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PREVIEW

AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS

NEWS AND COMMENTARY

Early Achievement Award

Memories of Perth 2007

Britney Spears and geophysics

Kevin07 takes control

2007 in review

ASEG Research Foundation

FEATURE ARTICLES

P223 EM software

4D seismic data to manage field production

Capel and Faust Basins

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- **Loki & LokiAir** for 3D mesh with topography
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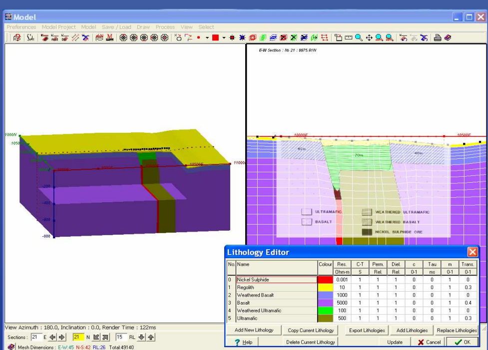

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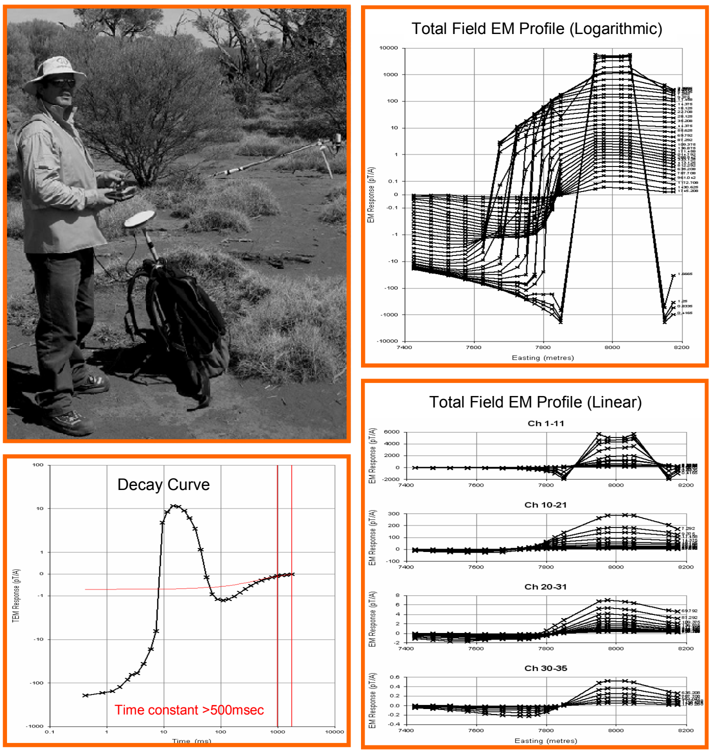

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PREVIEW

ADVERTISERS INDEX

Archimedes Financial Planning	3
Baigent Biosciences	3
EMIT	IBC, OBC
Flagstaff Geoconsultants	3
Fugro Instruments	2
Geoimage (Max Bye)	7
Geoimage (Sylvia Michael)	7
Geokinetics	18
Geophysical Software Solutions	3
IMT Geophysics	7
Outer Rim	7
Scintrex	23
Systems Exploration	34
Vortex Geophysics	IFC
Zonge	45

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CONTENTS

Editor's Desk 2

ASEG News

President's Piece 3

Executive Brief 4

People 7

News

Conferences and Events 8

- Memories of Perth

Canberra Observed 13

Research Notes 14

- ASEG Research Foundation

Industry Review 17

Geophysics in the Surveys 21

Feature Papers

P223 software for interpreting EM surveys 25

Capel and Faust Basin surveys 31

Kimberlite exploration using integrated airborne geophysics 35

4D seismic modelling of oil 39

Web Waves 44

Book Reviews 46

- The Economics of Climate Change
- The Last Oil Shock

Calendar of Events 48

FRONT COVER

The cover shows the giant Japan-sponsored IODP drilling vessel, The CHIKYU. Credit: JAMSTEC / IODP, *see p.14*

Preview is available online at:
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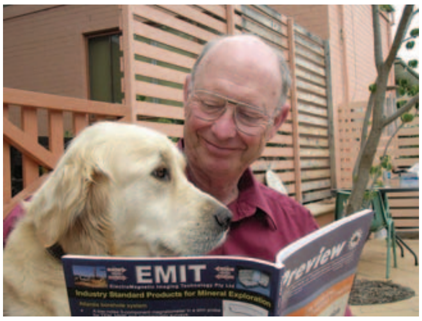

David Denham with a new proof-reader.

We need new material

Welcome to 2008 and a new look *Preview*. As you can see from Richard Hecker's article on page 4, we made great strides with *Preview* during 2007 and are now getting much greater exposure as a result of going online and including past issues in the database (see www.publish.csiro.au/journals/pv). Richard has done a great job with this work and we are beginning to reap the benefits.

At the Perth meeting we distributed a questionnaire to survey what members liked and did not like in *Preview*, *Exploration Geophysics* and the *Membership Directory*. The FedEx is considering the results of this survey but I can say that the members who completed the questionnaire valued all three publications.

We need to keep them at a similar or higher standard in the future. And this is where you all can help. Editors can only interact with a limited number of explorers and researchers. We rely heavily on working geophysicists to identify items of interest or hot topics in the industry or the laboratory. You don't necessarily have to write articles yourself – although that would be good – but if you can point the editors in the right directions for topics of interest, and maybe who could write about them, that would be even better.

In this issue

There's lots of interesting material in this issue of *Preview*. The very successful Conference in Perth was a great source of material and Brian Evans and Howard Golden are to be congratulated on their efforts. So we have included the Best Conference Paper by Megan Smith as well as presentations on diamond discoveries and frontier oil results.

There is also an interesting article by Art Raiche on his ~35 years work on practical EM research for real exploration. It's well worth a read and contains some interesting anecdotes on how the environment for doing research has changed during that time.

We then have lots of pictures taken at the Conference. I would like to thank Jerry Lee for the Conference Dinner shots and Sam Bullock for most of the other photos. Pictures are usually more interesting than words and we were fortunate to have these talented people in Perth to activate the shutters.

One of the major beneficiaries at Perth was the ASEG Research Foundation. This funds student research projects and a substantial amount of money was donated during the conference. Read Phil Harman's article on page 15 to find all about the ASEG's Research Foundation.

As well as the Conference, we have an interesting analysis of 2007 from a resource sector perspective and of course a few notes on the changes in Canberra with the ascendency of Kevin07. Finally, there are two fascinating book reviews covering the *Economics of Climate Change – the Stern Review* and *The Last Oil Shock*.

So have a good read and if you have half an hour to spare then pen a few thoughts down that we can use in future issues.

Delivering value to members online

The year 2007 ended with a very successful Conference in Perth. However, a little heralded event also occurred in 2007. This was the review of the performance and functionality of ASEG's website. The review was undertaken by Wayne Stasinowsky, as his first official duty as the Federal Webmaster.

It has been recognised for some time that the website is not delivering full value to members. A well-designed website can offer a lot more to both members and other stakeholders. In my first President's Piece in June 2007, I wrote about the role of a modern professional society. Although I identified a list of 30 different functions or roles that learned societies can undertake to various degrees, perhaps the most relevant for the ASEG are:

- Publishing; both scholarly and popular magazines and journals;
- Networking through conferences and other special meetings;
- Nurturing students and promoting career development through continuous education;
- Promoting the interest of members in political and public discourse; and
- Outreach including educating the public about geophysics and the role it plays in the resource industries.

Successfully undertaking the above functions can be facilitated through a well-designed website. Indeed to remain relevant, I believe that it's imperative that the ASEG uses the web as the principal medium for delivering value. I think I am safe in saying that the vast majority of younger members prefer to access information through the web. But this requires a website rich in content that is targeted to what members want. For example the ASEG is already publishing online whilst maintaining the hard copy publications of both *Preview* and *Exploration Geophysics*.

Of course underpinning the above functions are administrative systems that enable the ASEG to efficiently deliver the information required by its members. These administrative systems include management of membership details including allowing members to access their details online 24/7.

Wayne Stasinowsky in his review identified significant deficiencies in the website and recommended the following areas be addressed as a matter of priority:

- Membership records and membership renewals;
- Archiving and deleting redundant files and images;
- Some state branch areas require updating; and
- Member login functions need to be addressed.

I am pleased to report that under Wayne's management the task of addressing these areas has already been started and is now well underway. Over the coming months, you will receive emails regarding website progress and inviting you to contribute ideas for content.

Clearly there is still much to be done to ensure that the ASEG website will increasingly deliver value to its members and the ASEG Federal Executive is committed to moving down this path. No doubt the website will improve and become a much more valuable resource to members.

Joe Cucuzza
joe.cucuzza@amira.com.au

ASEG News

Demand grows for *Preview* online

In early 2007 the ASEG's publications *Preview* and *Exploration Geophysics* migrated to **CSIRO** PUBLISHING. One of our first tasks was to provide a greater online presence for the publications. The first step was a dedicated website for each of the publications, at www.publish.csiro.au/journals/pv and .../journals/eg, respectively. From these websites you can read the publications online, sign up for email early alerts or RSS feeds, and explore the archives.

Preview is published online as single PDF of the issue. When the first online issue was published, *Preview* 126, there were 300 downloads of the issue; by time the conference issue arrived in November this swelled to over ten times that – 3400 downloads in a month. Authors and advertisers in *Preview* now enjoy increased prominence.

The archive of older *Preview* issues attracts interest too. Back issues to *Preview* 82, from 1999, were placed online in October. *Preview* readers have clearly made use of this during the last two months of 2007. During 2008 the archive will expand back twenty years to *Preview* 15, published in mid-1988.

We look forward to 2008 and watching *Preview* and *Exploration Geophysics* expand further and the activities of the ASEG become more visible to an ever wider and increasingly international audience. Geophysicists, explore these websites!

Richard Hecker
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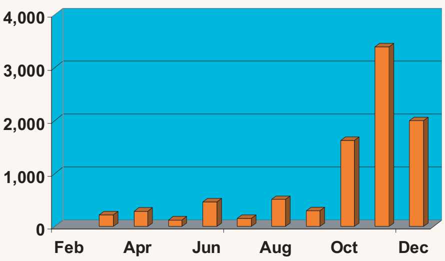
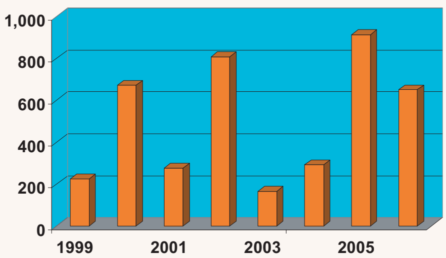


Downloads of Preview 126–131, published in 2007, during 2007.



Downloads of Preview archive during 2007.

Early Achievement Award

The Federal Executive has approved the introduction of a new award, called the Early Achievement Award. It is for members who are less than 36 years of age who have made significant contributions to the profession of exploration geophysics through publications in *Exploration Geophysics* or similar reputable journals.

Roger Henderson, Chairman of the Honours and Awards Committee, says the award is designed to recognise early achievement without requiring a longer period of time that characterises other awards. It was first suggested by Roger and strongly supported by the NSW Branch. The detail of the award, which can be seen on the ASEG website at http://www.aseg.org.au/about/awards/awards_criteria.htm, was worked out by the Honours and Awards Committee and the Federal Executive.

Selection criteria

The successful recipient must be member in good standing of the ASEG, must be a graduate for at least 3 years and must present a paper at the ASEG Conference where the award is presented. A maximum of one award will be offered at each ASEG Conference.

Method of nomination

Nominations are to be from a member and supported by a seconder who is also a member. Nominations are to be received no later than 2 months before each conference – so nominations will close on 19 December 2008. Documentation, including as much information as is relevant, is to be supplied in digital form to the Chairman of the Honours and Awards Committee (rogah@tpg.com.au). Nominations will be assessed and, if deemed worthy by the Honours and Awards Committee, recommended for acceptance by the Federal Executive.

Nature of Award

1. Cash award: $2000.
2. A complimentary registration at the Conference.
3. A commemorative wall plaque.
4. The Citation published in Preview.

So start planning now for Adelaide 2009!

National Summit on the Plight of University Geoscience Education and the Supply of Geoscience Graduates

The 'National Summit on the Plight of University Geoscience Education and the Supply of Geoscience Graduates', hosted by the Australian Geoscience Council Inc. at Geoscience Australia on 27 September 2007, represented one of the first concerted efforts by the entire geoscience community in nearly a decade to identify and put into practice strategies that will create an effective national geoscience education program. The summit was well attended by representatives from industry, academia, government and the professional geoscience associations. In sharp contrast to previous summits of this nature, there was consensus on the broad issues and proposed mitigation strategies, which hopefully will lead to a more sustainable and viable geoscience education system in years to come.

The key issues were presented from the perspective of each of the sectors of the geoscience community and are summarised below.

The university and public education perspective

The issues related to the tertiary education sector were presented by Ray Cas and Rob Norris from Monash University. The key concern emanating from the tertiary education sector is that in Australia we are currently experiencing an education plight despite a boom in the natural resources sector of the economy. At present the natural resources sector is contributing between 40 and 60% of Australia's national export earnings. Some of the causes of this plight include:

- A decline in the number of students continuing on to complete honours and postgraduate studies.
- The inability to attract larger student numbers.
- A decline in the number of geology and geophysics staff within departments over the past 15 years.
- A change in the university budget models to a linear relationship between student numbers and funding allocations. Under this model most Geoscience Departments survive financially on the benevolence of their host universities. Compounding this is the fact that geoscience courses are amongst the most expensive to run.
- Little or no geoscience subjects taught in secondary schools. This leads to most geoscience graduates only discovering and switching to geoscience once they have begun their tertiary education.
- Industry demand and high starting salaries leading to students leaving the university system at third-year level; thus, further diminishing the pool of students continuing onto postgraduate studies and further research.

The employers' perspective

The employers' perspective was presented by Kevin Tuckwell, the Executive Director of the Minerals Tertiary Education Council (MTEC). Since its establishment in 1999, MTEC has been an active player in promoting and developing capacity building programs aimed at tailoring geoscience education to meet the expectations of industry, such as: Mining Education Australia (MEA); Minerals Geoscience MSc and Hons Programs; and Metallurgy Education Partnership (MEP) scholarships. One of the key observations made by MTEC is that the level of Year 12 Science participation is declining, especially in the geosciences, and tertiary enrolments are represented increasingly by mature age students rather than matriculating school leavers. Also highlighted was the fact that widespread fragmentation of the tertiary geoscience education system will continue to devalue the system.

The petroleum industry perspective

The key concerns expressed by Don Sanders, Director or the Australian Petroleum Production & Exploration Association (APPEA), and Phil Ryles, Chief Geologist, Woodside Energy Limited, were related to the need for the industry to attract highly capable geoscience graduates to meet the demand for skilled labour. Highlighted by both Don and Phil was the need to start promoting the industry and geosciences in general at the primary school level. They presented an example from the successful pilot program being driven by a consortium including APPEA, Woodside Energy Limited, Curtin University, The University of Western Australia, the CSIRO, the Geological Survey of Western Australia, and others.

The perspective of government institutions

Tony Robinson, General Manager Corporate, Geoscience Australia presented the government perspective. He highlighted the pressures of a growing government mandate in geosciences and the difficulties being posed both now and into the near future by the 'baby boomer' wave of retirements. The observations from the government institutions are that there is an ever-changing need for specialists within the geosciences. This has the flow-on effect of requiring specialists with a greater degree of flexibility and adaptability, a deeper and wider grounding in science, a higher level of numeracy and who have far more spatial capability. To meet this requirement, the government institutions must ask the question: are universities producing what we need? The answer is evidently that some are and some aren't. The need for 'breadth and depth' in the scientific knowledge of graduates highlights the need, from the government institutional perspective, for a consolidation of the small, fragmented earth science departments and schools into larger ones following a similar model to that of ANU or Melbourne universities.

Key outcomes and strategies

Following the general discussions generated by the above presentations the following key strategies were agreed upon:

- There is a need for a national coordinated approach to geoscience education in Australia, involving both industry and academia.
- A high level strategy document must be written linking geoscience education to environmental issues on the political agenda (e.g. geosequestration and groundwater resources).
- There is a need to identify a set of action items and who will action them.
- There is a need for universities to move to a more targeted research and teaching agenda to maximise their funding opportunities.

These strategies could be encapsulated within a National Tertiary Geoscience Education System based on the following principles:

- Engagement of primary and secondary school students by industry and professional societies.
- Raising the profile of geoscience education.
- Attracting higher quality, and more, students by prescribing higher Tertiary Entrance Rank scores for undergraduate geoscience courses.
- Providing a united voice for all tertiary geoscience departments.
- Training of more school teachers in geoscience.

Matthew Purss
President ACT Branch, ASEG

ASEG News

Invitation for candidates for the Federal Executive

In accordance with Article 14.1.12 of the ASEG Constitution, any Member may nominate any other eligible Member for any of the following elected offices of the Federal Executive:

- President
- President-elect
- Secretary
- Treasurer

Nominations can be made by forwarding the name of the nominated candidate to the Secretary:

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for Association Management
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Email: secretary@aseg.org.au

All candidates must be willing to give written consent when requested and support from nine additional Members will be sought for all nominations.

Nominations must be received via post, fax, or email no later than Friday 22 February 2008. Positions for which there are multiple nominations will then be determined by postal ballot of Members and results declared at the Annual General Meeting.

ASEG Annual General Meeting

The 2008 Annual General Meeting of the Australian Society of Exploration Geophysicists will take place at 5:30 p.m. on Thursday 1 May 2008, at Chifley on the Terrace, St Georges Terrace, Perth, WA.

Be there to make a difference!

For more information, contact
Troy Herbert
(email: secretary@aseg.org.au
or tel: +61 8 9427 0838).

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Secretary: Vacant

New members

The ASEG welcomes the following new members to the Society. Their membership was approved at the Federal Executive meetings held on 26 September and 30 October 2007. New memberships arising from the Perth Conference will be listed in *Preview* 133.

Name	Affiliation	State
Simon David Atkinson	Axiom Geoscience	Qld
Drew Allan Breen	Uranium 1	SA
Andrew Clark	Macquarie University	NSW
Nathan Paul Gardiner	Gippsland Offshore Petroleum	Vic
Felix Genske	Macquarie University	NSW
Kelly Keates	Zonge Engineering	SA
Timothy Lloyd	Curtin University	WA
James Meade	Macquarie University	NSW
Averrouz Mostavan	Petroleum Geo-Services	WA
Elyse Schinella	Macquarie University	NSW
Christopher Andrew Semeniuk	Curtin University	WA
Francesco Senatore	Coffey Geotechnics	WA
Mark Shore	Magma Geosciences Inc.	Canada
Peter John Tralaggan	Macquarie University	NSW
Liejun Wang	Geoscience Australia	ACT

News

Successful Perth Conference demonstrates a dynamic resource sector

ASEG Conferences are the lifeblood of the society. They provide excellent opportunities to network with business contacts and discuss new developments in the ever complex search for new resources. The Perth Conference provided an excellent opportunity to do these things and the Conference Organising Committee led by Howard Golden and Brian Evans is to be congratulated on the work they did to achieve such a successful outcome.

The Conference statistics speak for themselves. A total of 184 papers were presented of which 73 were in the Minerals streams, 77 in Petroleum and 34 in Near Surface. In addition there were 36 posters comprising 13 Minerals, 19 Petroleum and 4 Near Surface. So there was a good balance between the minerals and petroleum sectors.

Attendance in Perth was estimated to be 779. This is much higher than the figure of 594 for the equivalent Sydney conference in August 2004 – which was also jointly sponsored by PESA, but falls short of the estimated 1200 registrants who attended the 2006 Australian Earth Science Conference which was held with the Geological Society of Australia in Melbourne. Delegates came from 31 different countries. This compares with the 33 different countries represented at the 2006 Melbourne meeting. After Australia, Canada with 23 registrants, UK with 17 and the USA with 13 provided the most registrants.

The Exhibition was a huge success with 82 exhibitors covering a wide range of resource interests.

Support from sponsors was critical and the Conference Organising Committee is to be congratulated on obtaining support from such a wide range of institutions. Of particular interest was the Platinum Sponsorship provided by Curtin University. This is the first time that an academic institution has taken on this role at an ASEG Conference. It was therefore great to have Jeanette Hacket open the Exhibition at the Icebreaker.

Jeanette Hacket, Vice-Chancellor of the Curtin University of Technology opening the Exhibition in Perth.

I have included a few photos from the Conference and its Dinner. See how many people you can recognise. Many of the images were provided by Sam Bullock from Fugro. As you can see he did a great job with his camera.

David Denham

Melbourne to host IUGG meeting in 2011

Not to be outdone by Brisbane hosting the 34th International Geological Congress in 2012, Melbourne will host the 25th International Union of Geodesy and Geophysics from 19 June to 1 July 2011.

Australia did well at the 24th IUGG held in Perugia, Italy early this year. Not only did we earn the right to host the 25th IUGG, but Tom Beer, a senior scientist with CSIRO Marine and Atmospheric Research and an expert in environmental risk, has been elected President of the IUGG until the Melbourne meeting.

For those not familiar with the IUGG, it is essentially the Big Earth organisation and comprises eight Associations. These are in the fields of meteorology, oceanography, volcanology, seismology, hydrology, geomagnetic science, geodesy and cryospheric science. As Tom Beer said after his election, 'The union fosters collaborative research and information exchange between Earth scientists in 68 countries. It also encourages the application of this research to societal needs, such as mineral resources, mitigation of natural hazards and environmental preservation.'

The Melbourne meeting is expected to attract more than 5000 scientists from around the world and should provide a real boost to Australian geosciences.

ASEG awards in Perth

Grahame Sands Award

For innovation in applied geophysics through a significant practical development of benefit to Australian exploration geophysics in the field of instrumentation, data acquisition, interpretation or theory

Iain Mason and Geomole Pty Ltd for ground probing radar

Ground probing radar is a well known geophysical technique for near surface investigations. The ease of conducting surveys and interpreting results makes it a particularly attractive technique, provided there is adequate penetration through the near surface layers. Beneath the weathering, in a borehole environment, issues with conductive surface layers do not arise. Iain Mason has been at the forefront of the development of borehole radars for over 15 years.

In 1991, he was commissioned by WMC to develop borehole radars to attack Kambalda's 'deep-ore with profit' problem. He predicted and then verified that the Lunnon Basalt, which hosts the nickel sulfide ore was translucent to radar waves. His first slimline VHF borehole radars were successfully operated at Hunt Mine in July 1993.

Since then, Professor Mason and his research team have improved the design of the radars, the methods of deployment and the methods for interpretation. Currently, a bistatic radar system, comprising separate transmit and receive antennas, and a monostatic system that transmits and receives from the same antenna are available.

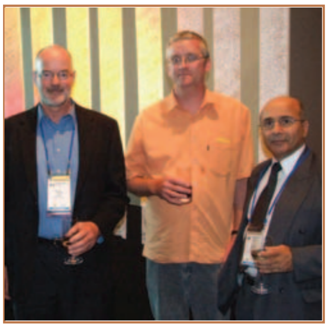
All acquisition and data storage is undertaken using batteries and electronics housed inside the antennas. Complete waveforms are digitised at 250 MHz

Continued on p. 10



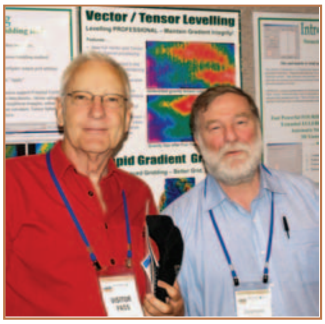
Memories of Perth 2007











Continued from p. 8

sample rates and stacked to provide 12 bit dynamic range. A patented VHF duplexer allows the monostatic operation. Tool diameter is 31.7 mm and the total length of the monostatic radar is 1.6 m.

These tools fit within the AQ drill holes that are most commonly drilled in underground metalliferous mining. Operation for the bistatic radar requires a logging winch to withdraw the radar from the hole.

For the monostatic radar, it is possible to pump the probe down drill rods and to obtain a radar survey while the rods are being pulled from the hole. Surveys can thus be obtained in non-vertical holes and in holes where the walls are in poor condition and prone to collapse. Surveys are now being 'shot' in mines in Australia, Canada and South Africa by mine staff and drillers without the mobilisation of specialist geophysical crews.

The slimline radars do not provide directional radar signals. To resolve the interpretational issues that arise, Professor Mason has supervised the development of an interactive computer program that allows simultaneous interpretation of radargrams from multiple holes. When combined with basic geological understanding, directional ambiguity can thus be reduced. For tactical mine planning, the survey targets are orebody boundaries and any disrupting elements such as faults and dykes. There have been numerous successful surveys where anomalous geologic conditions have been mapped ahead of mining.

The commercialisation of these borehole radar systems is undertaken through Geomole Pty Ltd, formed in 2000 by Professor Mason and the CRC for Mining Technology and Equipment. Geomole is the holder of two international borehole radar patents with three others pending.

There are no other borehole radar systems that offer such comprehensive specifications. Geomole and Iain Mason, the inventor of this leading borehole radar system, are most worthy recipients of the Grahame Sands Award.

ASEG Service Certificate

For distinguished service by a member to the ASEG, through involvement in and contribution to State Branch Committees, Federal Committees, Publications and Conferences

Michael Hatch

Mike's profile amongst the ASEG community has been established since emigrating from the United States in the early 1990s and joining the South Australian Branch of the ASEG in 1994. Upon joining the ASEG Mike was coerced into becoming a member of the South Australian Branch Committee. As a committee member Mike has enthusiastically volunteered considerable time to drive the local branch in providing services to society members and also promote the field of geophysics to the greater community. On the state level, Mike has held various roles including: a member of the SA Branch Committee from 1994 to present, during which time he was President from 1998–2000 and also currently holds the role of Secretary.

As Co-Chair of 16th ASEG Conference 2003, Mike contributed to the smooth sailing conference which made a record breaking profit while providing an informative, valuable conference for registrants and exhibitors. Since the conference Mike has fed the experience gained from running the conference back into the society through his role as a Federal Conference Advisory Committee member.

