an introduction to the practical aspects of ore treatment and mineral recovery, 7th Edition

by B.A. Wills, T.J. Napier-Munn and the staff of the Julius Kruttschmitt Mineral Research Centre

Publisher: Butterworth-Heinemann, an imprint of Elsevier Ltd, 2006, 444 pp.
Price: $110.00, ISBN-13: 978-0-750-64450-1

The 2006 edition of Mineral Processing Technology is the 7th revision of a widely used text on converting ores into mineral concentrates that are used to produce metals and other raw ingredients used in a modern economy. This edition updates previous editions to incorporate recent developments in the field of metallurgy. However, the authors did not willy-nilly change text from the previous editions, preferring the philosophy that 'if it ain't broke, don't fix it'. As a consequence, the referencing in the book is quite variable, with some very up to date and others citing papers from the 1980s as examples of current practice.

The book contains 16 chapters, mostly written or revised by the staff of the Julius Kruttschmitt Mineral Research Centre at the University of Queensland. The first four chapters are more general in scope, covering the geology and geochemistry of minerals and ores, the economics and efficiencies of mineral processing, the handling of ores from the stope to the processing plant, metallurgical accounting and particle size analysis. The latter 12 chapters are more detailed and treat processes that are used to convert the ore to concentrates and tailings. Most of these latter chapters begin with an introduction that covers the physical and chemical principles that govern the metallurgical processes, followed by descriptions of these processes and the machines used, quality control methods, and practical examples from operating mines.

I found the first four chapters to be very useful as background to the later chapters and as background to the minerals industries in general. Although the geological and geochemical background is very basic, it did provide context as to how geological characteristics of ores (e.g. grain size, mineral intergrowth) have important ramifications in the economic extraction of metal-bearing concentrates: if concentrates cannot be extracted from ore-grade material economically, the material is not ore. The book also has an appendix which summarises, for each economically interesting element, ore minerals and their properties. The discussion of the economics of the minerals industry is also very insightful and provides context beyond the minerals processing. Both the chapters on metallurgical accounting and particle size analysis provide an up-to-date synthesis of these important quality assurance practices.

Metallurgical engineering is quite a diverse subject as illustrated by the last twelve chapters of this book. Broadly the processes that are described in these chapters fall into three categories, comminution of run-of-the-mine ores to grains sizes amenable to later processing, separation of economic valuable minerals from waste, and separation and disposal of waste (fluids and tails). The separation processes use a large variety of physical and chemical properties to effect mineral separation, including density, surface chemistry, magnetic susceptibility, electrical conductivity and many others. The longest chapter of the book, on froth flotation, describes how the hydrophobic/hydrophyllic properties of minerals are used to effect separation by the addition of various chemicals to aerated water-ground ore mixtures. The other chapters comprehensively cover crushing and milling of the ores, physical separations and dewatering.

The book in general is well written and reasonably well edited. The only complaints I had were the use of vague units in some early tables, and, in some cases, the lack of definition of technical terms. The latter problem is particularly important to geoscientists who are not familiar with metallurgical jargon.

This book is designed both as undergraduate-level metallurgical textbook and as a basic reference for metallurgical engineers working in the mineral processing industry. Although it provides a very comprehensive account of metallurgical practices, it is probably too detailed for most geoscientists. However, it could be an important reference for those involved in assessing project feasibility and it provides important context on the limitations metallurgy may present in determining if a mineral deposit becomes an ore deposit.

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May			**2008**
28–30 May	AEM 2008, 5th International Conference on Airborne Electromagnetics http://geo.tkk.fi/AEM2008	Helsinki	Finland
June			**2008**
9–12 Jun	70th EAGE Annual Conference & Exhibition www.eage.org/events/	Rome	Italy
11–12 Jun	Imagining Real Life on a Greenhouse Earth Email: info@manningclark.org.au	Canberra	Australia
July			**2008**
20–25 Jul	19th AGC, The Australian Earth Sciences Convention 2008 Joint Geological Society of Australia and Australian Institute of Geoscientists Meeting www.gsa.org.au/events/calendar.html	Perth	Australia
August			**2008**
5–14 Aug	33rd International Geological Congress www.33igc.org	Oslo	Norway
September			**2008**
14–17 Sep	EABS III Energy Security for the 21st Century www.pesa.com.au/pdf/eabs_call_for_papers.pdf	Sydney	Australia
November			**2008**
9–14 Nov	SEG International Exposition and 78th Annual Meeting http://seg.org/meetings/	Las Vegas	USA
24–27 Nov	Pacrim Congress 2008 www.ausimm.com.au/main/events/docs/pacrim2008.pdf	Gold Coast	Australia
December			**2008**
15–19 Dec	American Geophysical Union, Fall Meeting www.agu.org/meetings	San Francisco	USA
February			**2009**
22–26 Feb	**ASEG's 20th International Conference and Exhibition** **www.aseg.org.au**	Adelaide	Australia
April			**2009**
24–27 Apr	CPS/SEG Beijing 2009 International Geophysical Conference and Exposition http://seg.org/meetings	Beijing	China
May			**2009**
24–28 May	American Geophysical Union, Joint Assembly www.agu.org/meetings	Toronto	Canada
31 May–3 Jun	2009 APPEA Conference & Exhibition www.appea2009.com.au	Darwin	Australia

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