In summary, Mike has enthusiastically and energetically embraced the ASEG in many of its aspects for 14 years and should also be commended for his contributions to geophysics in research, education and industry as well as the significant amount of voluntary time and effort Mike has put into the ASEG. Without people like Mike to get on and do the work the ASEG could not provide its members with a high quality society.

David Cockshell

Dave has been a long standing member of the ASEG, having joined in 1977. He has been active at both the state branch level and also at federal level. Although Dave is predominantly known for his work in the petroleum industry, his exposure to hard rock and groundwater geophysics has provided him with a diverse geophysical background that has enabled him to serve the needs of many sectors within the geophysical community.

Dave has been an active part of ASEG since joining and has been:

- A SA Branch Committee member from 2001 to present
- The SA Branch Treasurer from 2003 to present
- Treasurer for the 6th ASEG Conference in 1988
- Treasurer for the 16th ASEG Conference 2003 – which made record breaking profit
- And currently Treasurer for 19th ASEG Conference to be held in 2009 – which plans to make record profit

Dave has also coordinated the DISC Lecture in 2002 and on numerous occasions has organised many meetings and seminars for the local ASEG community.

Dave's tireless efforts, often behind the scenes, predominantly undertaking the thankless task of treasurer, has ensured that the society has been able to function in an efficient manner and provide the members with a quality service. Dave has diligently served the ASEG for a number of years and thoroughly deserves this award.

Iain Mason after receiving the Graham Sands Award from Co-Chair of the Conference organising Committee Howard Golden.

Michael Hatch receives his ASEG Service Certificate from Howard Golden.

A happy David Cockshell, after receiving his ASEG Service Certificate from Howard Golden.

The Gerald W. Hohmann[1] Career Achievement Award for 2007

Art Raiche

The 2007 Hohmann Award was made to Art Raiche in recognition of a lifetime of achievement in the field of numerical modelling of electrical and electromagnetic responses in exploration geophysics. This award recognises a lifetime of achievement in Art's chosen field, but in particular, it also pays tribute to his leadership and vision. The road has not always been smooth but through Art's persistence and persuasion he has influenced many of us and dragged us, sometimes reluctantly, into the 21st century. Far from working as a cloistered academic, Art has interacted with and taught a generation or two of geophysicists what can be done with his sophisticated software tools and made a significant contribution to our understanding of electrical and electromagnetic methods.

Art is, of course, well known in this field both within Australia and around the world. Since migrating to Australia in 1970, he has been active in CSIRO in various positions, but always working in electromagnetic modelling and interacting with practicing exploration geophysicists. Although he officially retired in 2006, he has continued working to complete his current AMIRA project. We believe it is timely, now that he has completed this project and seems determined to really retire from the field, to celebrate his achievements in this way.

During his time with CSIRO, Art led eight AMIRA projects (or one project with seven extensions), with more than 50 sponsors, over a period of 27 years. This has brought him into contact with a wide range of sponsor representatives; including practicing company geophysicists, exploration managers, software developers, government agencies and students. Although the projects were based in Australia, many of the sponsors were based around the world and Art's work linked them with the Australian geophysical community. In addition, Art has frequently published and presented at international conferences, universities, government agencies and companies in over 12 countries, making his work known to a global audience. In fact, he and Jerry Hohmann co-authored a paper in 1988 on the inversion of CSAMT data.

The AMIRA projects were all directed at aspects of electrical and electromagnetic modelling and inversion and they have progressed steadily from 1D through 2D and 3D, with increasing levels of complexity and sophistication. Along the way, this work has revealed many insights into the way the earth responds to these methods and contributed to both the development of improved instrumentation and to improvements in interpretation tools.

Art has co-authored two books, led or co-authored over 100 scientific papers, held honorary appointments at four universities, supervised numerous postgraduate students and mentored many junior scientists.

He has also maintained a wide range of varied interests, including his Dobermans. As Art moves into retirement he plans to remain active and to pursue other interests including studying classical Greek, ancient history, cooking and working towards a licentiate for flute performance. One thing is for certain, he won't sit still and his energy will simply be redirected.

Art Raiche receives the 2007 Gerald W. Hohmann Career Achievement Award from Bob Smith, one of his nominators.

[1]The GWH Career Achievement Award is awarded annually by the GWH Memorial Trust for teaching and research in applied electrical geophysics. The Trust is an active memorial to the work of Gerald W. (Jerry) Hohmann as a scientist and educator. Jerry was an international leader in the theory and application of electrical and electromagnetic methods for the exploration of the earth's crust.

Conference awards from Perth

Conference Awards at the Closing Ceremony were presented by the Howrd Golden, one of the Co-Chairs of the Conference Organising Committee. The awardees are listed below.

Best Paper Award

Megan Smith – Using 4D seismic data to understand production related changes in Enfield, North West Shelf, Australia

Megan Smith receives her Best Paper Award from Howard Golden.

Honourable mentions

Minerals: Hugh Tassell – Combining passive and active seismic data in understanding the terrane structure of the Eastern Goldfields

Petroleum: Nick Crabtree – Closure confidence: how big is that field? A case study

Near Surface/General Interest: Myra Keep – Seismicity in Northern Western Australia

Best Presentations

Minerals: Branko Corner – Radon emanometry in uranium exploration using activated charcoal: Namibian case studies

Petroleum: Megan Smith – Using 4D seismic data to understand production related changes in Enfield, North West Shelf, Australia

Near Surface/General Interest: Lisa Worrall – Regolith geophysics: retrospect and prospect

Branko Corner receives his Best Presentation Award from Howard Golden.

News

Best Poster

Kirsty Beckett – Inferring soil chemical and physical mobility using 256-channel NaI radiometric data

Kirsty Beckett receives her award for the Best Poster from Howard Golden.

Best Exhibitor

Ikon Science (Martin Bawden)

Martin Bawden receives the Best Exhibitor Award on behalf of Inco Science.

Laric Hawkins Award

For the most innovative use of geophysics in a paper presented at the Conference

Andrew Duncan – Total Field EM for highly conductive targets

Honourable mentions

Brett Harris – High resolution seismic reflection and radar for hydrology

Jason Sun – Imaging of fractures and faults inside granite

EM workshops in Europe

Threads of the present widespread activity in electromagnetic (EM) geophysics, both Australian and international, link a variety of meetings held recently. These meetings have covered a range of styles: large and small, formal and informal, specialist and general.

Thus EM was strong at the Exploration 2007 Conference held in Toronto, Canada, 9–12 September 2007. This meeting was the fifth in a series held every 10 years, starting (in 1967) with a meeting which marked the centenary of Canadian Federation. EM was also strong at the SEG meeting held in San Antonio, Texas, 23–28 September 2007.

In a different tradition, the International Union of Geodesy and Geophysics (IUGG) held its assembly in Italy this year, and the next will be in Melbourne in 2011. Its member association International Association of Geomagnetism and Aeronomy (IAGA) will meet next in Sopron Hungary, in 2009. Both IUGG and IAGA traditionally hold sessions on EM induction in the Earth, and the IAGA Working Group which specifically focuses on this topic held its biennial workshop last year in El Vendrell, Spain (see http://www.agu.org/eos_elec/) and will meet in 2008 in Beijing.

Amongst this tapestry of activity, I recently attended and here report on two workshops held in Europe, which were intentionally juxtaposed in space and time. The Fourth International Symposium on Three-Dimensional Electromagnetics (3DEM4) was held in Freiberg, Germany on 27–30 September 2007, and the 22nd Colloquium on Electromagnetic Depth Research (EMTF 2007) was held across the border at Decin-Maxicky in the Czech Republic from 1 to 5 October 2007. At the time of writing, there is more information on these two meetings at the websites http://www.geophysik.tu-freiberg/3dem4 and http://rebel.ig.cas.cz/activities/emtf/emtf_2007_ramec.htm

3DEM4 with the theme 'New Horizons' was hosted by Klaus Spitzer and Ralph-Uwe Borner and colleagues of the Institute of Geophysics of the Technical University of Freiberg. The meeting followed 3DEM3, which was held in Adelaide in 2003 juxtaposed with the ASEG conference and exhibition of that year. 3DEM2 and 3DEM1 were held respectively in 1999 (Utah) and 1995 (Connecticut), and Australian geophysicists have made many contributions to the series. At Freiberg there were good presentations on orebody-style EM, that is, controlled-source methods over orebody models. The matter of airborne time-domain EM over one-dimensional situations (such as in use to study the salinity problem in Australia) was not canvassed as extensively as it might have been, perhaps because of competition for participant time amongst the various September meetings. However, another growth method in EM, controlled-source seafloor EM as applied to the investigation of sedimentary basins and especially gas hydrate deposits, was well aired. So also was natural-source field magnetotellurics, with impressive case histories from different tectonic settings around the globe. Attention was given to what is actually the best form of the observed data to invert. Into this question also came contributions from the New Zealand group which has developed 'phase tensor' analysis.

The 22nd Colloquium on Electromagnetic Depth Research was hosted in the Czech Republic by Joseph Pek and colleagues of the Geophysical Institute, Czech Academy of Sciences. Previously the meetings of this series have been in Germany. Their initiation in 1963 is attributed to Julius Bartels, when the extra geomagnetic observatories of the 1957–58 International Geophysical Year revealed new information about Earth electrical conductivity structure. Research in the topic was led in Australia at the time by W. Dudley Parkinson of the then Bureau of Mineral Resources. With all international participants very welcome, the 22nd Colloquium again received its traditional support from German scientists, and exhibited the widespread and comprehensive activity around the world of German researchers in electromagnetic methods. The geophysical work of the Czech Academy of Sciences was well displayed, and the meeting particularly remembered the contributions to EM made by the Czech scientist Oldrich Praus (deceased 2006).

Continued on p. 13

Enigmatic changes to education, science and research in new Rudd government

Although the new Rudd government generated a breath of fresh air in Canberra, the administrative arrangements of his government in the Education, Sciences and Research sectors appear at first glance to be overly complex. According to my assessment there are at least six departments with significant responsibilities in these three key sectors.

First up, we have the ***Department of Education, Employment and Workplace Relations***, with Julia Gillard, the Deputy Prime Minister, at the helm. Some of the matters she will deal with include:

- Education policy and programs including schools, vocational and higher education
- Education and training transitions policy and programs
- Science awareness programs in schools

As Matthew Purss writes in this *Preview* (page 5), teaching science at schools and universities is crucial to the future of our industry.

Then we have the ***Department of Resources, Energy and Tourism***, which is headed up by Martin Ferguson. This has responsibility for:

- Energy policy
- Mineral and energy industries, including oil and gas, and electricity
- Energy-specific international organisations and activities
- Minerals and energy resources research, science and technology
- Geoscience research and information services including geodesy, mapping, remote sensing and land information co-ordination
- Renewable energy technology development
- Clean fossil fuel energy
- Industrial energy efficiency.

This department is very important for the ASEG's industry links.

Then we have the ***Department of Innovation, Industry, Science and Research***, with Kim Carr as the responsible minister. His department is responsible for issues such as:

- Industry innovation policy and technology diffusion
- Promotion of industrial research and development, and commercialisation
- Export services and marketing, including export promotion, of manufactures and services
- Investment promotion and small business policy and implementation
- Facilitation of the development of service industries generally
- Weights and measures standards and analytical laboratory services
- Science policy
- Promotion of collaborative research in science and technology and co-ordination of research policy
- Commercialisation and utilisation of public sector research relating to portfolio programs and agencies
- Research grants and fellowships
- Information and communications technology industry development

CSIRO, AIMS and ANSTO also come under Kim Carr's portfolio. So Kim Carr looks after most of the research activities, which appear to be separate from the teaching aspects of the education system. How this is going to work out is not immediately clear.

Fourthly, we have the department of the ***Environment, Water, Heritage and the Arts***. This deals with:

- Environment protection and conservation of biodiversity
- Meteorology, Air quality and Land contamination
- The Australian Antarctic Territories
- Environmental research
- Water policy and resources
- Ionospheric prediction and community and household renewable energy programs.

This department is led by Peter Garrett.

Then there is the ***Department of Climate Change***, which is headed by Penny Wong. This is responsible for:

- Domestic and international climate change policy
- Design and implementation of emissions trading
- International climate change negotiations
- Renewable energy policy, regulation and co-ordination
- Greenhouse emissions and energy consumption reporting
- Greenhouse mitigation and adaptation
- Co-ordination of climate change science activities
- Energy efficiency policy and standards

And finally the ***Department of Broadband, Communications and the Digital Economy***, which has Stephen Conroy as Minister. This portfolio deals with:

- Broadband policy and programs
- National policy issues relating to the digital economy
- Content policy relating to the information economy

So there appears to be several overlapping issues. For example, Gillard and Carr in the education sector; Wong, Carr, Garrett and Ferguson on energy and Conroy, Carr and Ferguson on innovation. We will have to see how they all interact. At first glance it might appear that Peter Garrett has missed out because he does not control climate change issues. However, he has responsibility for water policy and resources and that just by itself is crucial for our future. So it may be a carefully planned balancing act, with the overall control vested in Prime Minister and Cabinet, as it was under John Howard. We will have to wait and see.

For those who would like to follow these issues up on more detail they should go to: http://www.pmc.gov.au/parliamentary/index.cfm. This is a very interesting site which outlines very clearly the portfolio responsibilities in the Rudd government and is a must for any political observer.

Continued from p. 12

The 3DEM series was started in memory of Gerald W. Hohmann by a group of his friends and colleagues. At the conference dinner in the Freiberg 'Ratskeller' at the meeting this year, Hohmann Awards for career achievement in the topic of 'Electrical methods applied to geothermal exploration and development' were presented to Adele Manzella of the Institute of Geosciences and Earth Resources of the National Research Council of Italy, and to Toshihiro Uchida of the National Institute of Advanced Industrial Science and Technology of Japan.

The next 3DEM meeting is planned for Japan in 2011.

Ted Lilley
Visiting Fellow, Research School of Earth Sciences
ANU, Canberra

News

$301 million for new ARC 'Discovery' research projects and Australia now joins IODP

In October 2007, Julie Bishop, the then Minister for Education, Science and Training announced that 878 new projects would receive more than $300 million over the next five years under the Australian Research Council's Discovery Projects scheme. This is a significant increase over the 2006 announcement, when $275 million was provided for 822 Discovery Projects.

The Linkage Projects also received increased funding with $65 million committed compared to $59 million in 2006. And nestling within the Linkage Infrastructure, Equipment and Facilities Proposals is $6 million over five years for Australia to join the Integrated Ocean Drilling Program (IODP). The Australian Research Council (ARC) bid to become an associate member of the IODP was backed by the US National Science Foundation, and leaders of the Japanese, European, and Korean IODP groups, who regard Australia very highly. The Australian team which put together the bid was led by Richard Arculus at the Australian National University and congratulations are in order to Richard and his team. The Australian IODP Group now comprises 14 universities, plus two CSIRO Divisions, Australian Institute of Marine Science (AIMS) and Australian Nuclear Science and Technology Organisation (ANSTO). This will enable Australia to have six to seven shipboard places per year, plus membership of several IODP committees. New Zealand has joined us in a consortium, taking the membership level up to 30%. Geoscience Australia has also agreed to provide some geophysical support with data for site surveys.

Neville Exon: Interim Head of the Australia Secretariat

The Australian Secretariat will be situated at the ANU. It will carry out all overall planning and coordination with our international partners, and fund necessary travel for the program. Neville Exon is Interim Head of the Secretariat. Australia was a member of IODP's precursor, the Ocean Drilling Program (ODP), but a funding mechanism for joining IODP had been a problem, until the ARC support in the latest research funding round. The members of the consortium will provide an additional $2.85M during the next five years.

The IODP is the world's largest multinational geoscience program, and includes almost all Organisation for Economic Co-Operation and Development (OECD) countries. The IODP carries out deep scientific coring around the world's oceans, and provides 'ground truthing' of global geoscientific theories based on remote sensing techniques. Results from drilling within and outside Australia's marine jurisdiction will give understanding of the oceans' state under past climates through high resolution records of the range of oceanographic and biological responses to climate change, the role of the deep biosphere in shaping oil and gas deposits, hydrothermal and igneous processes involved in ore genesis, and enhanced understanding of some of the world's largest earthquake- and tsunami-generating processes.

Discovery Grants still hard to win

The Discovery Projects scheme provides funding for research projects that can be undertaken by individual researchers or research teams. They use approximately 75% of the research money that ARC has available for research. Table 1 summarises the funds provided for Discovery Projects in the last five years. The success rate has steadily declined.

Notice how the success rate is still close to 20%. Of the 4114 proposals assessed only 91 were considered to be ineligible. As in 2006, the success rate for proposals aligned to the four National Research Priorities, adopted by the previous government, was almost the same as proposals that were not aligned. In 2007, 3539 proposals were aligned with National Research Priorities. If the success rate is the same, whether the proposal is aligned to these priorities or not, one wonders why we have priority areas for Discovery Grants.

Eight tertiary institutions received funding of more than $12M (see Table 2, p. 38). Last year only seven institutions reached that level. Melbourne University has jumped over Sydney University and the ANU to take top spot for both success rate and overall funding. Otherwise the order is similar to the 2006 table. Details of the geophysically related Discovery and Linkage Grants will be included in the April *Preview*.

Richard Arculus: team leader for Australia's IODP bid

Table 1. ARC Discovery Project funding, 2004–2008

	2004	2005	2006	2007	2008
Applications received	3260	3441	3766	4047	4121
Withdrawn	20	27	24	14	9
Applications funded	875	1055	917	822	878
Average total grant size	$271 939	$282 030	$298 350	$334 267	$342 593
Success rate (%)	27.0	30.9	24.5	20.4	21.4
Requested funds over project life for approved proposals (million)	$1160.6	$443.7	$496.1	$502.1	$532.0
Total funding approved (million)	$238.0	$295.5	$273.6	$274.8	$300.8
Average first year funding	$84 060	$94 340	$103 768	$105 019	$106 469

Perth conference a winner for the Research Foundation

At the 2007 Perth Conference the ASEG Research Foundation raised a total $10 080 for the support of student research projects. The money was raised through the generosity of individual conference participants and a number of companies. Individuals who made donations were placed in a draw held at the conference dinner. Prizes included fantastic leaf paintings donated by Philip Middleton, a CD/DVD combo player donated by B&H Australia and wines from Cockatoo Ridge Wines Limited.

By the time the conference dinner rolled around on Tuesday night a total of $800 had been raised. At the dinner Chris Nind of Scintrex stimulated a round of further donations from a variety of companies when he generously volunteered that Scintrex would match the $800. With the able assistance of the evening host – a penguin (or was it Barry Long?) – a further ten companies agreed to follow suit donating a total of $8800 on the evening, a fantastic outcome.

The amount raised is a significant boost for the Research Foundation and will support at least two projects for one year. Well done and thank you to all! Thanks also to Louise Middleton of the ASEG Secretariat who played a leading role in coordinating the week's activities.

What is the ASEG Research Foundation?

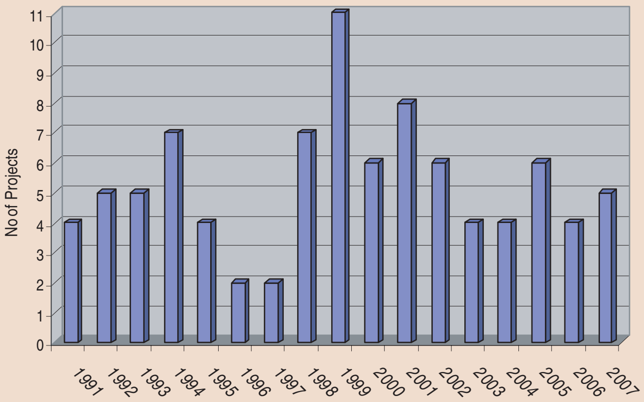
The ASEG Research Foundation was established in 1988 to encourage the study of exploration geophysics by providing students with support for research projects. Funds are specifically targeted at field or laboratory work carried out as part of study for an Honours or postgraduate degree.

Members of the Foundation are formally nominated and go though an approval process and registration involving the CSIRO legal department. This allows the Foundation to be registered so that all donations qualify for tax deductibility in Australia.

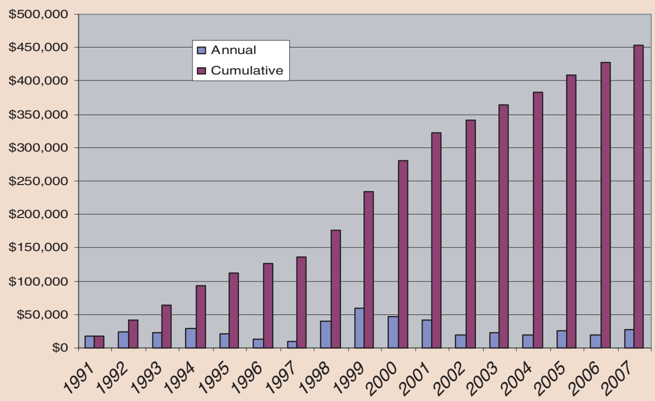
Currently there are 21 members of the Foundation drawn from a broad cross-section of the geophysical community including academics and experienced professionals in the main disciplines of exploration geophysics. They are divided into two technical committees that assess and rank research proposals in the areas of mining and petroleum geophysics. The Chairman is always on the look out for further candidates who are willing to serve as Foundation members.

Our track record

Since 1991, the Research Foundation has spent a total of $454 000 supporting 76 research projects (see charts below). This has contributed to the completion of 45 Honours, 12 Masters and 19 PhD degrees in 11 tertiary institutions. Subjects have been evenly spread among the minerals and petroleum disciplines at 35 each, with projects in the areas of environmental and engineering geophysics making up the



Number of projects per year



Annual and cumulative expenditure

Grants made for the 2007 academic year

Institution	Supervisor	Student	Degree	Grant	Topic
University of Adelaide	Graham Heinson	Michael Hatch	PhD	$5037	Geophysical interpretation of temporal variations of surface and groundwater hydrology
Curtin University	Brian Evans	Matthew Saul	Hons	$4950	Virtual source imaging – testing the concept using physical models
Curtin University	Milovan Urosevic, Brian Evans	Christopher Harrison	PhD	$9800 $8700	Feasibility of seismic methods for imaging gold deposits in WA
Curtin University	Brett Harris	Sean Phillips	Hons	$2007	Feasibility of deep ocean electromagnetic exploration in Australia's offshore oil and gas basins
Curtin University	Bruce Hartley Ramadhan	Abdullah Al	PhD $5000	$5000	Reservoir imaging using microseismic events

remainder. The level of support each year varies with the number and quality of the applications and more importantly the financial resources of the Foundation.

Applying for a grant

The Foundations is seeking applications for the 2008 academic year. Students apply for grants through their supervisors. Projects are ranked by the technical committees and the grants are made in early March. Expenditure of the individual grant is managed by the student's supervisor and unspent funds at the end of each project are returned to the Foundation. A condition of receiving a grant is that the results are published in *Preview*.

The application process is coordinated by the Research Foundation Secretary, Doug Roberts. Further information is available through the ASEG website at www.aseg.org.au/about/rf/ or through the ASEG secretariat at (08) 9427 0838.

Funding the Research Foundation

The capacity of the Research Foundation to support good projects is directly related to the funds it has available. These come from different sources including a portion of corporate ASEG membership fees, generous donations from individual ASEG members and other interested individual and corporate sponsors, and grants from the ASEG through the Federal Executive. A big thank you to the individual ASEG members and companies that supported the Foundation's fund raising activities at the recent conference. They are below.

Individual donors and their affiliations

Ben Walton (Plaza Imaging), Roger Clifton, Chris Anderson (PGS), Terry Allen (PGS), Nev Mathers (GeoKinetics), Ian Hawkshaw (RPS), Huisheng Wang, Andy Gabell (Airborne Petroleum), Stephen Busuttil (GRS), Ric Battig (GRS), David Denham, Steve Goodacre (ZEH Software), Colm Murphy (Bell Geospace), David Castillo (Geo Mechanics), Leo Fox (Phoenix Geophysics), Barry Long, Patrick Squires, Duncan Cogswell (Borehole Wireline), Martin Hargrave (Ikon Software), Chris Leech (Geomatrix), Vesna Rendulic (Shell), Dave Isles, Ned Stolz, Howard Golden and Nick Sheard.

Company Donors

Alpha Geoscience, Carpentaria Exploration Limited, Fugro, Geoforce, Geotech Airborne, Hampson-Russell, Paradigm, Scintrex, Terrex, Velseis, Western Geco.

The Foundation is helping to create the future of our profession. The need for on-going funding is unending. Members of the ASEG may donate each year at membership renewal time or can make a donation at any time of the year through the ASEG secretariat. I urge everyone to seriously consider making regular donations to help keep the Foundation viable.

Phil Harman
Chairman, ASEG Research Foundation
phil.harman@gravitydiamonds.com.au

Continued from p. 13

Good news on Open Access data

FASTS recently reported some good news from both the US and the EU on access to publicly funded research. To quote from the FASTS release:

> *'As many of you may be aware there has been concern about the costs of academic publications undermining public access to research for many years. One response has been debate around the world to expand 'open access' publications through mandating publications (and data) from publicly funded research being placed in publicly available repositories.'*

There have been recent developments in the US and Europe that are likely to have significant effects on the organisation and funding of publicly funded research globally. First, in the US, on 26 December 2007, President Bush signed an omnibus funding bill containing a provision requiring the US National Institutes of Health (NIH) to mandate Open Access for NIH-funded research. This is probably the first time that Open Access has been mandated for any Government funding agency world-wide by legislation (although some agencies in Europe require it in their own non-legislated funding rules). The Bush decision came about despite extensive lobbying from the academic publishing industry.

Secondly, on 10 January this year, the Scientific Council of the European Research Council placed its guidelines for Open Access on the internet (the document is dated 17 December 2007). In essence, the proposed guidelines make Open Access mandatory for ERC funded projects and explicitly include both data and articles. This is the first EU-wide mandate and will be significant because ERC distributes about 15% of the EU research budget.

For more information on the US decision, go to: http://www.earlham.edu/~peters/fos/newsletter/01-02-08.htm#nih. For Europe, go to the European Research Council site at: http://erc.europa.eu/. Also the FASTS website provides more information in Australia. It will be very interesting to see how the ARC and NHMRC respond to these decisions in the US and Europe.

Eristicus

Resource industries power ahead – 2007 in review

Resource stocks ride high

Resource stocks listed on the ASX continued to perform well during 2007. Figures 1 and 2 show the total market capital of the resource companies listed on the ASX in the top 150 Australian companies. It also shows how the top two companies, BHP Billiton and Rio Tinto, have performed together with the All Ordinaries Index. Notice how well the resource stocks have out-performed the All Ordinaries Index.

By the end of 2007 there were 25 resource companies in the top 150 companies. This compares with 17 at the end of 2006. BHP Billiton once again dominated the market. Its market capital rose from $84 billion at the start of the year to reach a maximum of $158 billion in October before settling down to $138 billion at the end of the year.

Rio Tinto also performed spectacularly. It started the year at $32 billion, rose to $66 billion and finished at $61 billion. So if you had bought and sold at the right times you could have doubled your money on either of the two largest resource companies.

However, the biggest winner was Fortescue, which increased its value from $3.5 billion to an amazing $24 billion during the year and as a result enabled its CEO Andrew Forrest to become Australia's richest man with a cool $8.7 billion, well ahead of second placed James Packer who is worth about $7.2 billion.

Last year the uranium companies did well. This year the gold, iron ore, coal and the oil companies were the best performers. Newcrest grew from $8.4 to $14.6 billion and Lihir from $3.7 to $6.7 billion. In the oil sector, Woodside, Santos and Oil Search all increased their value by about 50% whereas Origin, the third largest Australian oil company (excluding BHP Billiton), struggled to maintain its value, finishing 2007 at a disappointing increase of only 3%.

Completed takeovers during 2007 were much lower than in 2006. However, BHP Billiton's bid for Rio Tinto caused more than a few ripples in the industry, not least with the Chinese, their main customers for iron ore. At the time of writing the long term status quo is in place and they are still performing well as separate companies.

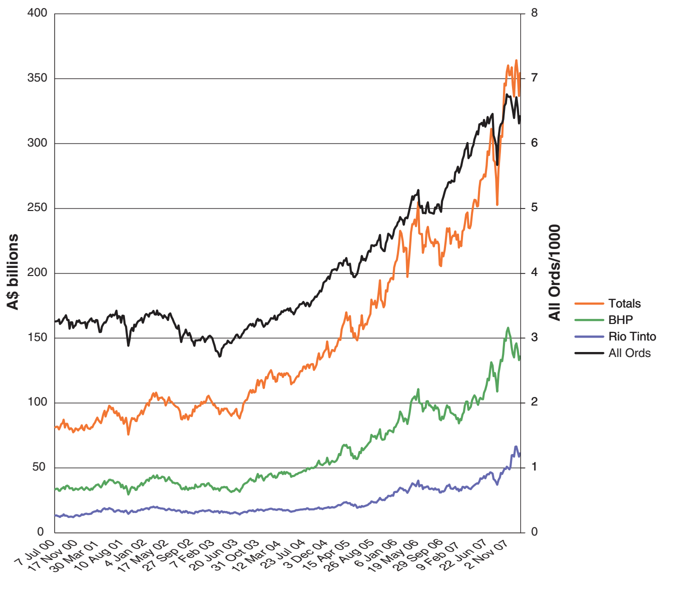


Fig. 1. *Total market capital (in $billions – left hand axis) of the resource companies in the top 150 listed companies on the ASX (red), together with a history of the top two; BHP Billiton (green) and Rio Tinto (blue), and the All Ordinaries Index (right hand axis). Notice that from 2000 the resource stocks consistently out-performed the All Ords Index.*

No stopping the minerals explorers

Figures released by the Australian Bureau of Statistics in December 2007 show that the trend estimate for total mineral exploration expenditure increased by $35.9M (7.4%) to $523.5M in the September quarter 2007. The estimate is now 38.4% higher than the 2006 September quarter and is now at an all-time record. Figure 3 shows the expenditure estimates from September 1999 through September 2007. Both the trend and the seasonally adjusted numbers are powering ahead.

The largest contributions to the increase this quarter were in Western Australia – up $26.0M or 10.6% to a massive $293M – another all-time record. Queensland also recorded a large increase, up $5.5M or 7.4% to a record $84.9M and South Australia increased by $3.1M to a record $87.2M. Only Victoria registered a decrease and this was a very small $0.3M, down to $17.7M. As expected, the Western Australian contribution dominated the national figures and contributed 52% of the national total.

The trend estimate for metres drilled increased by 1.6% this quarter to 2557 km. The current estimate is now 11.8% higher than the September quarter estimate for 2006.

The Greenfield investment is a healthy 41% of the total. It is now at $210 million, compared to the September quarter for 2006 of $139 million.

Figure 4 shows the longer term trends from March 1986. It indicates that in real terms (CPI adjusted) the expenditure levels are far greater than ever recorded.

No wonder everyone is flat out looking for new resources! How long can these trends continue?

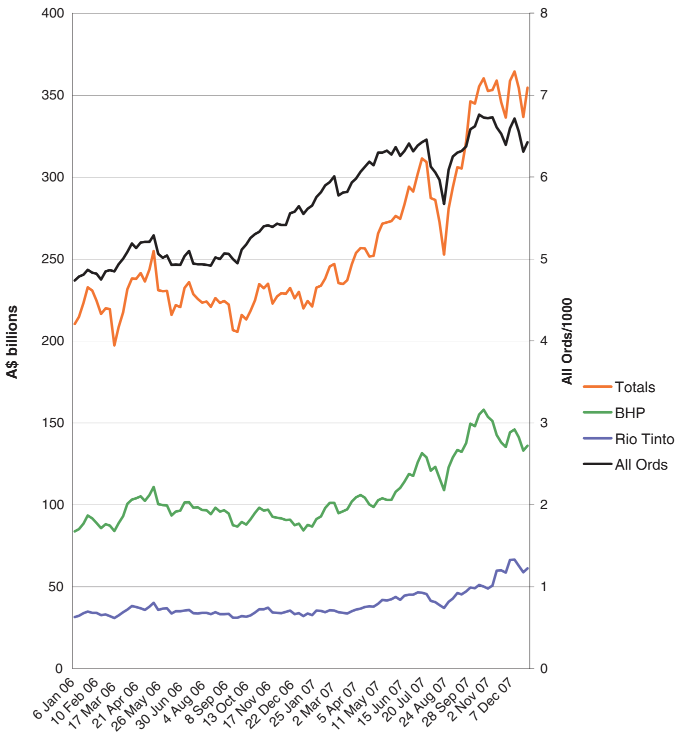


Fig. 2. *Detail of Fig. 1 for the period 2006 through 2007. The scales and colours are the same as in Fig. 1.*

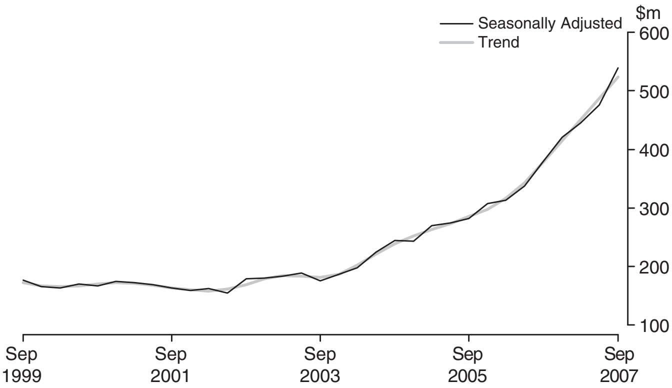


Fig. 3. *Trend and seasonally adjusted quarterly mineral exploration expenditure from September 1999 through September 2007 (provided courtesy of the Australian Bureau of Statistics).*

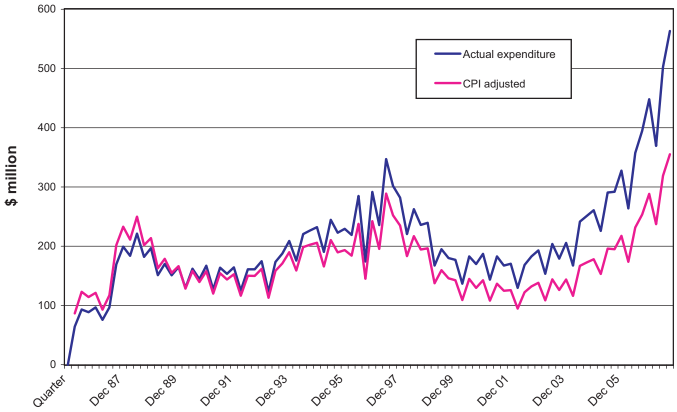


Fig. 4. *Quarterly 'actual' mineral exploration expenditure from March 1986 through September 2006 (from ABS data). The black curve represents actual dollars spent and the purple curve shows the CPI adjusted numbers to 1998/99 levels (ABS data).*

Petroleum – another strong result

The petroleum sector turned in another good performance. Although expenditure on petroleum exploration for the September quarter 2007 decreased by $33.8M, at $698.3M, it was still the second highest on record.

Expenditure on exploration on production leases decreased by $2.2M (1.4%) to $153.1M, while exploration on all other areas decreased by $31.7M (5.5%) to $545.2 in this quarter. There was a decrease of $11.6M (1.9%) to $584.9 in offshore exploration, while onshore exploration expenditure decreased by $22.2M (16.4%) to $113.4M.

Western Australia dominated the September quarter. It had the largest increase in petroleum exploration expenditure of $21.1M to a massive $546.5M. This amounts to 78% of the national expenditure and is more than ten times greater than second-placed South Australia, which only reached $52.7M.

Figure 5 shows a plot of the quarterly petroleum exploration expenditure from March 1986. Notice that in the last year, there has been a significant increase in exploration expenditure. Clearly the government's Big New Oil Program, together with the increase in the crude oil price to about US$100 per barrel are having the desired effect of encouraging petroleum exploration.

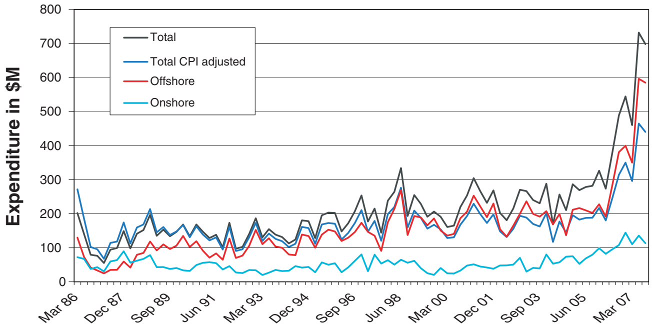


Fig. 5. *Quarterly petroleum expenditure from March 1986 through September 2007. The individual offshore and onshore numbers are actual numbers spent at the time, not CPI adjusted. The black graph shows the contemporary dollars spent and the blue curve shows the CPI adjusted number to 1989/90 dollars for the total of the petroleum exploration expenditure.*

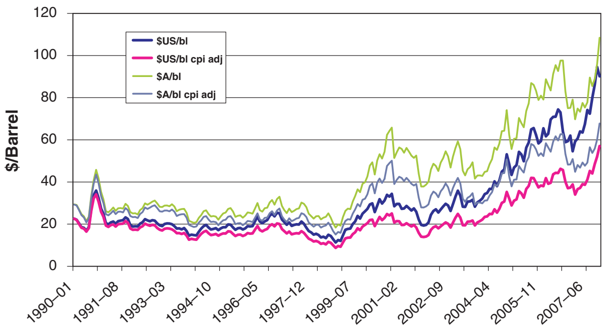


Fig. 6. *Price of West Texas Crude from 1990 through 2007 in $US and $A. The CPI adjustment is to 1989/90 $US and $A values.*

Commodity prices remain strong in 2007

The price of oil continued to increase throughout the year and in early 2008 reached US$100/barrel. Since mid-1999 the price of oil has steadily increased, and in the last six months the rate of increase has surged, as the supply of oil was not able to meet the global demand. Figure 6 tells the story with the price increasing by 68% over the calendar year. Significantly, in real terms, the price is the highest it has been since the Second World War and shows no sign of changing course. However, considering that there are 159 litres to the barrel, the price at the pump of A$1.50 a litre is not too much of a mark-up over the raw price of about $0.70 per litre.

Gold also performed soundly during 2007 with a price rise of about 27% over the year. As shown in Figure 7, since mid-2005, the price of gold has really taken off and looks certain to reach A$1000 per ounce very soon. The current gold price (as with the price of oil) is higher than at any time since the Second World War.

Figure 8 shows the variation in prices for a selection of the six other main non-ferrous metals during 2006–07. Tin and lead have done well (now you know why car batteries are so expensive), but the other four have had a mixed performance. The main point of note is that the prices are all firm and there is plenty of encouragement to invest in mineral exploration.

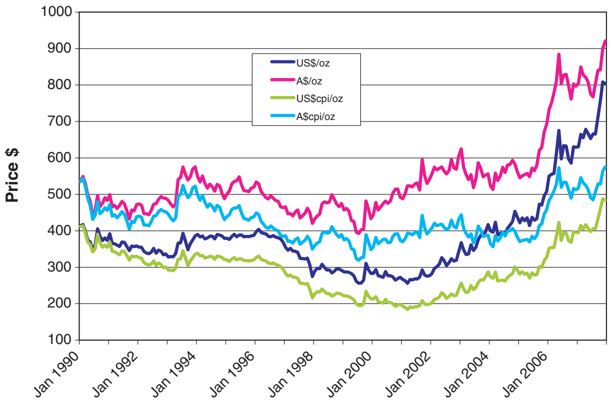


Fig. 7. *Gold prices in $A and $US per oz, with and without CPI adjustments. The CPI adjustments are normalised to1989/90. Notice that the price in Australian dollars does not increase in real terms until mid-2005.*

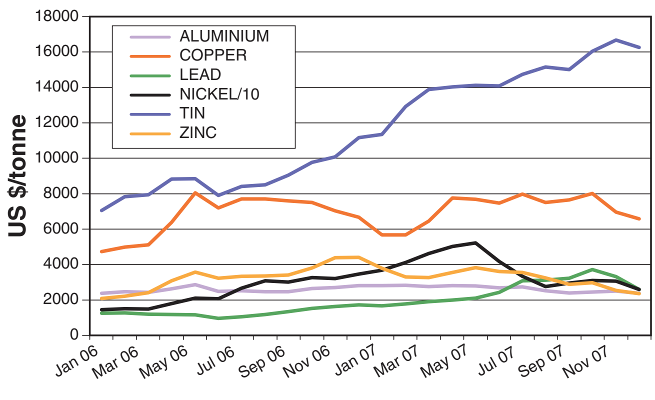


Fig. 8. *Metal prices for aluminium, zinc, copper, lead, nickel and tin, in $US/tonne except for nickel, where the price is ten times the plotted values. Notice the gradual decline in copper prices since May 2006 and the doubling of prices for Ni, Zn and Tin.*

Offshore exploration acreage proposed for release in 2008

It is anticipated that Martin Ferguson, the Minister for Resources, Energy and Tourism will announce the 2008 Acreage Release package at the annual APPEA conference in Perth, on 6 April 2008.

The map shown in Figure 9 indicates the Australian offshore petroleum acreage areas currently proposed for release in 2008.

This preliminary advice is provided to allow industry greater lead time to assess areas and to facilitate acquisition of speculative seismic data.

In addition there are several areas open for bidding from the 2007 acreage releases. These are summarised in Table 1.

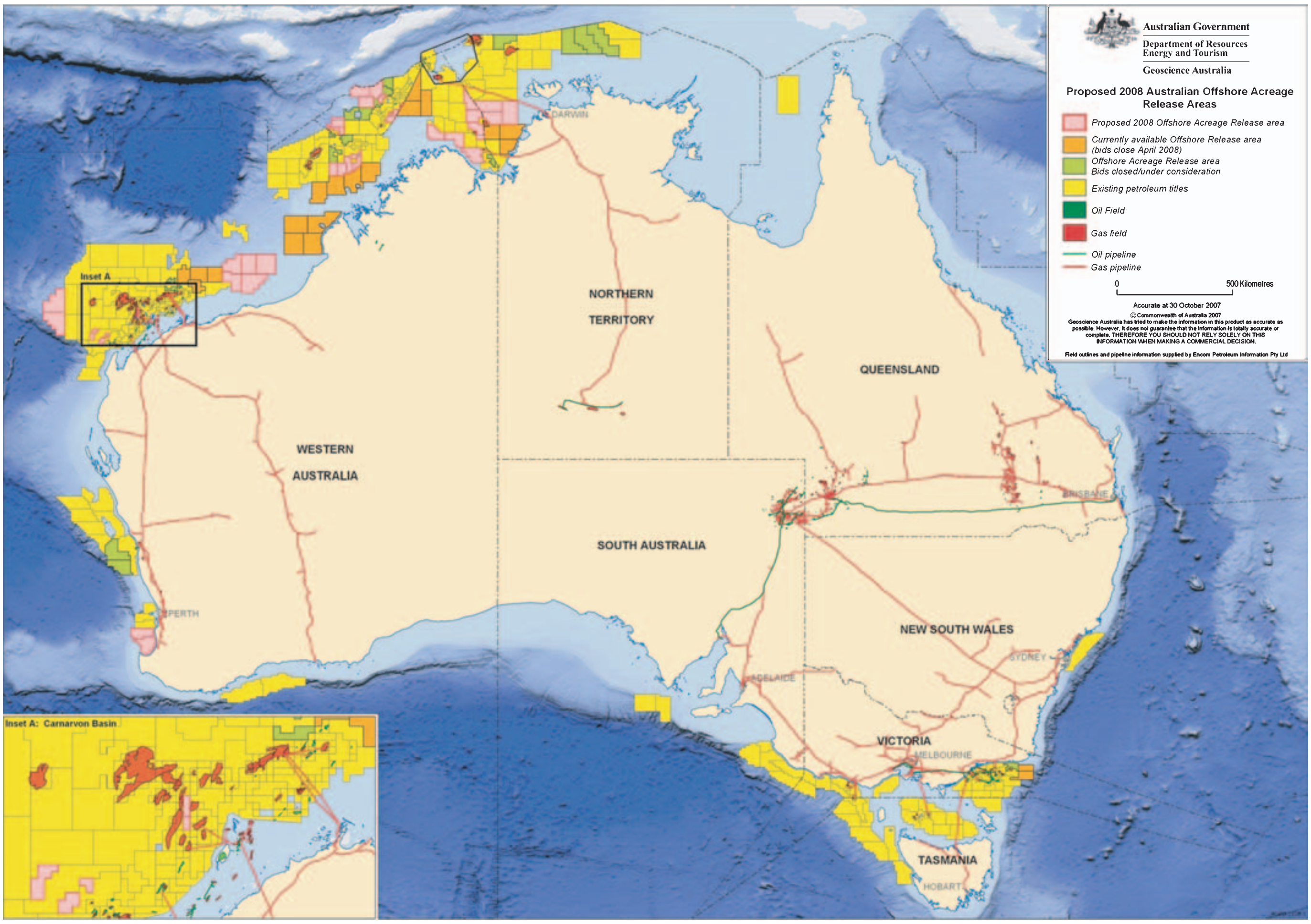


Fig. 9. *Proposed 2008 Offshore Acreage Release areas (pink); currently available offshore release areas (orange); areas where bids have closed and are under consideration (green) and existing petroleum titles (yellow). Oil fields are shown in dark green and gas fields are coloured red. Gas and oil pipelines are also shown.*

Table 1. Summary of areas currently available for bidding from the 2007 rounds

Release/round	Areas	Bid Closing Date
2007 Acreage Release, Second Closing Round [20 areas]	V07-2 to 3; Gippsland Basin NT07-3 to 5; Petrel Sub-Basin, Bonaparte Basin W07-8 to 15 and 18 to 21; Browse, Canning and Carnarvon Basins W07-1 to 3 Londonderry High, Bonaparte Basin	Thursday, 17 April 2008 Thursday, 17 April 2008 Friday, 18 April 2008 Friday, 18 April 2008
Re-release of 2007 areas, (from first closing round) [3 areas]	V07-1 Gippsland Basin NT07-2; Money Shoal Basin W07-4; Petrel Sub-Basin, Bonaparte Basin	Thursday, 17 April 2008 Thursday, 17 April 2008 Friday, 18 April 2008

Further information on these areas and application requirements can be found by visiting this website: www.industry.gov.au/petexp or by requesting a free CD-ROM by email: petroleum.exploration@industry.gov.au

Improvements to the Australian National Gravity Database

From Tuesday 5 February 2008 gravity data held in the Australian National Gravity Database will be based on a new gravity datum called the Australian Absolute Gravity Datum 2007 (AAGD07). This new datum supersedes the previous ISOGAL84 datum. To convert observed gravity values from ISOGAL84 to AAGD07, the following formula should be used:

$$g_{(AAGD07)} = g_{(ISOGAL84)} - 0.78\ \mu m/s^2$$

Other improvements that will also take effect are:

- The Vertical Datum will use ellipsoidal heights relative to the GRS80 ellipsoid
- The Horizontal datum will not change, and continue to use the GDA94 datum
- Theoretical Gravity will be calculated using the closed form of the 1980 international gravity formula and will also include an atmospheric correction
- The Free Air Correction will be calculated using the second order approximation for the change in the theoretical gravity based on the GRS80 ellipsoid with height relative to the ellipsoid
- The Bouguer Correction will be calculated using the closed form equation for the gravity effect of a spherical cap of radius 166.7 km with height relative to the ellipsoid

As a result of these changes, Free Air and Bouguer anomaly data downloaded from the Australian National Gravity Database via GADDS from Tuesday 5 February 2008 onwards, will differ from that downloaded before 5 February 2008.

To assist users with compatibility with their existing databases, Free Air and Bouguer anomalies will also be provided using geoidal (AHD) heights and the previous equations. Users will also be able to select individual fields from the point-located gravity data for input into their own software packages to calculate Free Air and Bouguer anomalies using geoid heights instead of ellipsoid heights and utilising their favourite Free Air and Bouguer anomaly formulae.

These improvements have been made to provide more accurate Free Air and Bouguer anomalies and to remove long wavelength errors from the gravity data that are introduced when using geoid heights in place of ellipsoid heights. A complete description of the new formulae used to create the Free Air and Bouguer anomalies will be included in a text file incorporated in the zip file of downloaded data delivered via GADDS.

For further information on the improvements to the Australian National Gravity Database, please contact Ray Tracey (email: ray.tracey@ga.gov.au; phone: +61 (0)2 6249 9279) or Mario Bacchin (email: mario.bacchin@ga.gov.au; phone +61 (0)2 6249 9308).

New gravity data added to the Australian National Gravity Database in 2007

During 2007, over 101 000 new gravity stations were added to the Australian National Gravity Database (ANGDB), which now contains more than 1 400 000 gravity readings. Table 1 lists the surveys added to the ANGDB and Figure 1 depicts their locations.

With the exception of the Cooper Basin North Survey, which was acquired by Geoscience Australia under its Onshore Energy Security Program, all the new gravity data were provided to Geoscience Australia by the respective State or Territory geological surveys.

All open file data in the Australian National Gravity Database can be obtained free-of-charge using the download facility 'GADDS' at http://www.geoscience.gov.au/gadds. For further information, please contact Mario Bacchin (email: mario.bacchin@ga.gov.au; phone +61 (0)2 6249 9308).

Table 1. Gravity Surveys added to the ANGDB during 2007

State	Survey	Stations
Western Australia	Murchison	3556
	Blackstone	309
Northern Territory	Tanami Gravity along seismic lines	1808
South Australia	Northern Olympic Domain	14 542
	Southern Stuart Shelf	4557
	45 Company Surveys	17 957
Queensland	Mt Isa Area C	9047
	Mt Isa Area D	4822
	Mt Isa Area E	6124
	33 Company Surveys	24 323
	Cooper Basin North	3548
New South Wales	Braidwood	917
	Woodlawn Mine	1385
	Far South West NSW	3519
	Thomson	4729
Total		**101 143**

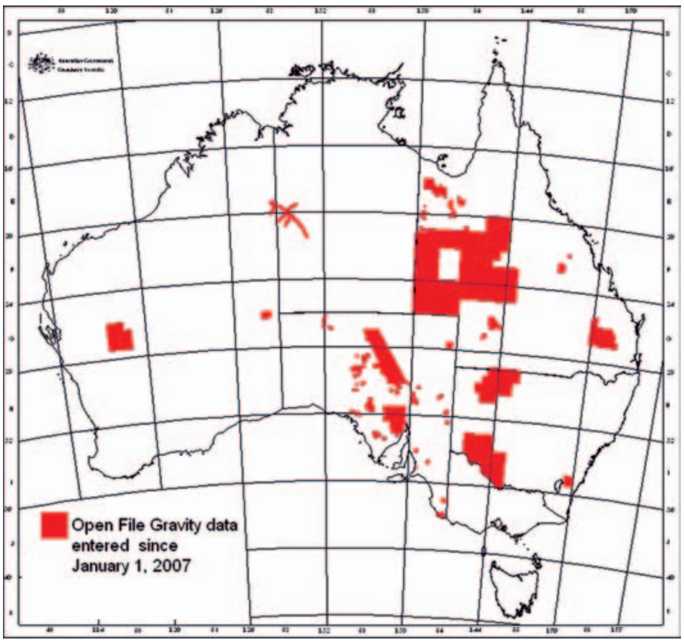


Fig. 1. *Open File Gravity Data entered into ANGDB in 2007.*

News

Update on geophysical survey progress of Queensland, Western Australia, Northern Territory, Tasmania and Geoscience Australia (information current at 10 January 2008)

Tables 2–4 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. Some of the surveys in Tables 2 and 4 are very large and the total acquisition program amounts to over 1 750 000 line-km of new airborne data. All the surveys are being managed by Geoscience Australia. Locality diagrams for the Normanton, Bass Strait, SWCC – Dumbleyung, Offshore NW Tasmania and Offshore SW Tasmania surveys are shown in Figures 2–6.

Table 2. 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
North-East Tas.	MRT	GPX	18 Mar 07	52 000	200 m 90 m E/W	8600	100% complete @ 12 Sep 07	28 Nov 07	123 – Aug 06, p. 39	19 Dec 07
East Isa North	GSQ	UTS	3 Apr 07	113 000	400 m 80 m E/W	39 940	100% complete @ 15 Jul 07	18 Sep 07	125 – Dec 06, p. 32	9 Oct 07
East Isa South	GSQ	Fugro	10 Mar 07	145 900	400 m 80 m E/W	51 560	100% complete @ 15 Jul 07	7 Nov 07	125 – Dec 06, p. 31	28 Nov 07
AWAGS2	GA	UTS	29 Mar 07	145 350	75 km 80 m N/S	7 659 861	100% complete @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	100% complete @ 21 Sep 07	10 Jan 07	127 – Apr 07, p. 27	TBA
Tanumbirini	NTGS	UTS	16 Jul 07	69 463	400 m 80 m E/W	24 047	100% complete @ 16 Sep 07	TBA	126 – Feb 07, p. 35	5 Dec 07
Canning Basin Onshore	GA	Fugro	20 Apr 07	102 656	800 m 80 m N/S	70 192	100% complete @ 15 Jul 07	TBA	127 – Apr 07, p. 26	30 Oct 07
South Kimberley	GSWA	GPX	Jan 08	163 000	400 m 60 m N/S	57 920	TBA	TBA	128 – Jun 07, p. 26	TBA
Canning Basin Offshore	GA	Fugro	22 Jun 07	44 643	750 m 80 m N/S	32 640	100% complete @ 8 Aug 07	TBA	129 – Aug 07, p. 33	30 Oct 07
Westmoreland	GSQ	Fugro	2 Sep 07	59 753	400 m 60 m N/S	21 010	100% complete @ 7 Dec 07	TBA	129 – Aug 07, p. 33	TBA
Cooper Basin East	GSQ	UTS	Jan 08	214 352	400 m 60 m N/S	76 980	TBA	TBA	130 – Oct 07, p. 29	TBA
Cooper Basin West	GSQ	Fugro	8 Nov 07	N-S lines 161 088 E-W lines 479 93	400 m 60 m N/S & E/W	N-S lines 57 700 E-W lines 16 710	TBA	TBA	130 – Oct 07, p. 29	TBA
Normanton	GSQ	TBA	Apr 08	114 4 87	400 m 80 m E/W	74 410	TBA	TBA	This issue	TBA
Bass Strait	MRT	Thomson	Jan 08	46 425	800 m 90 m E/W	29 021	TBA	TBA	This issue	TBA
Offshore NW Tas.	GA	Fugro	Jan 08	43 824	800 m 90 m E/W	27 512	TBA	TBA	This issue	TBA
Offshore SW Tas.	MRT	Fugro	Jan 08	26 554	800 m 90 m E/W	16 745	TBA	TBA	This issue	TBA
South-West Catchment Council – Dumbleyung	GSWA DAFWA and SWCC	TBA	TBA	743 60 total (675 83 @ 100 m spacing and 6777 @ 400 m spacing	100 m 30 m NS and 400 m 60 m N/S	7783 total (100 m lines 5948 400 m lines 1835)	TBA	TBA	This issue	TBA

TBA: To be advised

Table 3. Airborne EM survey

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 the Rudall River NP	339 50	32% complete @ 30 Nov 07 Demobilised for summer Restart first week of Apr 08	TBA	130 – Oct 07, p. 30	TBA

TBA: To be advised

Table 4. 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
Cooper Basin North	GA	Daishsat	TBA	3537	4 regular	56 590	17 Jun 07	31 Aug 07	128 – Jun 07, p. 27	9 Oct 07
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	TBA

TBA: To be advised

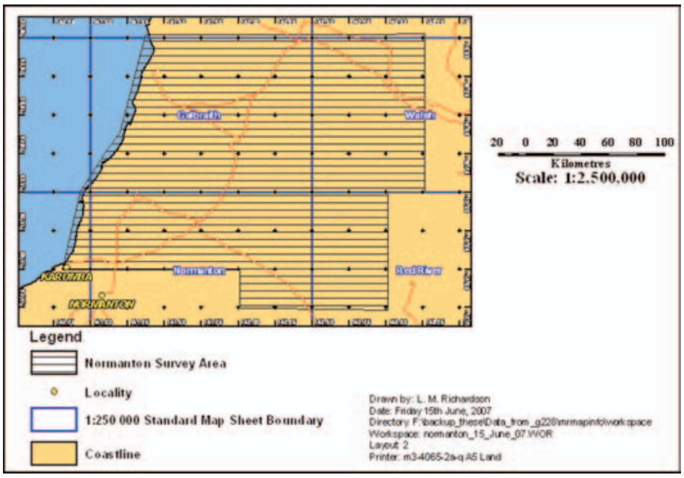


Fig. 2. *Location of Normanton (Queensland) airborne geophysical survey.*

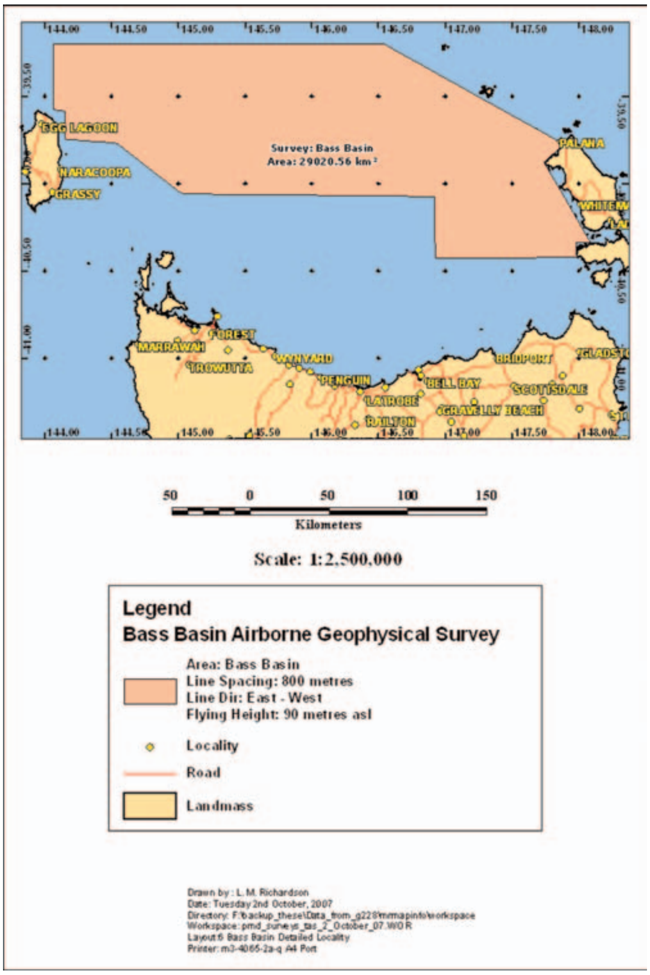


Fig. 3. *Location of Bass Basin airborne magnetic survey.*

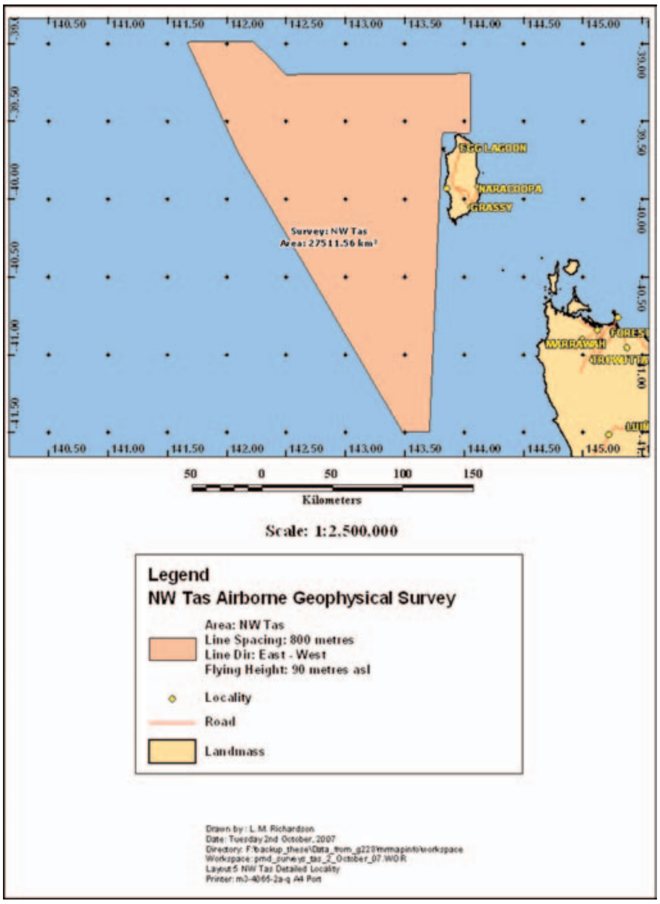


Fig. 4. *Locations of offshore NW Tasmania magnetic survey.*

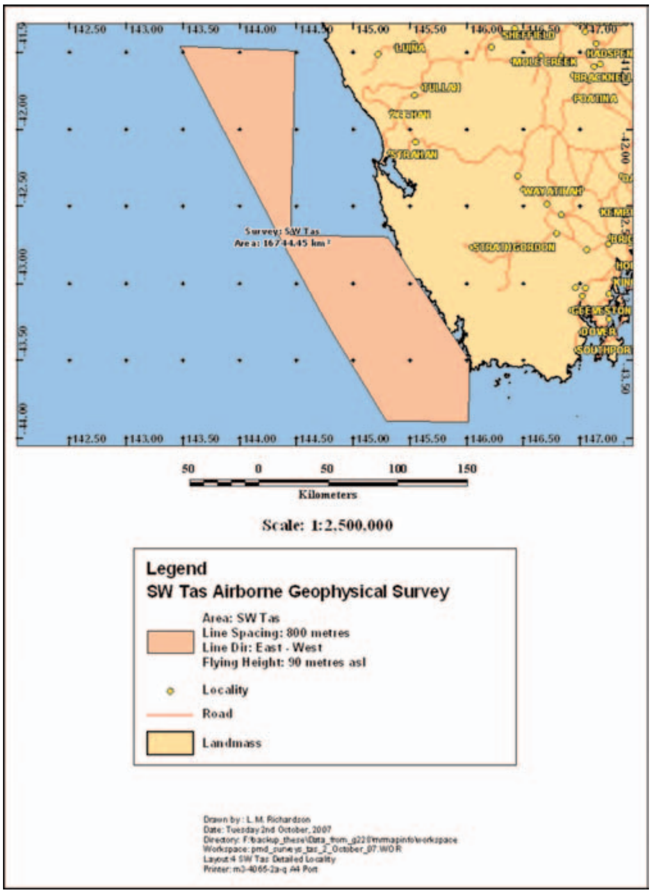


Fig. 5. *Location of offshore SW Tasmania magnetic survey.*

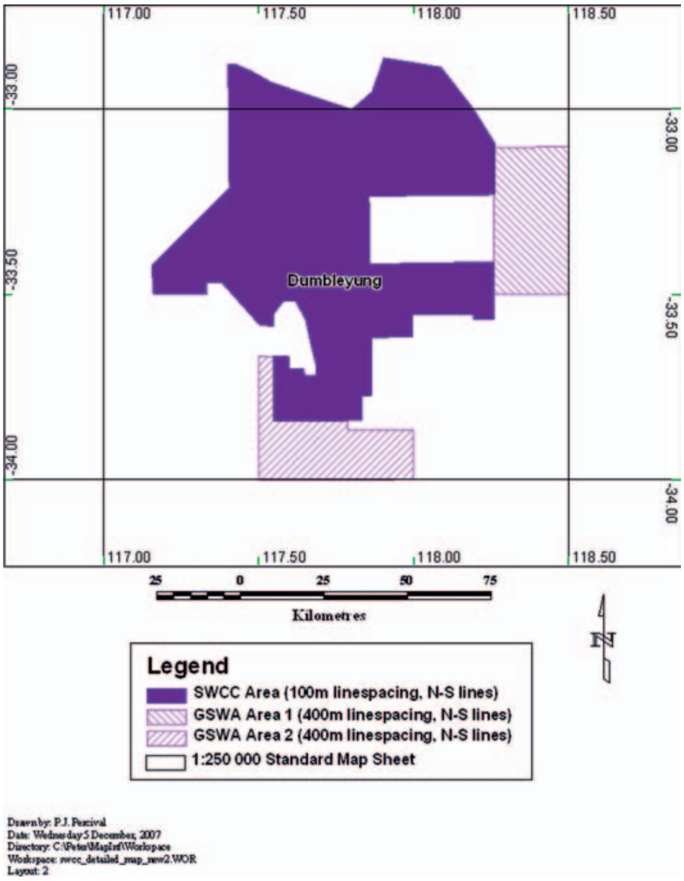


Fig. 6. *Location of the detailed Dumbleyung airborne geophysical survey.*

Queensland's Smart Initiatives bears fruit

In July 2005, the Queensland Department of Natural Resources and Mines announced a $20M Smart Exploration and Mining Initiative to stimulate mineral exploration in the state over the next 4 years. At just over the half way mark through the program, it is instructive to review what has been achieved and what is planned.

A major part of this initiative has involved the acquisition of airborne magnetic and radiometric data in the more prospective areas of Queensland. Figure 7 (p. 30) shows the areas of the state covered by data with 400 m or less line spaced data, and outlines the areas proposed to be flown in the future and their tentative release dates. The data from the surveys are available for download from www.geoscience.gov.au/gadds or on rDVD from sales @dme.qld.gov.au.

There has also been a program of acquiring gravity, hyperspectral and deep seismic data. Figure 8 (p. 30) shows the location of deep seismic lines and hyperspectral blocks, as well as the areas covered by 4 km or less station spaced gravity data. It also outlines the areas proposed to be covered by gravity data in the near future. The gravity data are available for download from www.geoscience.gov.au/gadds or on DVD from sales@dme.qld.gov.au, and the hyperspectral data is available for download from www.em.csiro.au/NGMM/. For further information please contact geophysics @dme.qld.gov.au.

The P223 software suite for planning and interpreting EM surveys

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Summary

Over the past 27 years, the AMIRA P223 project series has produced an extensive body of EM modelling and inversion programs used by the minerals, environmental and defence industries for planning and interpreting EM surveys, and for the development of new EM exploration instruments. The models for both modelling and inversion include a general 3D finite-element full domain model (Loki class, Figure 1), 3D compact finite-element model embedded in a uniform host (Samaya class, Figure 2), 2.5D full-domain finite-elements (Arjuna class, Figure 3), multiple 3D plates embedded in a multi-layered host (Leroi class, Figure 4), 3D prisms in a layered host (Marco class, Figure 5) and a 1D layered earth (Airbeo and Beowulf). The programs can be used for any frequency or time-domain airborne, ground or downhole EM system. All are based on complex resistivity with options for including the Cole-Cole parameters to model induced polarisation effects.

Why develop and maintain so many different model classes instead of just the very general, full-domain 3D programs Loki and LokiAir? Basically it was to give industry the tools to handle a variety of problems, taking into account the time available for interpretation work and the level of information required. The simpler programs are easier to learn, faster to set up and require significantly less computation time.

Although previously these programs were available only to the project sponsors and their designated contractors, they are now available to anyone with an interest in such arcane matters. Initially, this will be on a commercial basis through EMIT's Maxwell graphical user interface. However, from 2010, the Fortran 90 source code, executables and documentation for all programs will be open source. One of our mantras was that our software is not useful unless it is used by the industry people for whom it was designed.

There are two purposes in writing this paper. The first is to make the wider EM interpretation community aware of the capabilities offered by the extensive software suite from the last project, P223F. The second is to discuss the technical, social and organisational factors which created and nurtured this long-running project series. The basic conclusion is to put faith in people rather than process. Serious innovation is much more likely to come from organic environments that encourage intellectual exploration and free interaction, rather than from process-driven organisations obsessed with excessive accountability and other managerialist practices.

Art Raiche

Art worked for CSIRO for 35 years, the last 15 with the rank of Chief Research Scientist. He was awarded the ASEG Gold Medal in 2006 and received the Hohmann award for excellence in applied electrical geophysics in 2007.

Introduction

Every year, there is substantial investment in electromagnetic (EM) surveys aimed at the discovery and delineation of prospective economic targets. In many cases, the information yielded by such surveys is well below that which was anticipated, because of inappropriate choices in the survey methods used and the reliance on inadequate interpretation methods. Given appropriate modelling tools, one can expect to optimise the information potential of EM surveys by computing answers to some basic questions. For a specified target and terrane, are EM methods capable of detecting and delineating the expected target? If not, why waste the time and money on EM surveying? If so, which EM system will yield the maximum information? What is the optimum trade-off between effectiveness and cost? With appropriate interpretation tools (including inversion), one can interrogate the data effectively to extract what information it may (or may not) contain with other questions. What confidence can be placed on the 'best' model that fits the data? How sensitive is the data to small changes in the target parameters? Which of the target parameters are best resolved? Does the data and subsequent model justify further surveying or even drilling?

Although these questions seem obvious, they are often not asked in explicit form due to the lack of appropriate tools. The recognition of the need for such tools was the impetus for establishing the first industry funded EM modelling and inversion consortium in 1980.

The basic aim was to produce robust, well-structured programs in a form that could be used by people in industry rather than their having to rely on case studies produced by researchers. Initially there was to be a two pronged approach: develop our own methods to enable more realistic geological modelling and at the same time, convert public-domain modelling programs into a more reliable and useful software. Eventually a third mode of operation developed. We took the ideas behind public domain software and developed our own algorithms to compute them. Fortunately at the start, we were fairly naïve and didn't realise the magnitude of the task that lay before us.

In the beginning

Getting started was somewhat challenging. Our first task was to convince industry that they needed to support our proposed software project. In those days, geophysical research was aimed mostly at developing new hardware. Modellers were regarded as a chimerical species, quite out of touch with what explorationists considered to be the real world. Bob Smith, then chief geophysicist for CRA, was one of the strategic thinkers of the time who was willing to invest in our ideas. With his help along with that of Jim May at AMIRA and Ken McCracken, then Chief of the CSIRO Division of Mineral Physics, we convinced a few more companies to join us. That started a small stampede of companies who were less than fully aware of what we were doing but felt that if CRA and BHP were in, they had better track along. Thus, we had seventeen sponsors for that first project. By the end of it, some realised that they could safely exclude themselves from subsequent projects. However, many of the original sponsors found value in what we had accomplished and joined with new sponsors, who were interested in what we had done, to back a second project. Thence one project seemed to lead to another over the next quarter century.

Up until the late 1980s, CSIRO was a wonderful platform from which to launch such a project. It was highly decentralised into semi-independent small divisions led by competent chiefs, of good scientific reputation, who knew their sectors. It also had the advantage of a large open organisation where scientists were free to consult across divisional boundaries with no concept of internal costing or worries about protecting intellectual property internally. Management kept in touch by talking directly to staff rather than through formal layers of reports. Under McCracken's leadership, at Mineral Physics, scientists were expected, to originate and manage their own projects with minimal interference from or dependence upon management. Strategic plans seemed to have been written after the event to highlight success and mask failure rather than serving as a preordained straightjacket to prevent new approaches. I believe that this environment played a crucial role in the substantial innovation produced by Mineral Physics in its early years in areas as diverse as electromagnetic modelling, EM equipment development (Sirotem), remote sensing, radiometrics, magnetics and nuclear methods.

Sadly, over the last decade, CSIRO has transformed itself from a once-respected research institute into a highly centralised, government enterprise, replete with intersecting layers of expensive management, focused on continual reorganisation. Scientific independence has been lost, with scientists reduced to the status of process workers. Initiative is still permitted provided that it can pass through a complex set of business criteria. My group was an anomaly in that in our last 10 years, we were able to use the prestige and generous funding of our international sponsors as a force to let us set our own agenda.

Applied philosophy and transmitting value

Traditionally, non-industry researchers seek funding from industry to support pre-existing research interests. In fact, that was how we started, but along the way, we changed. Since few people in the world would regard the development of EM modelling algorithms as an important human cultural activity in itself, one concludes that research into algorithm development has value only if it leads to tools that can be used by explorationists to locate and possibly define drill targets. Thus, we defined our research priorities in accordance with the needs of our industry sponsors. Not infrequently, we were kind enough to advise them on what we thought those needs should be.

This had several implications. The first is that if industry was to use our programs, these programs had to be written for the level of hardware available to the explorationists; i.e. algorithms requiring supercomputers were out. The second was that if we wanted our programs to be used, we would have to spend considerable time developing front ends that were easy to use and understand, and output formats that were easy to read and absorb. They had to contain the needed information and look 'pretty'. Now, in these days of self-documented graphical user interfaces and web design, this is regarded as obvious but when we started, the concept of 'user-friendly' was either unknown or ignored. GUIs hadn't been invented and most EM programs were poorly structured and produced poorly notated, almost unreadable, output.

Most modelling papers are written to illustrate the response of a given model type or algorithm to an ideal source, usually a magnetic dipole transmitter–receiver pair on or above the surface. However, the data derived from EM exploration is the result of the earth interacting with the exploration system in use. Thus a large part of our effort was dedicated to modelling the response of the actual exploration systems in use to the various model classes.

EM modellers are amongst the last bastion of the flat-earth societies. It was always our goal to be able to model the response of realistic geological structures including topography, unconformities, dipping faults and other non-parallel structures. Programs based on finite-element methods are ideal for this. However, mindful of the obligation to produce programs that could be run on machines easily available to the explorationists, this had to wait for us to develop faster, more efficient algorithms and more importantly, the development of desktop and laptop computers with sufficient computation speed and memory.

As our programs developed the capability to deal with more complex models and systems, they also required a greater degree of competence to be used effectively. Formal presentations at our semi-annual meetings were no longer sufficient. We began a program of visits to the offices of individual sponsoring companies around the world for more detailed training. We also set up facilities at CSIRO to enable sponsor visits for week-long private workshops. This was crucial if companies were to continue to derive value from our software. One of the frustrating things was that in many companies, the people we trained tended to be shifted to new responsibilities, thus negating the benefits of the training we had provided. Thus, whenever a sponsoring company employed specialist consultants for their EM work, we always encouraged them to include the consultants in the training sessions.

Education worked in both directions. One unusual aspect of our research philosophy is that we eschewed the usual concept of the research-provider and client relationship. Instead, we regarded the industry people who used our software as colleagues who could advise us on how well the software performed on their exploration tasks and what improvements were needed. Much of what we subsequently developed stemmed from their advice. Indeed, much of what we achieved during the past quarter century would not have happened without them.

Software structure

One of the most important things we had to learn was the discipline of writing structured software. Almost without exception, academic EM software is written in spaghetti fashion with little attention paid to the basic rules of information flow, modularisation and eliminating side effects. Indeed, it often contains non-standard language features that make it impossible to run reliably on machines with different operating systems. In a series of articles written in the late 1970s Les Hatton showed that programs created in this way tended to have around 50 times the number of errors compared with software written in structured style. Moreover, the poor structure made it much harder to find errors and even correct them once they were found. A lot of P223 software had its genesis on the ideas contained in programs that researchers from around the world made available to us. Although the concepts upon which the programs were based were valuable, the software realisation was not. Our usual mode of operation was to restructure the initial program to understand the concepts. Once this was done, we were able to use our own algorithms to recast the core modules and combine these with our existing software framework to produce what we naively hoped would be the final version. During the initial restructuring phase, we usually found many errors that were previously hidden by the original tangled structure. Typically the restructuring increased the speed, often by a factor of 10 and in one case, by a factor of 100, simply by revising the structure.

Over the years, our programs underwent many revisions. Sometimes it was because we devised faster or more accurate internal algorithms. Other times it was to incorporate new capabilities or to eliminate errors that appeared when the programs were used in earnest by industry. There is a saying amongst software designers that a program is complete only when it becomes obsolete.

The benefits of structured programming were fairly obvious. The modularisation and strict design of information flow cut revision time by an order of magnitude. It yielded one other important benefit. By maintaining a common modular structure across all program classes as much as possible, it was easy to port improvements in one program class to others.

We chose to write our programs in ansii-standard FORTRAN. We started with Fortran IV and as the language evolved to FORTRAN 95, we changed with it. By purchasing software capable of checking for non-standard or obsolete features, we were able to ensure that our programs could run on any operating system for which ansii-standard compilers existed. We chose FORTRAN because for numerical applied mathematics computations, it produces more efficient executables than is the case with other languages. FORTRAN has never become obsolete because it keeps changing.

During my working career, when I was invited to give lectures at universities with active research interests in electromagnetic geophysics, there was always interest in our mathematical approaches to EM modelling. However, any efforts to introduce concepts of structured programming in these talks were invariably met with complete disinterest. Imagine what would happen if cars were designed with no thought give to assembly procedures or maintainability.

Modelling

All models are based on full wave solutions; i.e. the quasi-static approximation is never used. All solutions are computed in the frequency domain. For time-domain modelling, a spectrum is computed from either 0.1 or 1 Hz to 100 KHz at six points per decade. This is extrapolated to DC, splined and converted to time-domain using a custom-designed Hankel filter. The raw time-domain response is computed out to five pulse lengths and folded back into a single pulse to account for residual excitation. This is then splined with the source waveform and integrated over receiver windows. Users can override the default spectrum.

All programs except the Loki class are based on direct solutions (Figure 1). Thus each additional transmitter position only requires an additional 2% of the computation time required by a single transmitter. Typically, for time-domain modelling, the Leroi (Figure 4) class runs in less than a minute. The Arjuna (Figure 3) and Samaya (Figure 2) class models usually complete within half an hour for time-domain work. Because of the huge matrices generated by the Loki, it is necessary to use iterative solutions. Thus each new transmitter position requires a separate solution. For a 60 000 cell model, Loki requires two minutes per frequency per transmitter position.

How accurate are these modelling programs? The thin sheet assumption underlying the Leroi class is accurate as long as the incident wavelength is less than half a skin depth. This means that the simulation should be accurate for rather thick targets of moderate conductivity; e.g. paleaochannels, but simulations of extreme conductors will be accurate for only very thin targets. The Arjuna class, based on 2D models, will be accurate as long as the footprint of the incident wave does not exceed the length of the target being modelled (Sugeng et al. 1993). The Marco (Figure 5)

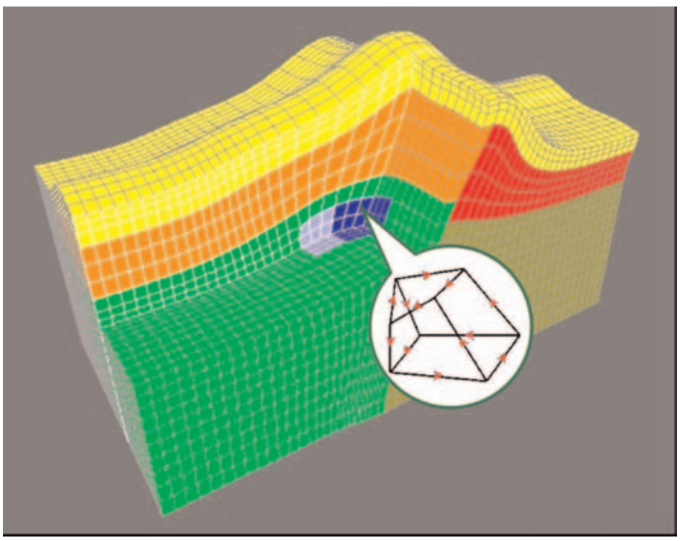

Fig. 1. *A 3D LokiAir model with a cut-out to show the interior structure. The shape of a typical edge element, defined by a tangential vector shape function is also shown.*

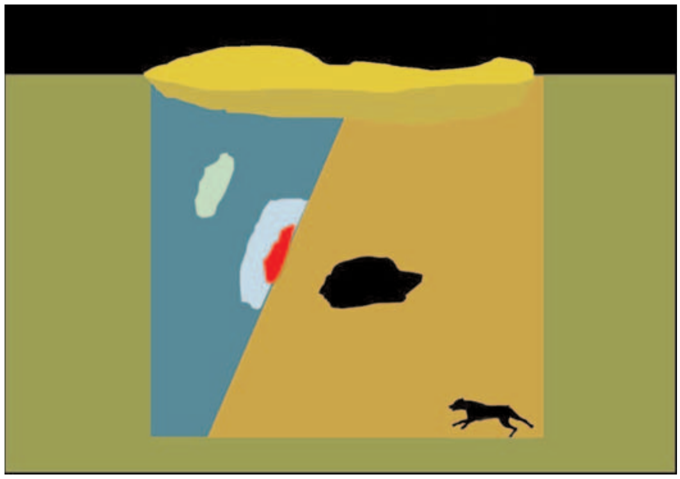

Fig. 2. *A Samaya model consisting of a heterogeneous region embedded in a uniform host. The non-flat topography is part of the region and must be confined to it.*

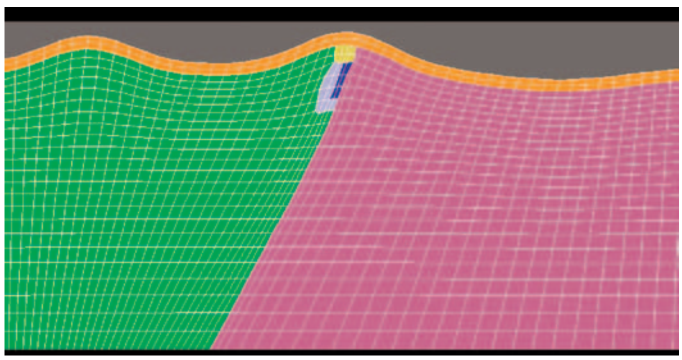

Fig. 3. *A 2D Arjuna model showing a target in an ultramafic zone under a paleaochannel at the edge of a fault. In Arjuna, topographic features can extend the length of the modelled region.*

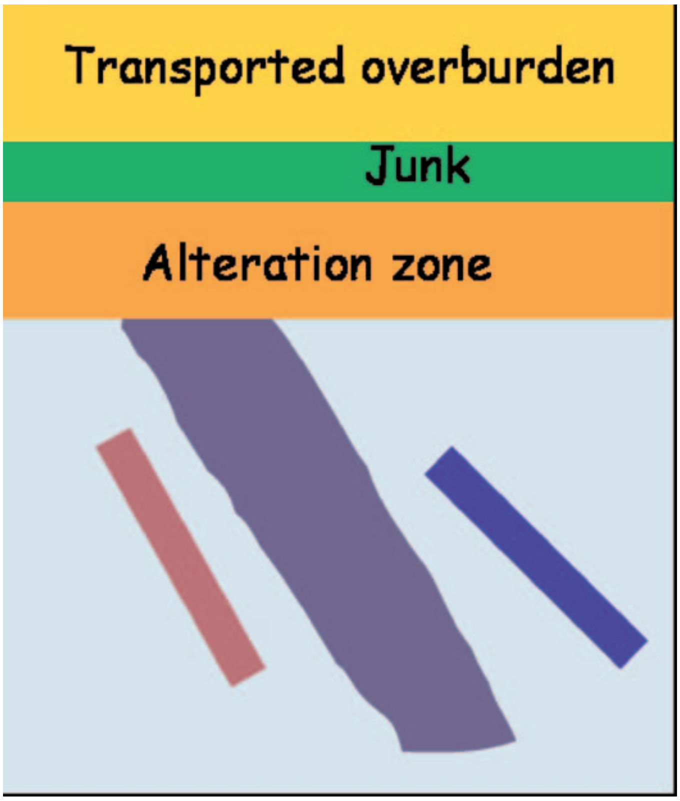

Fig. 4. *A Leroi model showing three dyke structures under three uniform layers. Although the central dyke looks quite thick to be modelled with a thin-sheet approximation, what counts is the skin depth thickness rather than the raw geometrical thickness. Thus, Leroi can used to simulate quite thick dykes of low to moderate conductivity.*

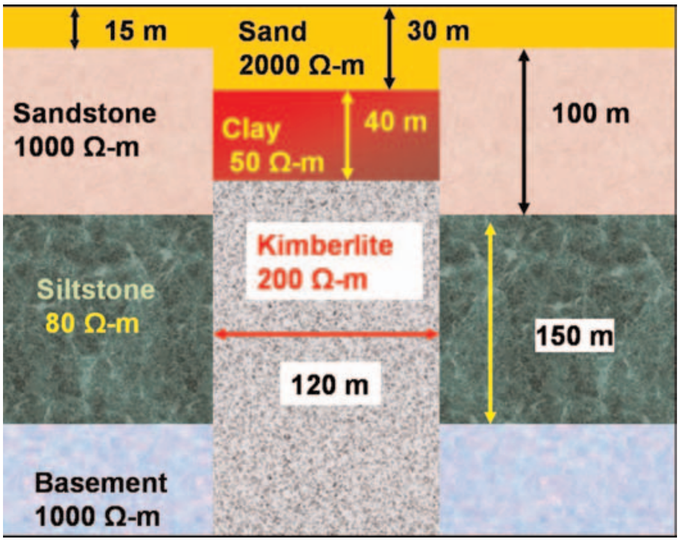

Fig. 5. *A Marco model of a kimberlite setting. As prisms can't cross layer boundaries, two prisms were used for the kimberlite, one for the clay alteration and one for the sand channel.*

class is based on the 3D integral equation method which is usually accurate as long as the resistivity contrast doesn't exceed 300 to 1. The Samaya class and Loki are based on edge-finite-elements. They are expected to be accurate for any conductivity contrast as long as the model is properly discretised (Sugeng and Raiche 2004).

Over the years we have done extensive testing using models that could be computed in common by each program; e.g. vertical and horizontal dykes. Since these were based on very different algorithms, it is most improbable that they could exhibit the same error structure. The results for common models were in agreement over regimes where the assumptions underlying each were valid, leading us to believe that the programs were producing correct results. On those occasions when program output was matched with results from known deposits, the agreement was satisfactory. Comparison with physical scale modelling was seldom useful because of the difficulty in eliminating errors in such modelling.

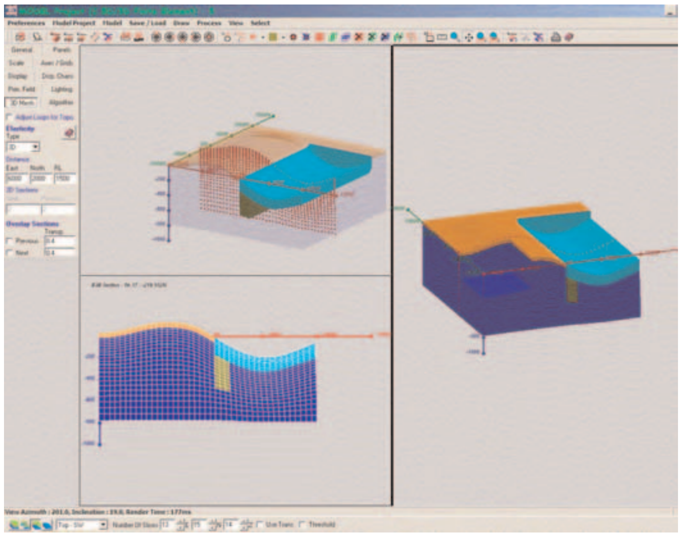

Fig. 6. *Using Maxwell to set up a 3D Loki model; separate windows are used to show a section view, the wire-mesh structure and the actual 3D structure.*

When setting up the control files to activate the programs, either through the Maxwell graphical user interface (Figure 6) or a text editor, the user specifies several seven-component lithologies: resistivity, conductance, relative magnetic permeability, relative dielectric constant and the three Cole–Cole parameters. One then populates the structure of the model with the appropriate lithology either using the painting tool of the GUI or by text. The Leroi and Marco class programs have been used extensively because they are easy to set up and require little expertise to use. The control files for the mesh-based programs require a lot more practice to set up, especially for the Loki class where one has to scroll through layers to paint in the 3D model. Runtime efficiency demands that one use the most parsimonious mesh consistent with achieving accuracy. This requires the use of GUI tools to deform the mesh to conform to geological structure, adding more cells near conductivity boundaries and redistributing existing mesh points. The creation of Loki was a major achievement but it will mostly go unused for the above reasons.

Inversion

Most of the P223 project series was devoted to developing modelling methods. The exception to this was the development of Grendl in the early 1980s, the first program ever developed for time-domain EM inversion (Raiche et al. 1985). This was later extended to produce the AEM inversion program Airbeo.

At the start of P223F, the final project, we set ourselves the goal of producing inversion programs that would take no more than one day to run on a high end laptop. Obviously those based on layered earth inversion (Airbeo and Beowulf) would run in a matter of minutes. Those based on thin sheet models (Leroi and LeroiAir) usually took no more than an hour.

We also developed inversions for ArjunAir (2.5D), SamAir (compact 3D finite-elements) and LokiAir (full domain 3D). Unfortunately, we were not able to complete inversion capability for the ground and downhole programs SamAir and Loki before the end of the project. This capability exists in prototype form only.

Although LokiAir inversion would seem to be an exception to our 24 hour limit rule, it was developed for sponsors who were using parallel systems. Since a 60 000 cell LokiAir model required less than two minutes per frequency per source position, given enough CPUs and memory, one could complete a full-blown full domain 3D inversion in less than an hour using the CPUs found in high end laptops.

The inversion for all model classes was based on the philosophy of reducing ambiguity and computation time by inverting only for those parameters that can have significant effect on the data derived from that model. The methodology, based on the damped SVD Gauss-Newton approach of Jupp and Vozoff (1975), is virtually the same across all programs except for the techniques used to compute the sensitivity matrix.

For 1D and 3D thin sheet models, the sensitivities are computed by finite-difference parameter differentiation. For 2.5D and 3D limited domain models, the sensitivities are computed using the reciprocity method. For 3D full domain models, the sensitivities are computed using the domain-differentiation method. Taking into account the fact that the variation in the dynamic ranges of both the EM data and the resistivity models are very large, the sensitivity matrix is constructed as a measure of the percent change in response due to a percent change of parameter. This negates the need to introduce artificial weighting to balance the dynamic ranges of the different data channels and model parameters. Any data weighed by the user is solely on the binary basis of being either accepted or rejected. Rejection can be applied to all data at specified stations, all data at specified channels or at user defined stations and channels. Data of magnitude less than the corresponding channel data noise floor are automatically rejected.

The inversion procedure begins by computing updates to those parameters that have a significant influence on the data, whilst damping the effect of the rest. As it proceeds and the misfit is reduced, the damping factors are relaxed to admit contributions from less important parameters. This serves to minimise the contributions of unimportant and irrelevant model parameters whilst preserving the contributions of important model parameters. The user defines the a priori geoelectrical model and any constraints via a lithological model which should reflect geological prejudice. The definition of a lithology is inclusive of resistivity, magnetic permeability, permittivity and all Cole-Cole parameters. Options for constraining model parameters include a user defined elasticity and the enforcement of soft upper and lower bounds.

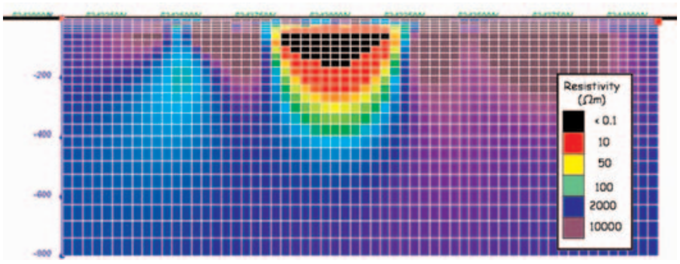

Fig. 7. *ArjunAir inversion of Dighem data over the Ovoid, courtesy of CVRD Inco & Condor Consulting. The extreme conductivity of the target and the low flight path of the helicopter meant that the 2.5D condition that the footprint of the target was not violated. Even though the target was an extreme conductor, the ArjunAir inversion was able to delineate its shape with depth from the currents that flowed around it.*

Earlier, I mentioned that ArjunAir was accurate as long as the footprint of the source excitation did not exceed the length of the model. Figure 7 shows a successful inversion of Dighem data from an extreme conductor.

Conclusion

The AMIRA P223 project series has come a long way over the past quarter century and delivered an impressive range of software to its sponsors. It is the product of many talented people from all over the world. In a time when incrementalism was scorned in favour of great leaps forward, its incremental progress from project to project led to major step change in our ability to understand the EM response of the earth to exploration equipment. Finally, it is at an end.

Acknowledgments

The P223F project might never have eventuated without the help of many people from around the world over the preceding decades. Peter Weidelt from Braunschweig, gave us the thin sheet algorithm upon which the Leroi class is based. Jerry Hohmann and Luis Rijo gave us their initial 2.5D program that served as the basis of Arjuna. Frank Morrison, Don Pridmore and KiHa Lee from Berkeley, gave us the finite-element, integral-equation hybrid prototype upon which the Samaya class was based. Keeva Vozoff and Dave Jupp from Macquarie gave us the inversion concepts and SVD subroutines that we employed in all of our inversion programs. When he joined our group, Zonghou Xiong brought with him what we thought was the world's best 3D integral equation program. Once it was restructured and changed to fit our framework, it became known as Marco and was modified to create MarcoAir.

Andrew Bennett, part of my first group, converted me to the logic of structured programming and did a lot of work on the public domain 2D and 3D resistivity programs of Abhijit Dey and Frank Morrison. He and Pravin Gupta, who visited us from Roorkee, did much of the early work of developing Samaya. Kim McAllister, who was part of our group, was instrumental in putting together the elements of the first version of Grendl.

Neil Flood, another group member, designed the first graphical user interface for our programs. This later became the basis for Encom products SiroEx and EM Vision. Steve Mann from Encom was the architect of EMGui, a GUI that allowed us to make use of the mesh-based programs we had created. Andrew Duncan and Allan Perry from EMIT brought us to a new level when they modified Maxwell for the P223E and P223F programs. For the first time, one environment could be used for setting up control files, running programs, visualising output and performing inversion.

Fred Sugeng had the astonishing ability to take other peoples programs, find their errors and clean the structure so that they ran up to an order of magnitude faster. After joining the group twenty years ago, he played a major role in the development of almost all the P223F programs. As a finite-element specialist, he introduced the concept of edge finite-elements that made it possible to model very high contrasts without resorting to the staggered grids

required by 3D finite difference programmers. Fred was the main designer for Loki.

After joining us as a postdoctoral fellow, Glenn Wilson had the prime responsibility of adding inversion capability to the mesh-based programs by combining them with the existing inversion subroutines. He devised the crucial sensitivity subroutines. These were based initially on the reciprocity method. He later devised a domain differentiation method for constructing sensitivity matrices that was more efficient for ground based inversion than the reciprocity method.

Joe Cucuzza from AMIRA deserves much credit for helping to form and manage the nuts and bolts of the consortia for each successive project.

I would like to thank the people from the more than fifty companies (many of which no longer exist) that have supported the project since inception: Aberfoyle, AGSO, Amax, Anglo American, AngloGold, Anglovaal, Aquitaine Minerals, AurionGold, Barrick, BP Minerals, BP, BHP, Billiton, BHPB, British Geological Survey, Cameco, pmd*CRC, Carpentaria, Chevron Minerals, Cominco, CRA, CVRD, DeBeers, Dighem, DSTO, Esso, EZ, Fugro, Geoex, the Geological Survey of Denmark and Greenland, the Geological Survey of Finland, GeoPeko, Geoterrex, Getty Oil, INCO, ISCOR, MIM, Newmont, North, NSW Mineral Resources, NT Minerals and Energy, Pancontinental, Pasminco, PNC, Placer Dome, Rio Tinto, RTZ, SA Mines and Energy, Seltrust, Shell, Stockdale, Sumitomo, Western Metals, and WMC.

Finally, in common with many of the scientists who made CSIRO what it was during its first 75 years, I would like to express my regret at what it has become over the past decade (Gare 2006).

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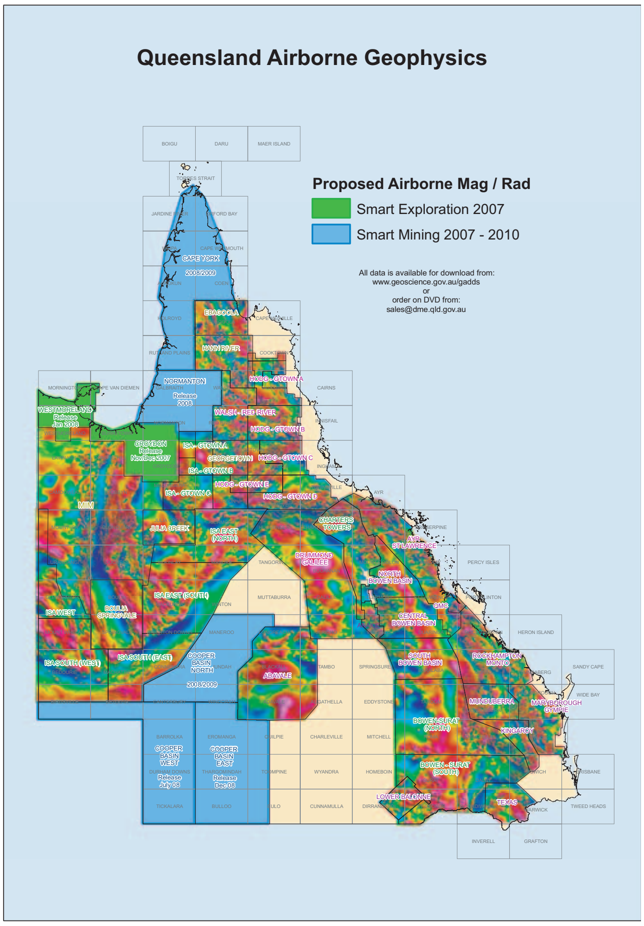

Fig. 7. *Queensland Airborne Geophysics. The image shows the TMI anomalies from the available data sets and the areas planned for further work though 2009.*

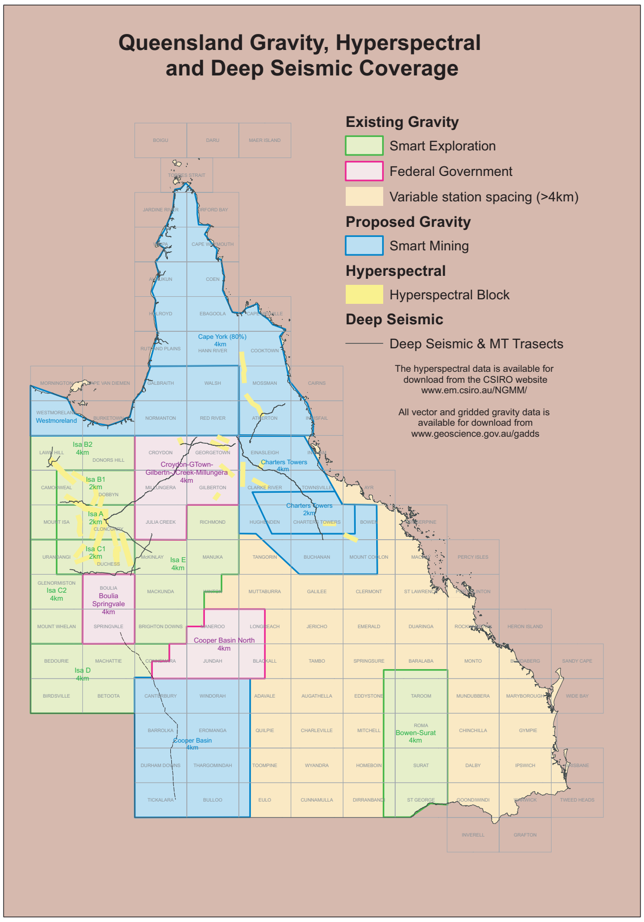

Fig. 8. *Queensland Gravity, Hyperspectral and Deep Seismic Coverage.*

Preliminary results from marine seismic survey GA302 over Capel and Faust Basins

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Summary

Data from 50 sonobuoys were recorded over the Capel and Faust Basins, 800 km to the east of mainland Australia in water depths of 1500–2000 m, during a 2006 seismic survey for Geoscience Australia. These data were interpreted and forward modelled by ray-tracing to provide an estimate of P-wave velocities in the upper sedimentary section and hence constrain estimates of sediment thickness. Also recorded were gravity and magnetic anomaly data which, in conjunction with the very high quality seismic reflection data, provided additional constraints upon the velocity models. Typical ranges in four model layers below water were: 1.9, 2.3–3.0, 3.6–4.7 and 5–5.3 km/s. Gravity models based on these results were compared to features identified on depth-converted seismic reflection lines and indicate that sediment thickness at densities approximating 2.3 t/m^3 may reach 5 km in several localities.

Introduction

Geoscience Australia completed a seismic survey over the Capel and Faust Basins in the Remote Eastern Frontiers (REF) region during the summer of 2006–07, to commence an appraisal of their hydrocarbon potential. The survey (GA302, Figure 1) was the final phase of the Australian Government's 2003–07 New Petroleum Programme to support subsequent acreage releases and promote exploration of these remote frontier basins lying 800 km east of Brisbane. The survey collected 5920 km of high-quality 106-fold 2D seismic reflection data using an 8 km streamer to 12 s TWT at 37.5 m shot interval. Gravity, magnetic and sonobuoy refraction data were also collected; the latter to estimate velocities for sediment thickness calculations.

The region is of interest as a possible frontier petroleum province, and the present work is aimed at improving the confidence of sediment thickness estimation. Lines 7, 9, 19 and 20 were examined where preliminary processed seismic reflection data were available.

Previous work

Previous seismic surveys over the area were reconnaissance lines shot on the R/V Rig Seismic in 1996 (GA177) and 1998 (GA206) by Geoscience Australia as part of the Law of the Sea programme.

Peter Petkovic

Velocity data over the Capel and Faust Basins are scarce. Two-ship seismic refraction work in the area and surrounds using explosive sources was reported by Shor et al. (1971). Moho depth was determined at 18 km at the western end of a reversed E–W profile and 29 km at the eastern end (Figure 1). Their model contains a 0.9–1.7 km thick sedimentary pile of 3.9 km/s P-wave velocity and an 8–13 km thick upper crust of 5.95–6.19 km/s. They noted that this was indistinguishable from crustal velocity data from eastern Australia and tentatively concluded that the province is a continental fragment. The lower crust velocity was computed at 6.82 km/s.

A synthesis of work over the REF province was prepared by Van de Beuque et al. (2003) who concluded, on the basis of the compiled data and pre-existing models (e.g. Gaina et al. 1998), that the region is underlain by continental crust (possibly Palaeozoic New England Fold Belt equivalents) detached from the Australian mainland during Tasman Sea rifting from the Late Cretaceous. Their subdivision places the Faust Basin in a 'central rift province' characterised by irregularly block-faulted basement, and the neighbouring Capel Basin in a 'western rift province' where basement is similarly faulted but the sediments are considerably thicker. To the east lies a 'planated basement province' where the sedimentary section is thin. Prior to GA302, data quality has not been adequate to define internal basement structure.

The present study utilised seismic reflection, refraction and potential field measurements from GA Survey 302 to examine the velocity structure of the sedimentary pile in numerous limited-area depocentres and hence allow a more reliable estimate of sediment thickness, a critical parameter in assessing petroleum potential.

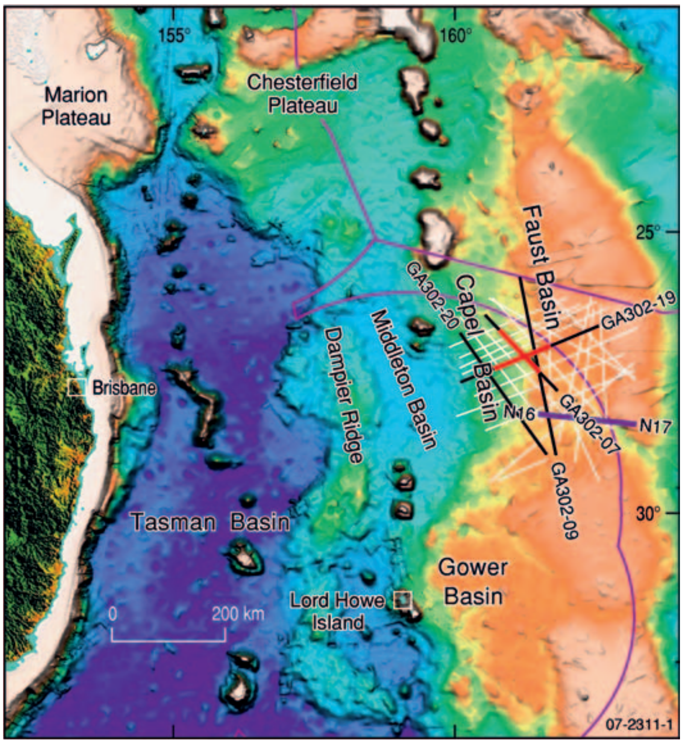

Fig. 1 . *Location of GA302 (white) with lines 7, 9, 19 and 20, the subject of this report (black), and portions of lines 07 and 19 (red) shown in Figure 2. A refraction transect from Shor et al. (1971) is in blue. Bathymetry image after Webster and Petkovic (2005).*

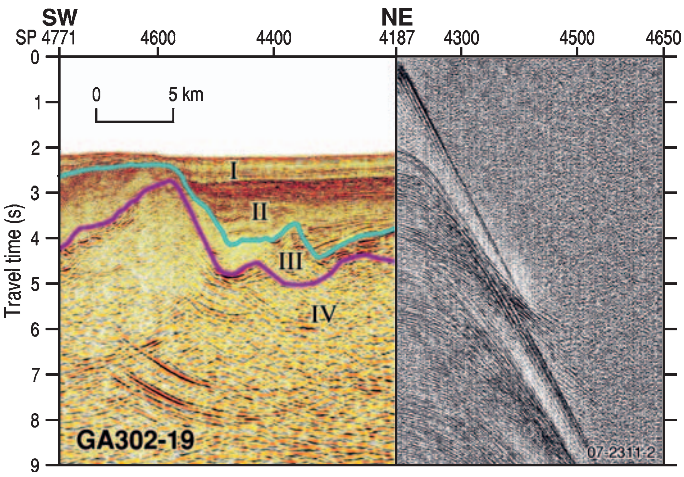

Fig. 2. *Seismic reflection records for parts of GA302-07 (SP 2330-5000, upper) and GA302-19 (SP 3560-6230, lower), showing a preliminary classification of reflectivity patterns into four types (I–IV) discussed in the text. Horizontal extent is 100 km.*

Seismic reflection data

Seismic reflection data available from preliminary test processing were converted to depth using smoothed stacking velocities. Two segments from the central part of the survey area (Figure 1) are depicted in Figure 2. Seismic reflectivity patterns are grouped into four packages:

(I) The shallowest sub-sea floor sequence is about 500 m thick and has well-defined parallel layering. Thickness is fairly constant, although somewhat thinner over basement highs. Interval velocity from stacking velocities is <2000 m/s for this layer.

(II) Beneath this package is a similarly highly stratified sequence but with high amplitude parallel events in its upper part. This sequence fills hollows and pinches out to zero thickness at the margins of the highs on which it rests. High amplitude events tend to dominate the upper part. The combined thickness of the type I and II shallow sequences reaches 2200 m in the depressions. The interval velocities computed from stacking velocities are 3500–4500 m/s in the deepest parts of this sequence.

(III) This unit underlies the former two packages and consists of a smooth upper surface below which is a pattern of non-linear, truncated, in places sinusoidal and high-angle events. The upper sequences meet it unconformably. Elsewhere, the upper boundary is marked by high amplitude events. The internal structure is typically highly reflective and very clear and shows considerable variation laterally. Stacking velocities cannot be used to estimate P-wave velocity in this section. A primary question for continuing work is whether III can be shown to be part of the sedimentary sequence, or whether it represents an economic basement of altered continental material.

(IV) Beneath type III may be found a package whose top is more ambiguous, but often consists of high amplitude events which are not imaged coherently in the preliminary reflection data, and the upper boundary is not simply defined.

Examples of these four types are seen in Figure 2 showing part of line GA302-19 trending ENE, which intersects Lines 07, 09 and 20. Type I and II section is thickest near SP 6600 at 2200 m and

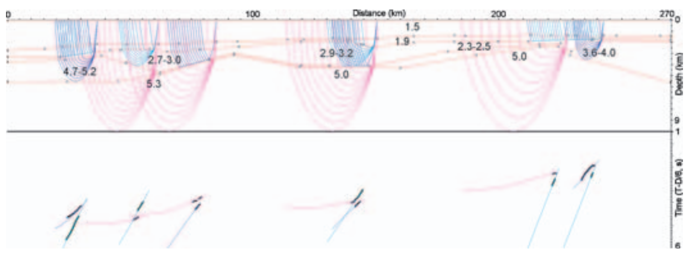

Fig. 3. *Sonobuoy GA302-19-72 after band pass filter and coincident reflection seismic data for GA302-19, on which top of possible type III and IV are shown in colour. The highest apparent velocity recorded from this sonobuoy is 4275 m/s, likely from near the top of III. Horizontal scale is 37.5 m/shot.*

type III is mostly transparent. The top of Type IV is relatively coherent in these examples, such as the fold structures near SP 4900-5400 and the steep boundary near SP 6000-6100. Type II may directly overly Type IV as evident across SP 5600-6000. Similar patterns continue to the East along this line. The Type I and II pockets reach 3 km thickness although in narrower compartments about 15 km wide, separated by Type III highs. These form half-grabens downthrown to the West.

Refraction data

Ninety six sonobuoys were deployed during the survey, however, many failed due to technical problems, leaving 54 with some useful data, recorded to maximum offsets of 17 km. A typical record is shown in Figure 3.

The data for lines 9, 19 and 20 were filtered to a band pass of 6–30 Hz and loaded into a seismic interpretation application where events were identified into initial categories according to apparent velocity and digitised. The first-arrival times were then adjusted for drift in the direction of ship motion by assuming any variation from a nominal speed of sound in water of 1500 m/s as due to currents in the direction of travel. The adjusted travel-times were then used to develop a layered velocity model by ray tracing using software based on an algorithm developed by Zelt and Smith (1992). A minimum number of parameters were used to define a spatial and velocity geometry, while achieving an approximate match between observed and computed travel-times by forward modelling. When a reasonable match is achieved, the program allows a further refinement of model parameters by inversion. Several iterations of model development are typically needed to achieve a good match between computed and observed travel-times, and may include reclassification of events at the digitisation stage and subsequent processes. Table 1 summarises the statistics.

Sparse sampling due to acquisition failures inhibited achieving continuity along modelled lines. GA302-19 had the highest sampling by six sonobuoys although the along-line distribution was irregular. Its model is shown in Figure 4.

In each of the models, a thin (~500 m) undetected layer was assumed below the sea floor, corresponding to Type I patterns in

Table 1. Sonobuoys modelled for this study, number of observed travel-time points used (N) and misfit between observed and computed travel-times in ms

Line	Sonobuoys	N	RMS (ms)
302-09	34, 36, 39, 40	540	34
302-19	66, 67, 72, 76, 77, 78	940	40
302-20	92, 93	383	38

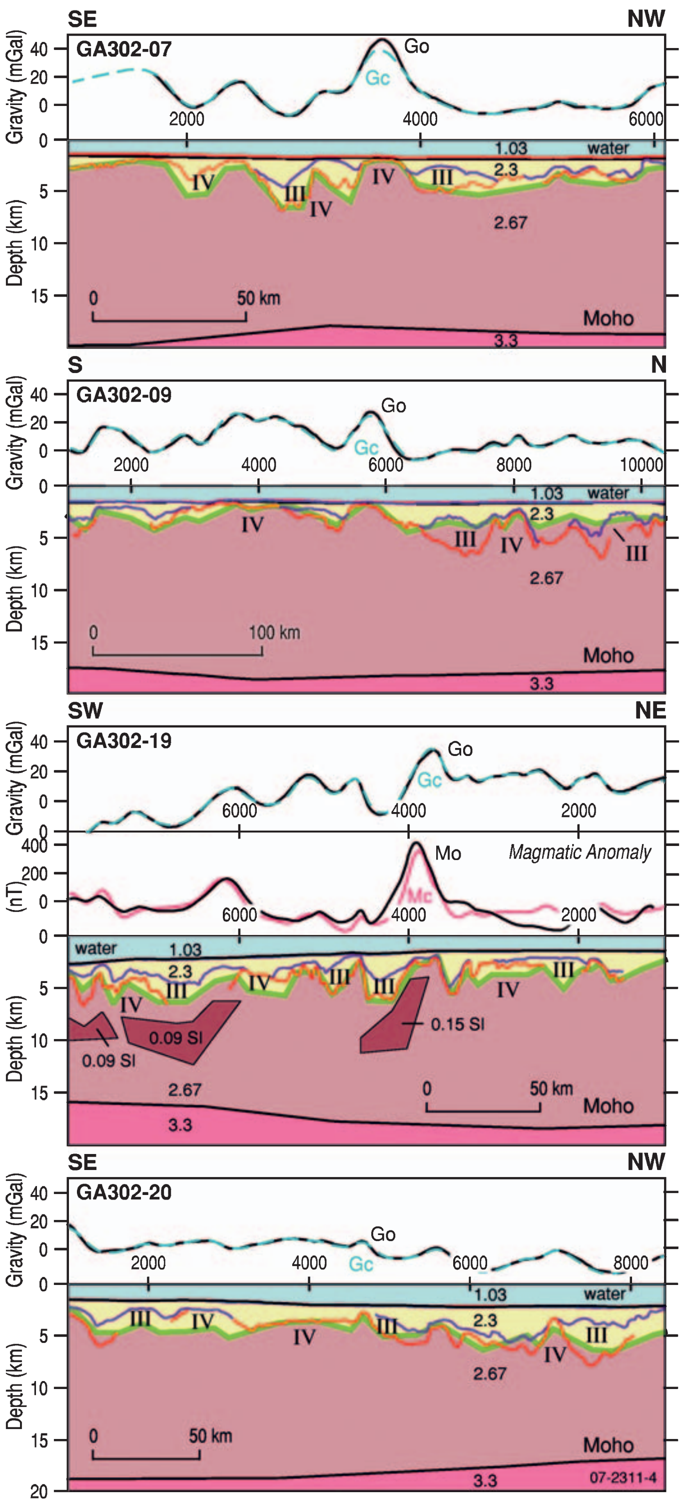

Fig. 4. *Velocity model by ray tracing for line GA302-19 along which six sonobuoys were recorded. The lower portion shows the observed travel-times as dots and computed travel-times as thin lines, with a reduction velocity of 6 km/s. The upper portion is the annotated velocity model with ray-paths.*

the seismic reflection data. Below this is a layer of variable thickness up to 2.5 km thick with velocity in the range 2.5–3.0 km/s. A fourth layer of variable thickness up to 2 km thick is modelled on lines 302-09 and 302-19 but not on 302-20. This layer has velocity 3.6–4.0 km/s but increases to 4.7–5.2 at the western end of 302-19. The lowermost layer is modelled at close to 5.0 km/s near its upper boundary.

Potential field models

An attempt was then made to estimate the depth to the most significant density contrast between the reflectivity types identified in the reflection seismic data and hence estimate the likely depth to basement. The velocity models gave some confidence that the stacking velocities were a reasonable approximation to P-wave velocities, at least to the shallow depths penetrated by refractions. Density models were constructed for the four lines studied by modelling the gravity field and compared to the depths to top of III and IV computed from stacking velocities (Figure 5). The ‘sediment’ layer density (2.3 t/m^3) was chosen to correlate to a velocity of 3300 m/s from Brocher’s (2005) relationship, the approximate average interval velocity from stacking velocities for this part of the section. Mantle (3.3 t/m^3), crust (2.67 t/m^3) and water (1.03 t/m^3) comprised the other layers. The background image shows bottom of water, top of III (blue) and IV (red). The bodies of the models are polygonal prisms with 500 km thickness, and hence the models do not account for out-of-plane density variations, which may be significant in this area.

The approach taken was to match the observed and computed gravity as closely as possible using the Moho with minimal variation to account for the regional field. No information is available on Moho topography; however, depth to Moho was estimated from the work of Shor et al. (1971). Following this, consideration was given to the depth to the modelled 2.3/2.67 t/m^3 boundary, in comparison to the depth to top of II and IV.

The models generally place the 2.3/2.67 t/m^3 density contrast (i.e. ‘basement’) near the top of type IV. This allows some optimism that III may be of sufficiently low density to warrant inclusion as part of the economic sedimentary package, although there are significant discrepancies in several places (e.g. the northern end of Line GA302-09 where the onset of density 2.67 t/m^3 is along the top of III). It is not possible at this stage to determine whether discrepancies between model basement and seismic pick of type IV is due to along-line density variations, out-of-plane 3D effects, incorrect identification of reflection boundaries, or variation in compaction of II, and these issues will be the subject of further investigation.

Line 302-19 also has complete magnetometer coverage, and an attempt to model the major anomalies (SP 3900 and SP 6100) has been made.

No data are available on which to base an estimate of magnetic body parameters. All we can say is that seismic data are replete with high amplitude events characteristic of magmatism. Van de Beuque et al. (2003) summarise and describe the several lines of evidence for the existence of igneous facies (acid to intermediate volcanics and basalts) in rocks of the province. The prominent anomaly near SP 4000 is over a basement high which on the basis of this model is possibly of volcanic origin. The lesser anomalies are approximately accounted for by the top of basement. The exception is across SP 2000-3000, where the model response is nearly 200 nT greater than observed. Again it is not possible to say at this stage whether this is due to along-line variations or out-of-plane effects, both of which are likely.

Conclusions

The preliminary review of the seismic reflection data and the gravity modelling suggests that the top of type IV is close to a modelled density increase from 2.3 to 2.67 t/m^3 and hence may represent the top of economic basement. However, the

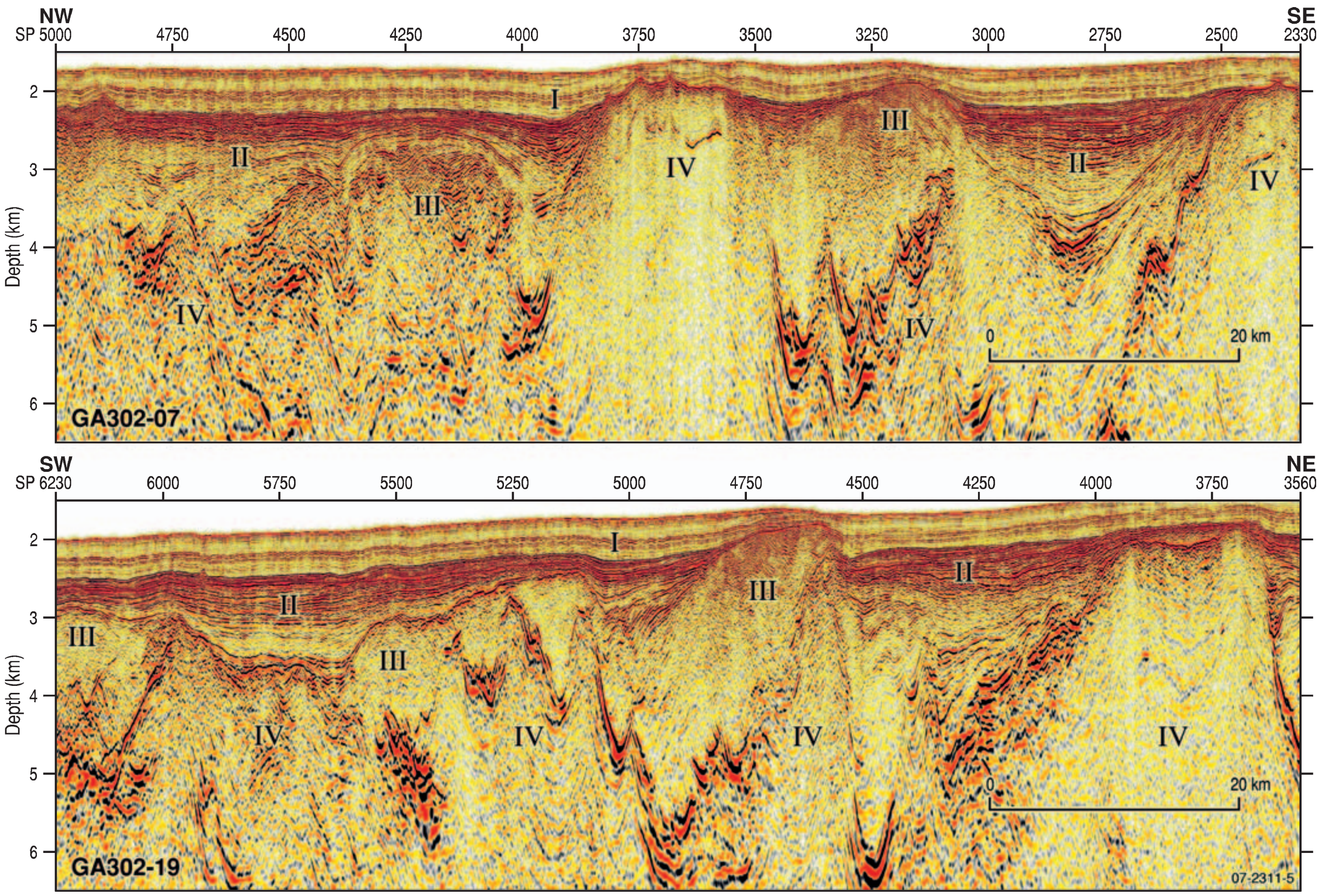

Fig. 5. *Density models in four layers where the 2.3/2.67 t/m^3 boundary (green) was chosen to match the observed gravity (G_O). A comparison of this with top of types III (blue) and IV (red) indicate model basement (green) generally follows IV. Horizontal scale is 37.5 m/shotpoint.*

reflectivity pattern within type III is discontinuous, is tilted, fractured and non-linear, and exhibits an inhomogeneous character suggestive of an older basin sequence deformed by compression. Both III and IV show numerous instances of highly reflective events which may be signatures of volcanic sills, dykes or flows. The magnetic data modelled along GA302-19 suggest also that massive magnetic bodies may be present at depth. These features are indicative of the complexity of structures in the section, which will require careful analysis to arrive at an assessment of geological history and hydrocarbon prospectivity. In the absence of a final interpretation of basement depth on seismic reflection sections it would appear, from this preliminary analysis, that sediment thicknesses of up to 5 km exist in some depocentres.

Acknowledgments

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Kimberlite exploration using integrated airborne geophysics

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Summary

Airborne magnetic and electromagnetic surveys together with kimberlite indicator mineral geochemistry have been standard practice in the search for kimberlites. The recent advent of the airborne gravity gradiometer (AGG) showed that airborne gravity gradiometry could also be a successful tool in kimberlite exploration. The installation of a digital AGG system on a helicopter led to the first airborne gravity gradient cum magnetic cum electromagnetic survey. The survey was flown over the central part of the Ekati tenement within the Lac de Gras kimberlite province. Each of these three geophysical methods relies on a different physical property contrast for its success. A selected sub-area shows that no one method would have identified all known pipes. But all known pipes would have been discovered by integrating all three data sets. The pipes in the selected area are associated with conductivity and/or gravity gradient anomalies; a few with magnetic anomalies. New data alone are not sufficient to guarantee success in a mature exploration environment. The geophysical data were individually inverted to create 3D density, magnetic susceptibility and electrical conductivity models. Integrating and applying classification techniques to the three 3D models was used in the generation of new targets. Drill testing of the targets has begun leading to the discovery of a new pipe.

Introduction

The diamondiferous kimberlites of the Lac de Gras kimberlite province, Northwest Territory, Canada, were discovered in 1991 (Fipke et al. 1995). The exploration for diamondiferous kimberlites was spurred on by the discovery of anomalous mantle-derived heavy mineral indicators in till samples near Exeter Lake. High-resolution aeromagnetic and airborne electromagnetic surveys combined with kimberlite indicator mineral geochemistry contributed directly to the discovery of 152 kimberlites within the Ekati property (Lockhart et al. 2004; Power et al. 2004; McElroy et al. 2006; Mustafa et al. 2006). The integration of these techniques became standard practice for further exploration in the region. Most of the kimberlites occur with surface areas of less than five hectares (Lockhart et al. 2004).

Shanti Rajagopalan

As the initially high rate of discovery declined, the challenge to find more kimberlites in what was now a mature exploration province was met by BHP Billiton in a variety of ways: new geophysical data were acquired and innovative interpretation techniques applied to their joint interpretation. This led directly to the generation of new targets and to the discovery of new pipes. In this paper we present an outline of the successful exploration strategy applied to the Central Ekati block of the Ekati tenement. We show pipe anomalies and a discovery from a selected sub-area of the Central Ekati survey (Figure 1).

Geophysical surveys

In addition to earlier high-resolution aeromagnetic and DIGHEM V electromagnetic surveys, the following data were collected over the Central Ekati region.

In July 2000, airborne gravity gradient (AGG) data were collected over the whole Ekati tenement (Figure 1) using the Falcon™ airborne gravity gradiometer on board a Cessna Grand Caravan (Liu et al. 2001). Data were acquired on east–west lines spaced 100 m apart and at a nominal survey clearance of 80 m. The fixed-wing AGG data showed that more than half of the known kimberlites have associated gravity anomalies.

Selected test areas were surveyed in 2006 using the Feynman AGG system on board a Eurocopter AS350-B3 helicopter (http://orion.bhpbilliton.com). The helicopter AGG system has several advantages over the fixed-wing system (Lee et al. 2006). The opportunity to fly lower and slower results in superior signal-to-noise ratio and better anomaly detection. The helicopter AGG data showed that over 90% of the known kimberlites in the test areas had associated gravity anomalies.

The second helicopter AGG survey was flown in 2006 over the Central Ekati block. The survey included measurements of both magnetic and RESOLVE electromagnetic data in addition to the gravity gradient survey. The RESOLVE system (www.fugroairborne.com.au) is an EM system with horizontal coplanar coils capable of measuring the EM response at five frequencies ranging from 400 Hz to 140 kHz and one coaxial coil (3300 Hz). It appears to retain the proven DIGHEM V advantages of tuned coils and long coil separation, resulting in improved signal to noise ratios for a helicopter EM system. Data were acquired on NS lines spaced 50 m apart and at a nominal clearance of 60 m.

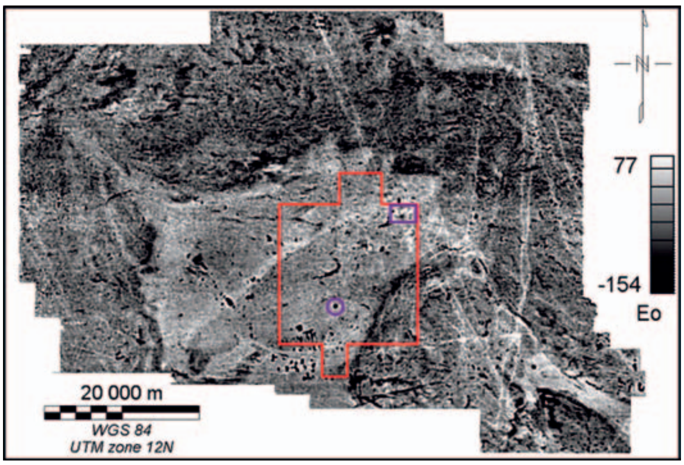

Fig. 1. *Fixed-wing vertical gravity gradient (G_{DD}) data over the Ekati tenement. The outline of the Central Ekati helicopter survey is shown in red, and the selected sub-area in blue. The circle shows the location of the Fox pipe.*

Kimberlite geophysical anomalies

Kimberlite intrusions in the Slave Craton are often, but not always, associated with a crater lake. Most pipes are characterised by a combination of distinctive physical property contrasts: higher electrical conductivity, lower density (exaggerated when the crater forms a lake); and, less often, higher magnetic susceptibility and/or remanent magnetisation. The distinctive geometry of kimberlite pipes gives rise to discrete geophysical anomalies which are readily recognisable (see Figures 2–4).

The geophysical data for the selected area show that no one method would have identified all known pipes. But all known pipes would have been discovered by integrating all three data sets. The pipes in the selected areas are associated with gravity gradient anomalies (Figure 2), electrical conductivity anomalies (Figure 3) and occasionally with magnetic anomalies (Figure 4).

However, easily recognisable geophysical anomalies had been followed up prior to the 2006 helicopter-borne geophysical survey. The identification of new anomalies and the prioritisation of previously detected, marginal geophysical anomalies was the goal of the 2006 geophysical program. Targets A and B are examples of targets in the area.

Interpretation methodology

The gravity gradient data over lakes were analysed to give an approximate water depth using a simple model which assumes that the entire gravity low is generated by water. The survey clearance was taken into account but the shape of the lake was ignored. The results were generated in a few minutes compared to the many hours involved in carrying out a full 3D inversion. The approximate lake depth map (Figure 5) highlighted sudden changes in lake depths that might be associated with a pipe crater, and that could be cross-checked against geophysical and geochemical data.

The geophysical data were inverted using proprietary inversion algorithms developed by BHP Billiton. The gravity and magnetic data were inverted to give 3D models. The electromagnetic data were inverted using a 1D algorithm, the results of which were gridded to produce a 3D model. The inversions resulted in 3D models of the density, magnetic susceptibility (remanence was not

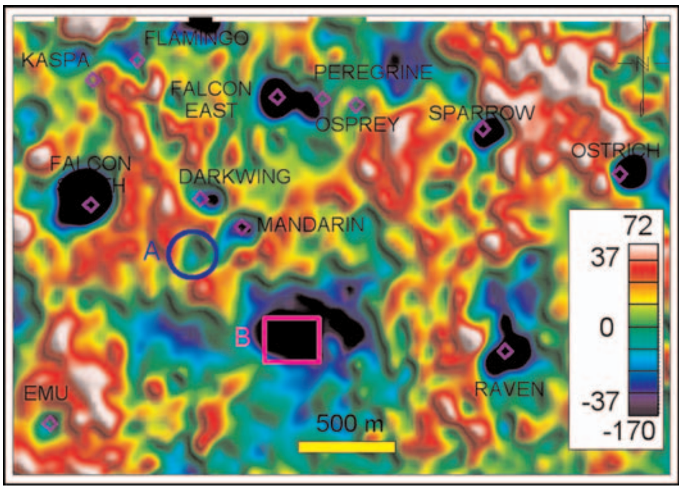

Fig. 2. *Vertical Gravity Gradient (Eö). All the pipes (diamond symbols) shown here, with the exception of Kaspa, are associated with gravity gradient anomalies. The pipe anomaly is accentuated by the presence of water. Targets A and B are shown for future reference.*

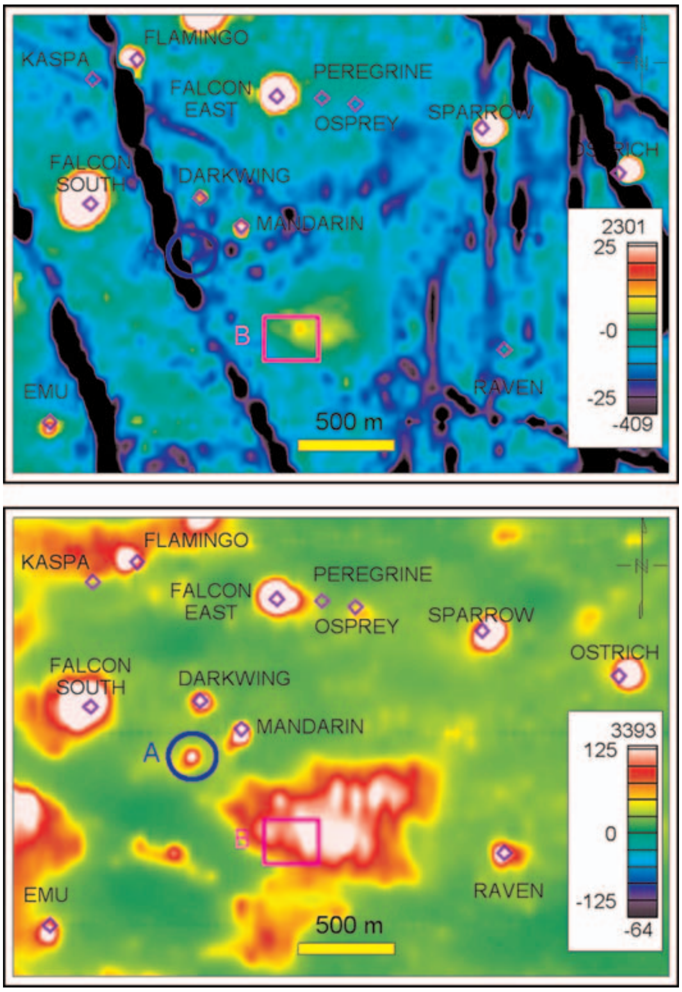

Fig. 3. *Coplanar, in-phase (upper) and quadrature (lower) 8200 Hz. Many conductive pipes show up as anomalous in the 8200 Hz data (some only in the in-phase data, some only in quadrature and some in both). Distinguishing between deep water or lake bottom sediments and pipes is only possible when evaluating anomalies at all the measured frequencies. Inverting for conductivity is the best analytical technique for interpreting the EM data. Target A has a weak GDD anomaly and discrete quadrature 8200 Hz anomaly. Target B appears more typical of a deep lake response.*

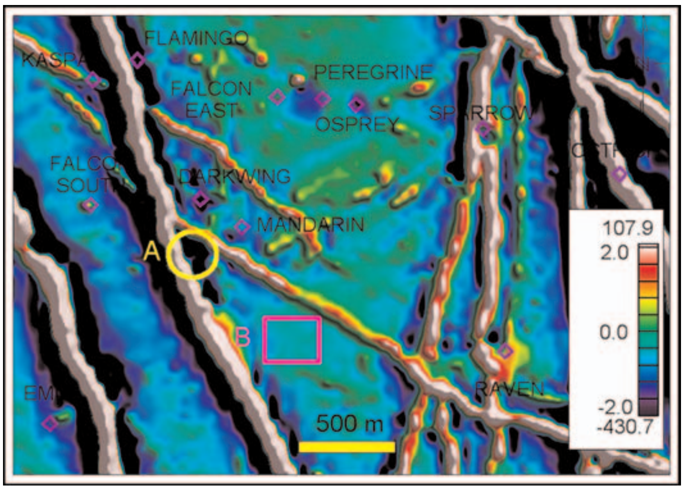

Fig. 4. *First vertical gradient of the Total Magnetic Intensity. Pipe magnetic anomalies range from discrete highs (e.g. Falcon South) to lows (e.g. Osprey where remanence is significant) to breaks in magnetic units (particularly obvious when a pipe, e.g. Sparrow and Kaspa, intrude a magnetic dyke). Note the location of target A at the intersection of two dykes.*

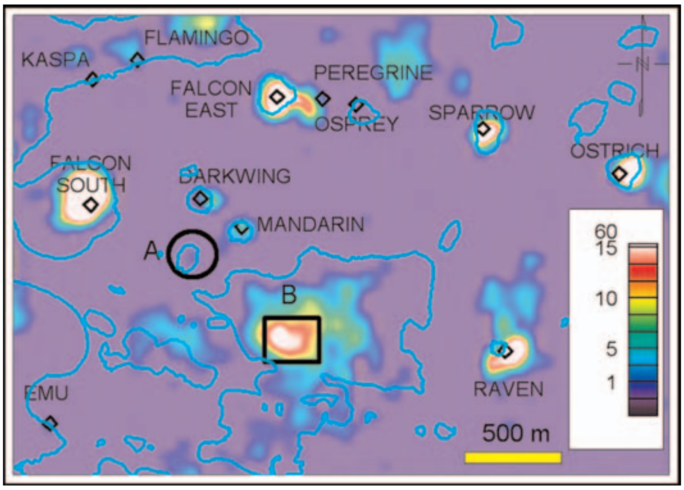

Fig. 5. *Apparent and approximate lake depths interpreted from the gravity gradient data by assuming that the entire gravity low is generated by a "vertical prism" of water. The colour scale shows lake depth in metres. The present lake outlines are shown in cyan – the lake boundaries change with time. Some lake depth anomalies extend beyond the present margins of the lakes. This is because the gravity gradient low extends beyond the lake margin. Targets A and B are also shown.*

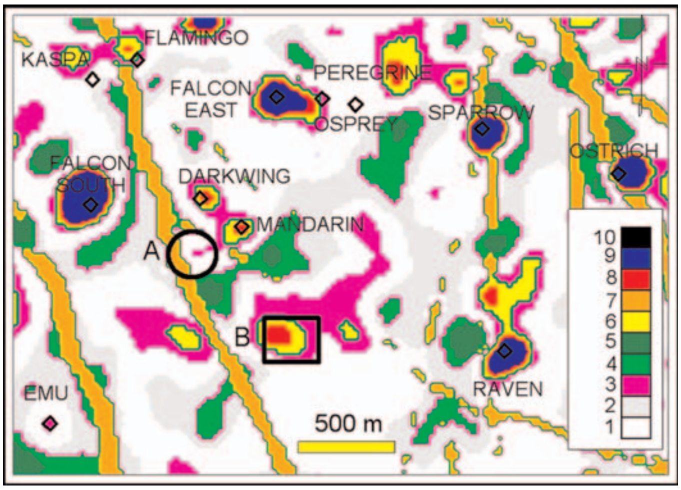

Fig. 7. *Shallow depth slice from the 3D classification model from part of the Central Ekati region. The region was divided into 10 classes, each characterised by a specific combination of physical property values. The figure is shown colour coded with each class depicted as a different colour. Class 9 is associated with low density, and classes 6 and 8 with high conductivity. The blue-red-yellow pattern (classes 9, 8 and 6) is typical of some pipes (and also of some lakes).*

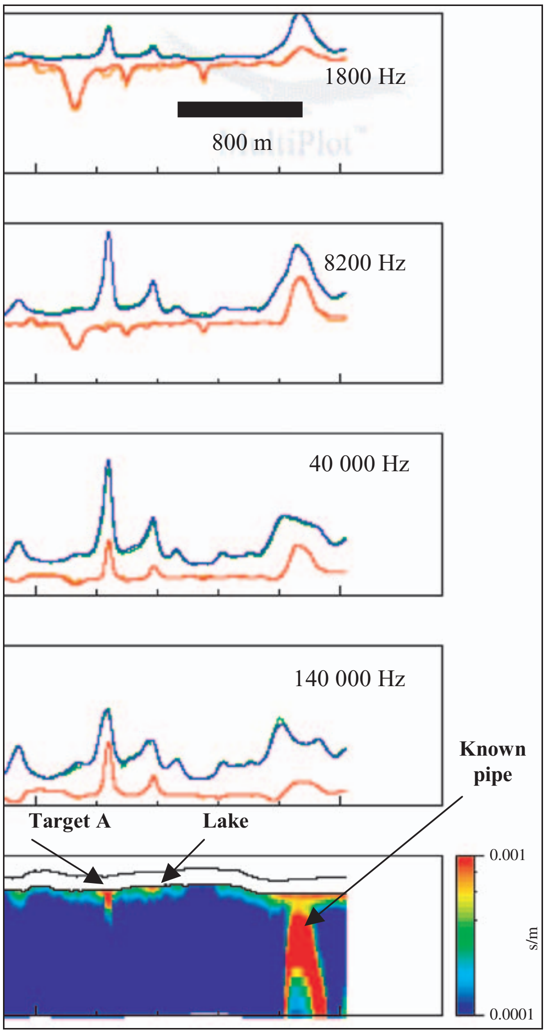

Fig. 6. *EM inversion results over target A and a known pipe (Darkwing) to the north. In-phase profiles are shown in red and quadrature in blue. The conductivity section shown over the known pipe is a classical anomaly over a conductive pipe. The "kick" associated with Target A is typical of less conductive pipes. Conductive zones associated with lakes are depth-restricted.*

taken into account) and electrical conductivity (the effects of magnetic permeability and dielectric permittivity were taken into account – see Huang and Fraser 2002). These models can be interpreted in 3D, or as depth slices or as cross-sections.

The inversion models add value to maps of the measured data because the inversions take a number of factors into account including topography and varying survey clearance. Inverting the EM data is particularly useful because of the plethora of channels to be analysed. Significant pipe anomalies are easily distinguished from lake water/sediment anomalies because the latter are characterised by surficial conductive layers whereas pipes are characterised by significant conductivity appearing at deeper layers (see Figure 6). Target A is seen to have a pipe-like response in the inversion and in the persistence of its anomaly into the lower frequencies. However, marginal conductivity and low density anomalies are, for the most part, associated with increasing depth of water in lakes, and/or with increased thickness of lake-bottom sediments. Distinction between these is difficult.

The Central Ekati 3D density, magnetic susceptibility and electrical conductivity models were classified using proprietary software to create 10 classes. The 3D classification model was cross-checked against known pipe locations to select the cluster patterns most commonly associated with kimberlite pipes (see Figure 7).

Discovery

A number of new targets were identified based on the interpretation of the helicopter geophysical data; the lake depths model, the 3D inversion models, and the 3D classification models. Testing of these targets has recently begun. Two targets are discussed here: A and B.

Target A, south of the known pipes Darkwing and Mandarin, is associated with a small but distinct gravity gradient and conductivity anomaly. Its inverted conductivity section (Figure 6) indicated a pipe. A drill hole into target A (Figure 8) intersected a new pipe, now called Redwing. Kimberlite was intersected from 84 to 188 m. A second drill hole tested the gravity anomaly east of the conductivity anomaly associated with Darkwing. The drill hole intersected a 30 m eastern apophysis to Darkwing. Target B was

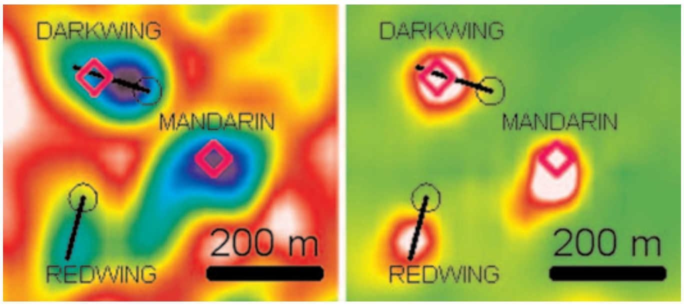

Fig. 8. *Vertical gravity gradient (left) and coplanar quadrature 8200 Hz (right) over target A and adjacent pipes (diamond symbol). The gravity gradient is in Eö and the quadrature is in ppm (white high & blue low). The images have been extracted from Figures 2 and 3, respectively. Drill holes (circle) and traces (black line) are shown. The southern drill hole tested Target A and intersected a new kimberlite, now called Redwing. The second drill hole tested the gravity gradient anomaly east of the EM anomaly associated with the Darkwing pipe and intersected a possible apophysis.*

interpreted as unlikely to be a pipe and not selected for further investigation.

Conclusions

Discovery in a mature exploration province calls for new technology and innovations. The combination of high-resolution helicopter-borne gravity gradient data together with RESOLVE EM and magnetic data provided a new data set. The prioritisation of new and of marginal geophysical anomalies was achieved through the integration of the geophysical data, the 3D inversion models, and the 3D classification procedure. A number of targets were generated and prioritised. Follow-up drilling resulted in the discovery of a new kimberlite pipe and an apophysis to a known pipe. Although geochemical data were not presented here, kimberlite indicator mineral geochemistry continues to be a primary exploration tool at Ekati.

Acknowledgments

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Continued from p. 14

Table 2. Numbers of proposals and success rates, for funding commencing in 2008 for Discovery Projects, by Administering Organisation

Administering Organisation	Proposals considered	Proposals approved	Success rate (%)	Funding over project life ($)
The University of Melbourne	406	112	27.6	38 004 295
The University of Sydney	391	98	25.1	34 497 035
The Australian National University	286	78	27.3	30 827 792
The University of Queensland	361	71	19.7	28 724 683
Monash University	358	75	20.9	27 659 169
The University of New South Wales	390	87	22.3	26 004 779
The University of Adelaide	157	41	26.1	14 143 514
The University of Western Australia	166	35	21.1	13 089 935

Using 4D seismic data to understand production-related changes in Enfield, North West Shelf, Australia*

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Summary

The Enfield oil field, located in the North West Shelf, Australia, began production in July 2006. In 2007, a 4D monitor survey was acquired to obtain a better understanding of injector pathways, stratigraphic and fault controlled reservoir connectivity, reservoir pressures and water front movement. A dedicated baseline survey was acquired in 2004 with good image quality. The monitor survey, acquired 7 months after production, is the first dedicated 4D monitor survey in Australia. In this paper we show that robust 4D anomalies are clearly evident after just 7 months of oil production. The 4D interpretation results tie well with the feasibility and modelling study and use both conventional and AVO volumes that are integrated with production and geological data.

Introduction

The Enfield oil field is located in approximately 500 m water depth in the North West Shelf of Australia. The field is currently being produced using three horizontal and two deviated oil producers, two gas injectors in the gas cap and six deviated water injectors. The field commenced oil production in July 2006.

The producing reservoir consists of two main sand intervals, a lower channel sequence and upper debrite, separated by a major flooding event defined by a 1–2 m thick shale present over most of the field. The gross reservoir ranges in thickness from 15 to 60 m with porosity typically in the range of 20–27%. The majority of the reservoir is expressed as a single peak–trough relationship on seismic, except where the reservoir exceeds 18 m (outside of tuning).

Prior to 2004, the sliver and horst blocks in the eastern part of the field were thought to be brine bearing. An AVO inversion showed

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*This paper is based on the presentation given by Megan Smith, which won the best paper award at the ASEG's 19th International Convention and Exhibition held in Perth in November 2007.

that Vp/Vs is required to discriminate oil here due to the presence of a different overlying shale relative to the main block. An appraisal well was drilled in 2004, confirming oil. This highlights the importance of AVO interpretation for fluid movement in this part of the field, hence it is included as part of the 4D study.

The Enfield baseline survey was recorded in 2004. The dedicated monitor survey was acquired in 2007, only 7 months after first oil production. Acquisition was designed using an innovative two boat configuration (Ridsdill-Smith et al. 2007). Four of the producers and five injector wells were active during acquisition. The repeatability of the survey was high with a final NRMS below 20%.

Modelling and feasibility work was conducted using acoustic logs from four appraisal wells, pressure-velocity measurements on field core and synthetics on a dynamic reservoir model (Wulff et al. 2007). These studies showed that a 4D signal should be detected after just 7 months of production. This signal is predominately due to reservoir pressure increases. A saturation effect (brine replacing oil) should also be detected if the increase in water saturation (ΔSw) exceeds 60% with respect to the *in situ* conditions.

The average reservoir pressure of the field prior to any production was around 3000 psi. During acquisition the difference in reservoir pressures due to water injection exhibited a wide range. A water sweep of up to 65% was recorded in one of the producers and no significant gas breakouts were noted.

The business decision to acquire 4D so soon after production was to better understand connectivity across the field and hence identify areas for infill opportunities, understand current injector pathways and optimise well locations for future drilling. It was also decided that an early monitor would be dominated by pressure effects making future monitoring of the field easier to differentiate saturation.

Final baseline and monitor data for 4D analysis include PreSDM full stacks, pre-stack gathers and near, mid and far angle stacks.

Methods

Feasibility study

Early feasibility work indicated that Enfield shows rock properties that are in general favourable for 4D monitoring. The Macedon sands are acoustically soft and sit at or above tuning thickness. Most of the pay can be identified with seismic amplitudes, with the exception of the highly faulted and thinner sliver block on the Eastern part of the field which requires AVO interpretation.

For the particular case of the February 2007 monitor survey, the critical risk factor was whether the 4D signal could be seen above the expected noise levels given the relatively short production time involved. In order to address that, a series of models were created by perturbing log data from four appraisal wells to represent the expected production changes (saturation and pressure). The effect of saturation change was modelled using Gassmann's equations, while the velocity dependency on pressure (or effective stress) was modelled using acoustic measurements performed on core plugs from two wells. Synthetic seismograms were computed for a

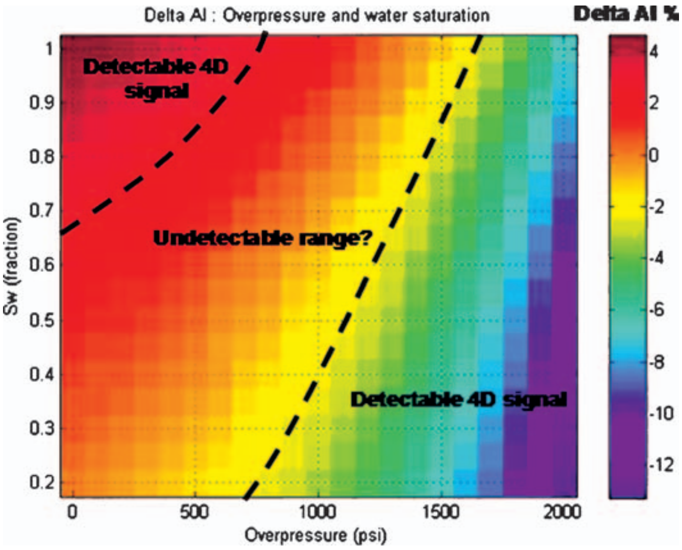

Fig. 1. *Matrix of Acoustic Impedance (AI) changes due to water replacing oil and reservoir pressure variations.*

number of pressure and saturation values and used to calculate the difference in amplitude with respect to the initial conditions. Random noise was added to these synthetics assuming a NRMS of 20%, typical of dedicated 4D surveys in the North Sea. Initial results suggested that the delta pressure signal should be clearly visible when greater than 600 psi. Detection of the delta saturation signal was expected to be a lot more challenging and visible on the synthetics when greater than 60%. There may also be areas of no 4D signal that may be due to negation of the opposing pressure increase and water saturation effects (Figure 1).

Additionally, the AVO response was also computed for different pressures and saturations. These results suggested that AVO attributes could help distinguish the effect of pressure increase from gas coming out of solution which would otherwise look similar on zero incidence (or full stack) seismic.

The analysis was further extended to include synthetic seismic computed from the history-matched (and seismically constrained) reservoir model. Elastic properties were calculated for each cell in the dynamic model using rock and fluid models that describe acoustic and elastic properties as a function of porosity, net to gross and saturation. Synthetic seismic volumes were computed

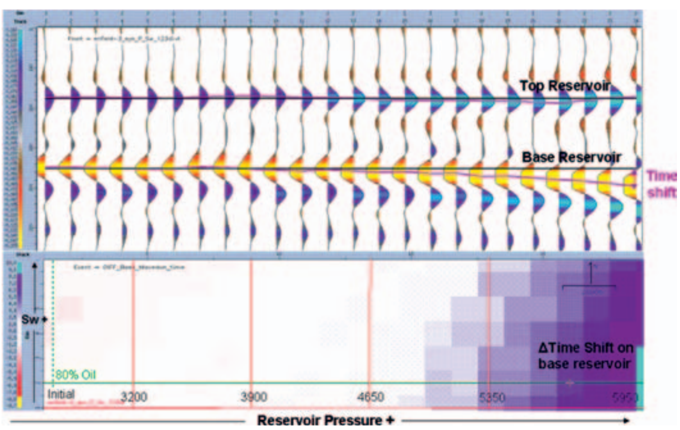

Fig. 2. *4D time shift modelling based on actual well log data. An increase in reservoir pressure results in a notable time shift at base reservoir. Time shifts >1ms begin where Δ Pressure exceeds 1000 psi. The tick marks are numbered every 20 ms.*

for the initial and repeat times, from which a difference volume was then computed and noise added in a similar way as previously described.

The effect of pore pressure increase on travel-times was also modelled using core and log data from one of the main injectors and suggested that an increase in travel-time (due to lower seismic velocities) could be expected at the base reservoir in the vicinity of the well bore when reservoir pressures were elevated by more than 1000 psi (Figure 2).

4D interpretation methodology

Our interpretation strategy consisted of: preliminary analysis (volume and horizon-based) on full stacks (Baseline, Monitor and Difference volumes) to identify the areas of major change as well as areas of no change within the producing zone. Further detailed work was done using pre-stack data to confirm and qualify the anomalies. Data quality attributes (NRMS maps, AVO goodness-of-fit and RMO residuals) were used to QC the amplitude data.

Data available for 4D analysis consisted of full stacks, angle stacks with the following ranges: 8–19° (near), 19–30° (mid) and 30–41° (far) and pre-stack gathers.

For the 4D interpretation workflow it is essential to include input and discussion from all the disciplines involved, namely the geologist, reservoir engineer and geophysicist. Modelling of the expected seismic response performed on the history-matched reservoir model was used to support the observations made on amplitude data (and vice-versa).

AVO interpretation

A prerequisite for 4D pre-stack volume interpretation is that the partial angle stacks must be aligned as well as possible. This includes the removal of any processing artefacts (e.g. residual move-out) and production-related time-shift effects observed on seismic data. Our approach included a combination of a morphing procedure to remove time-varying misalignments followed by cross-correlation of the stacked volumes. All corrections were

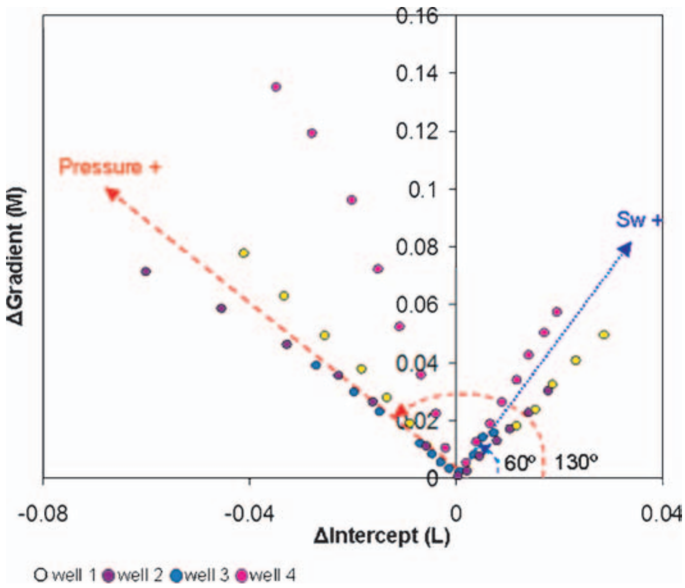

Fig. 3. *Well log modelling of increasing reservoir pressure and water saturation in 4D AVO ΔL & ΔM space. Gas replacing oil (not shown here) was also modelled and plots predominantly in negative ΔL & ΔM space.*

applied to the monitor volume with the baseline survey serving as time reference.

AVO intercept (L) and gradient (M) volumes were computed from the morphed partial stacks and used to compute pseudo-pressure and pseudo-saturation change volumes. Intercept and gradient attributes were also calculated for the reservoir interval from the base and monitor gathers and differenced to determine the effects of pressure, gas and water saturation in 4D AVO space (Figure 3). Gas replacing oil to reflect possible gas cap expansion or gas coming out of solution near the producers was also modelled but not shown in this figure. The modelling and final results showed that:

- Pressure increase is predominantly in +ve ΔM and –ve ΔL space
- Water saturation increase is mainly +ve ΔM and +ve ΔL space
- Gas saturation points dominate –ve ΔM and –ve ΔL space

Analysis of these volumes confirms that the pressure effect is significantly higher than the saturation change signal which may require seismic inversion to be properly quantified. A 4D inversion is currently underway which will address this issue. Additionally, the 4D inversion will be used to update the static model by using lithology and porosity volumes to constrain the model.

Full stack amplitude difference maps

Difference maps were made for top and base reservoir. The events were picked on the baseline and monitors separately before differencing to avoid any residual time alignment issues between the volumes. A first look at the amplitude difference maps confirmed the feasibility work in that a 4D signal is apparent after only 7 months of production. A positive difference between the monitor and baseline is interpreted as being a reservoir pressure increase, increase in GOR or gas cap movement. Conversely, a negative difference is due to brine sweep. Areas of no difference may have some production related effects that are below the detecting capabilities of the seismic outlined in the feasibility study. Amplitude difference maps were also normalised with the baseline data to account for the lower signal observed over the sliver and horst blocks. This allows for a better comparison between these blocks and the main area.

Results

The initial work focussed on the 4D interpretation in two areas of expected pressure and saturation changes. The first area describes

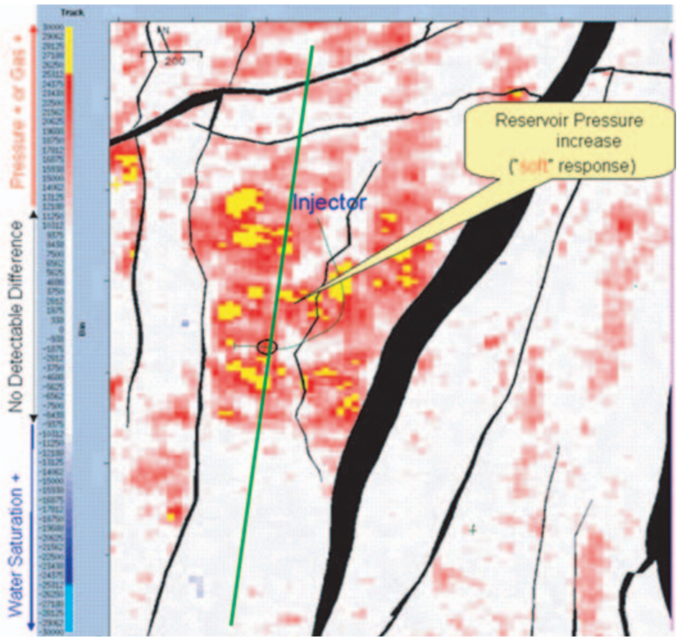

Fig. 4. *Top reservoir amplitude 4D difference map (Monitor – Baseline) showing strong, robust pressure anomaly at injector.*

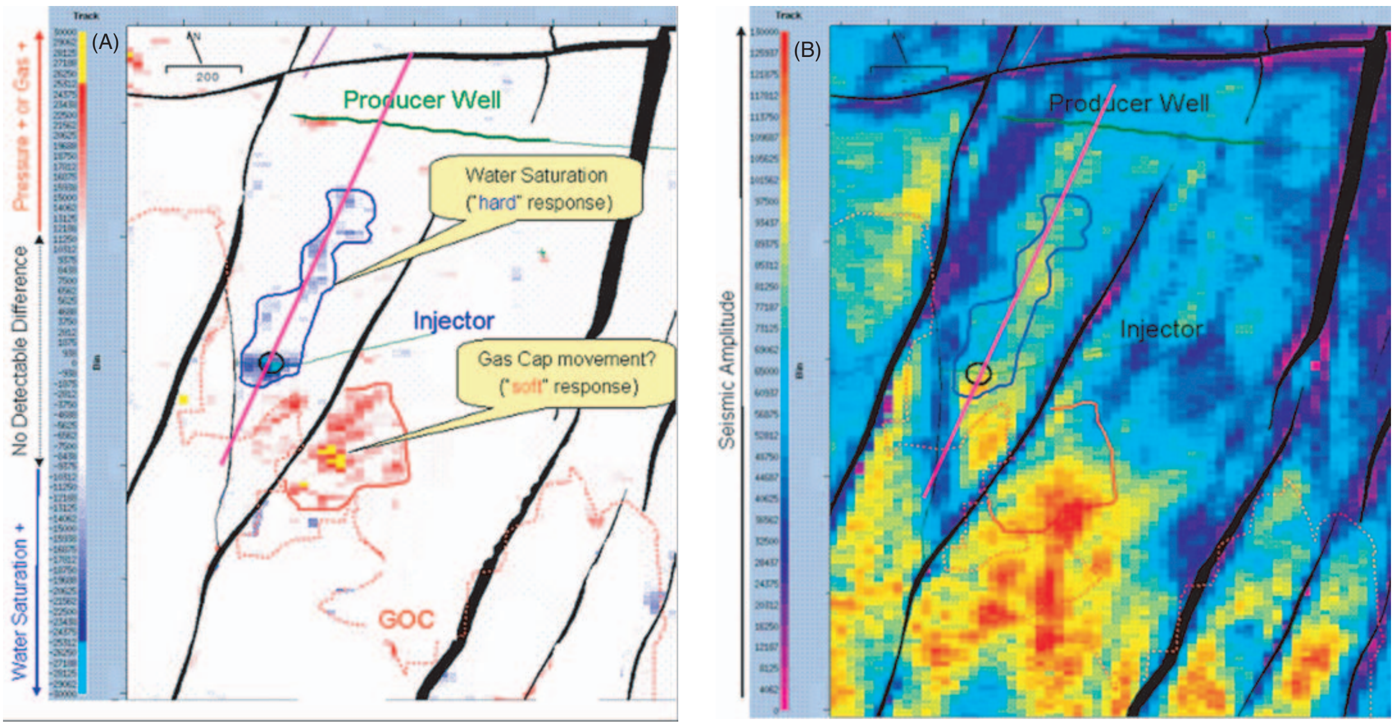

Fig. 5. *(A) Top reservoir amplitude 4D difference map (Monitor – Baseline) showing water saturation anomaly together with some potential gas cap movement. (B) Top reservoir amplitude map highlighting potential pathway of saturation sweep along higher amplitude (better reservoir development) geometry.*

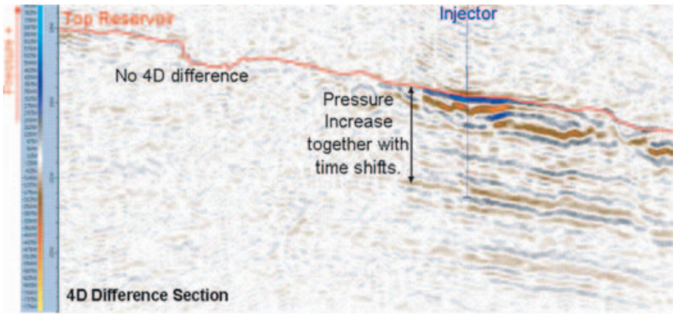

Fig. 6 . *4D seismic difference section (Monitor – Baseline) through pressure anomaly at water injector. Pressure response appears as a positive or 'softening' at top reservoir. The tic marks are numbered every 100 ms.*

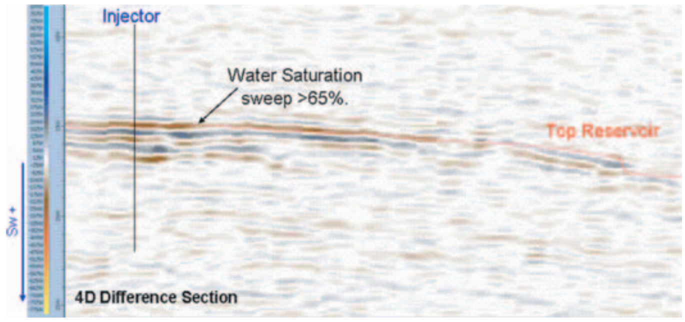

Fig. 7. *4D difference section (Monitor – Baseline) through water saturation anomaly at water injector. Water saturation response appears as a negative or 'hardening' at top reservoir. The tic narks are numbered every 100 ms.*

a water injector with a significant pressure and time shift anomaly, the second is a well with 65% water sweep.

Area 1 – pressure signal

A strong, robust anomaly is present at and away from one of the injectors and is interpreted to be a significant pressure increase (Figures 4 and 6). This anomaly is accompanied by time shifts that are indicative of pressure. As mentioned in the feasibility study, pressure increase and gas breakout appear the same on the near or full stacks therefore it is important to analyse AVO attributes to differentiate these. Gas will generally exhibit class III AVO whereas pressure will exhibit class IV behaviour. The amplitudes terminate abruptly to the south at a well defined stratigraphic edge indicating a potential tortuous pathway to the producer, also located south of this well.

Area 2 – saturation signal

After 3 months of production a water breakthrough and a rapid increase in water cut to 65% was observed in one of the producers. The well was shut-in along with the paired injector. Both wells were inactive during acquisition. The challenge of the 4D was to determine whether we could see this saturation effect. Amplitude difference maps together with seismic difference sections show a 4D anomaly, interpreted to be the saturation sweep. This helped confirm the Gassmann modelling. The anomaly is elongated with a well defined pathway directly between the injector and producer. Reservoir engineering data suggests that there is a very quick response time between the two wells. Amplitude and geological data revealed a high amplitude zone in the same shape of the anomaly that was interpreted to be good reservoir quality. This area is close to the gas cap which could have moved down dip into the oil leg, explaining the soft anomaly in the adjacent block. It was concluded from the integration of all available data that oil is swept along this narrow area and sidetracks may be required to tap into the remaining oil in the block (Figures 5 and 7).

4D AVO amplitude difference maps

Intercept (L) and gradient (M) difference maps were calculated at the reservoir interval for baseline and monitor. These attributes were differenced and projected in ΔL and ΔM space. Figure 8 shows the separation between an increase in pressure and gas that would otherwise appear the same using full stack amplitude differencing. Figure 9 shows the excellent separation between all 3 production-related effects, pressure, water saturation and gas saturation using 4D AVO interpretation.

Conclusions

The Enfield 2007 4D monitor survey is the first dedicated time-lapse seismic project in Australia. The results reveal a strong 4D response after just 7 months of oil production. The repeatability of the survey was high with a final NRMS below 20%. The 4D pressure signal is the dominant effect but water saturation changes can also be detected in certain areas.

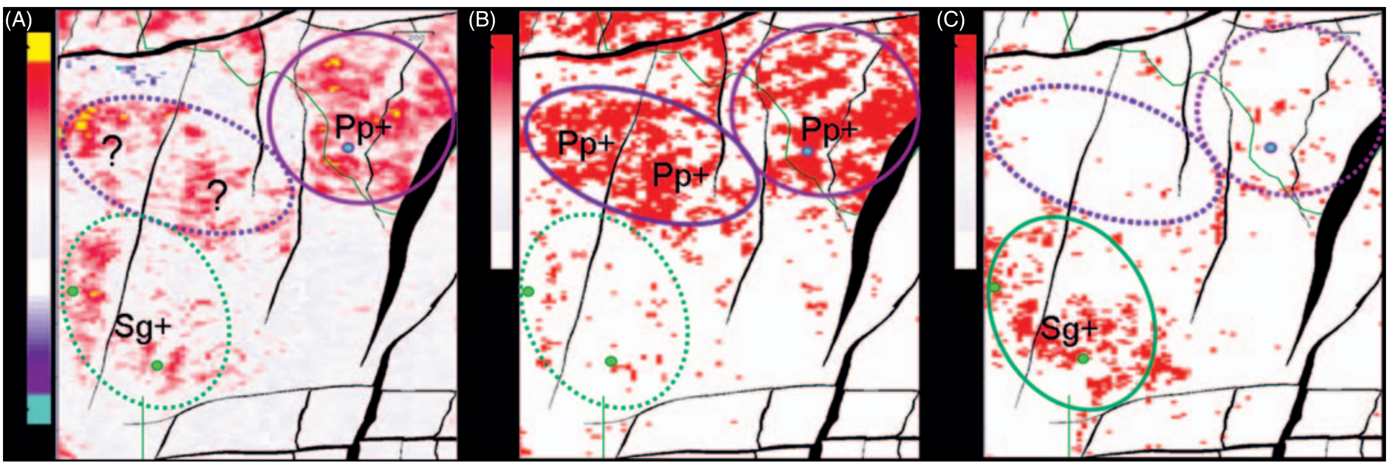

Fig. 8. *(A) Full Stack Amplitude Difference Map, (B) Pseudo Pressure Increase Map, (C) Pseudo Gas Saturation Increase Map. The maps were derived by combing AVO attributes in ΔL & ΔM space compared to the conventional full stack amplitude difference map (A).*

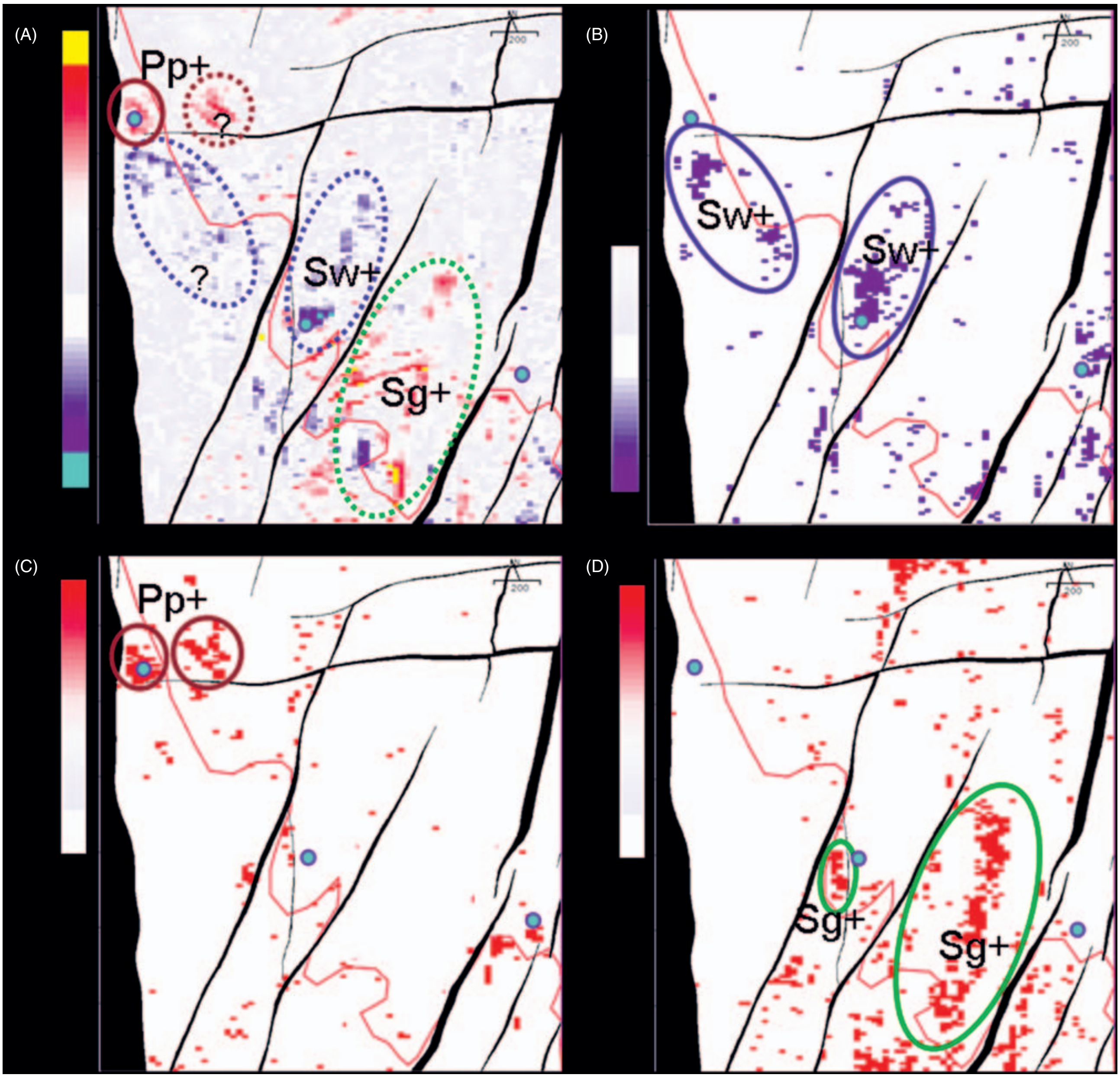

Fig. 9. *(A) Full Stack Amplitude Difference Map, (B) Pseudo Water Saturation Increase (C) Pseudo Pressure Increase Map, (D) Pseudo Gas Saturation Increase Map. The maps were derived by combining AVO attributes in ΔL & ΔM space compared to the conventional full stack amplitude difference map (A).*

Pseudo-pressure and saturation change volumes were created from AVO attributes and used to reconcile production data with 4D amplitude anomalies. This AVO workflow provided better separation between saturation (both gas and brine) and pressure. A 4D inversion is currently underway and is expected to provide further quantification of these effects. Future results will also be integrated into the static and dynamic model.

Integration of 4D seismic with production and geological data increased confidence in our interpretation. The interpretation has provided insight into sub-seismic connectivity controls and preferential permeable pathways. Time-lapse is considered a valuable reservoir monitoring tool for Enfield and more monitor surveys are expected to be acquired in the future.

Acknowledgments

The authors would like to thank Woodside Energy Ltd and Mitsui E&P Australia Pty Ltd (JV partner) for giving us the opportunity to present this paper. We would also like to acknowledge the following people. Roland Hamp (Enfield Development Manager), Dave Dickinson (4D Processor), Blair Berglin (acquisition), Simon Lang, Noel Guppy and, Trey Meckel (Geologists), Wayne Bailey (Structural Geologist) & all our colleagues in the Enfield Development Asset Team in particular Rae Jeffries, Kane Marshall, Rohan Irvin and Amna Ali (Reservoir Engineers).

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Britney and geophysics in Australia

Greetings from the new editor of 'Web Waves', already struggling to formulate a set of geophysics-related themes that will appeal to the readers of Preview and provide something more appealing than a superficial list of mildly interesting web links. If you have a particular interest or recommendation then please feel welcome to contact me!

Frankly, I would rather be trawling the web for news about Britney Spears than geophysics, and I appear to have hit the jackpot. The folks at Hakia Labs (http://www.hakia.com) return a comprehensive and elegantly formatted reply to the search phrase 'Britney Spears', leaving no stone unturned. How do they do it? First, the Hakia Company established which search phrases are the most popular worldwide. Britney obviously features highly. Second, they applied a small army of humans to manually filter the morass of Britney-type information on the web to deliver the articulate and comprehensive data awaiting anyone interested in dear Britney (supported of course by some programming language trickery). In comparison, a search on phrases such as 'geophysics' only returns a random and relatively worthless collection of semi-related web links.

Britney Spears

I make this introduction for a good reason, so read on. Geophysics is a tremendously diverse and (often) rather haphazard suite of disciplines. If you have successfully explained to your parents what a geophysicist does then you are doing better than me. As such, any geophysical company institution faces a great challenge if they want to build an online resource that meets the following outcomes:

1. It is simple to navigate
2. It is quickly obvious what resources are available to the internet visitor and
3. Those resources are useful and tangible, rather than simply being archived (and outdated) news.

Note to all geophysics-related web editors: the first two levels of your web resource need to be punchy, concise and visually appealing.

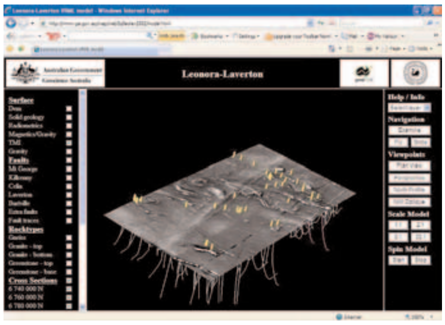
The Geoscience Australia (GA) and CSIRO websites are two cases in point. Both represent quite significant archives of information. Neither is particularly able to capture the interest of the first-time visitor. The GA website, however, probably contains the more immediately appealing tools and resources, as summarised below.

Geoscience Australia http://www.ga.gov.au

It is difficult to concisely review a web resource such as the GA facility, primarily due to its size and scope. The front page menu is indicative of the breadth of GA operations: Onshore Energy & Minerals, Earth Monitoring, Natural Hazards, Geomagnetism, Oil & Gas, Marine & Coastal, Geodesy & GPS, Satellite Remote Sensing (ACRES), Topographic Mapping, Education & Fab Facts, Library, Employment Opportunities, Projects Index. Each takes the visitor to a rather vast database of information, referenced by its own (new) menu system. As such, it is rather ponderous to keep mental track of the overall sitemap and to move efficiently from one sub-section to another in a separate menu.

Most immediately attractive are the Online Tools. MapConnect (http://www.ga.gov.au/mapconnect/) is an interactive map builder, including a range of cultural information. Unfortunately, nothing much seemed to happen when I tried accessing it from home. Sentinel (http://sentinel2.ga.gov.au/acres/sentinel/index.shtml) is a national bushfire monitoring system that provides timely information about hotspots to emergency service managers across Australia. The mapping system allows users to identify fire locations with a potential risk to communities and property. Most appealing is the Online Maps & Databases section (http://www.ga.gov.au/oracle/index.jsp), with links to self-contained repositories on the following topics: Energy, Environmental, Geochemistry, Geochronology, Geodesy, Geomagnetism, Geology, Geophysics, Earthquakes, Landslides, Floods & Nuclear Monitoring, Marine & Coastal, Minerals, Petroleum, Satellite Imagery, Topography, Reference Databases, and Products & Publications. The Interactive 3D Models area (http://www.ga.gov.au/map/web3d/index_vrml.jsp/) is hopefully a taste of things to come. Once an application called "Blaxxun Contact version 5.1" is loaded (and enabled!) to your browser, several VRML 3D models can be viewed and manipulated in real time. Two examples shown here are 2D seismic content for the Bremer Basin and geology + TMI + cross-sectional models for the Leonora–Laverton area, both in Western Australia.

Bremer Sub-basin 3D model from the GA website



An image of the Leonora–Laverton area, from the GA website

Otherwise, the GA website can be searched seemingly forever and is particularly useful as an educational resource, revealing endless databases of maps, geological and geophysical material, environmental data, etc. Collectively, the GA web resource is a sizeable achievement, but don't expect to establish what is available quickly. Commendably, there is a link for 'The first time user' at the bottom of the front page.

CSIRO
http://www.csiro.com.au

Likewise, the CSIRO website (http://www.csiro.com.au/) is something of a behemoth, with the front page a veritable minefield of links that will take the visitor deep into the bowels of a vast and complex maze of information. Formed in 1926, CSIRO is the single largest employer of scientists in Australia, with more than 6500 people conducting and assisting with scientific research at 57 sites in Australia.

Home page of the CSIRO website

Consequently, CSIRO is one of the largest and most diverse research agencies in the world. Overtly serving as a PR vehicle, the CSIRO website nevertheless contains several resources worth visiting.

The left column of links contains the database of CSIRO resources. The highest-profile links are Showcases, Flagships and Divisions. More general links then include Astronomy & Space, Energy, Environment, Farming & Food, Health & Wellbeing, Information & Communication Technology, Manufacturing, Materials, Mining & Minerals and Transport & Infrastructure. The top row of links addresses the fundamental CSIRO message, news, educational resources, publications and career opportunities.

A difficult challenge for such a broad enterprise is to make key online information quickly identifiable and accessible by the casual visitor to the website. In this sense, as is commonly the case, CSIRO struggles. As an example, I searched using the front-page engine for one of CSIRO's highest-profile enterprises: CO_2 sequestration; 1622 hits were revealed. Where to go from there? Read them all?

Thus, the pitfalls of online databases of such magnitude. As is the case for the GA website, the CSIRO resource is an invaluable educational resource and will evidently present unlimited material to a visitor searching for a specific topic. As long as they have time on their hands to sift through all the responses to their search...

Happy searching.

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The Economics of Climate Change (The Stern Review)

by Nicholas Stern

Publisher: Cambridge University Press, 2007, 692 pp. (pbk)
RRP: $89.95, ISBN: 13978-0-521-700801

The cover of this door-stopper of a book shows a picture of the planet Earth which graphically displays the extent and intensity of energy consumption in Europe and North America – and the apparent paucity of energy use elsewhere. The logo utilises a picture of the Antarctic ice cap, which we know has contracted appreciably while this book was being written.

These symbols pick up the main themes of the Stern Review – an extraordinarily comprehensive coverage of the global climate change phenomenon, a convincing analysis of its severity and consequences, and a range of prescriptions for dealing with it. The conclusions emphasise the necessity for international co-operation and propose a number of institutional mechanisms to bring this about.

While efforts have been made to make this volume user-friendly, it is not an easy read. Some of the arguments are highly technical and will not be comprehensible to many readers. The complexity and range of the discussion means that the overall logic is not always readily apparent, despite the useful 'Key Messages' at the head of each chapter, the 'break-out' boxes to explain selected topics, and some very effective graphs. This reviewer did not find the index to be as helpful as it could be: a search for 'carbon sequestration' divulged only a reference to a Working Group, 'carbon storage' pointed to ways of preserving forests, while the intended object of the search was eventually found as 'CCS – Carbon Capture and Storage'.

As it turns out, CCS occupies a central position in the overall exposition. The Review points out that the bulk of the present and projected CO_2 emissions result from energy generation and that our predominant reliance on fossil fuels is likely to persist for some decades. It is implied, if not actually stated, that CCS is the most readily available means of mitigation, costly though it may be. The incentive to embark upon CCS is proposed to come from setting a globally accepted carbon price and instituting a carbon trading regime, the price to be sufficiently high to cover the costs of CCS (or alternative means of reducing emissions).

The Stern Review is an economic treatise and does not purport to be a scientific one (or, indeed, a financial one). The economic analysis and argument rests on the science available, and the Review recognises the uncertainties in it. Given the emphasis on CCS, and its inherent long term lack of sustainability, it would be useful to see an analysis of the alternatives for treating CO_2 emissions – can there be no feasible means of transforming the gas into a solid, in the same way as Synroc for nuclear waste? And are there really adequate storage sites on the globe to accommodate the volume of gas needed to reach the intended targets?

Proponents of nuclear energy and other means of power generation (including renewables) will find little to help them in the Stern Review. These options are recognised and catalogued, but not promoted as realistic alternatives or analysed in any detail.

The drivers of increased global energy consumption (and hence carbon emissions) are rising standards of living and population growth. As the editor of *Preview* has pointed out, limiting population growth was not seen by the Review as a policy instrument that could be applied to limit climate change. Given that population growth potentially also affects the sustainability of life on earth in many ways (such as the supply of food and water) other than energy, this is a surprising omission. After publication, Stern explained this by asserting that the question of population growth was already being addressed by others.

Technical work in the Stern Review has aroused debate and controversy. Much of the analysis is based on projections and modelling, with the inevitable uncertainties that follow. Sceptics have claimed underestimates of mitigation costs, and exaggeration of benefits. To take an example, the current level of CO_2 equivalent in the atmosphere is around 430 parts per million (ppm). Stern proposes a target of stabilising at 550 ppm, observing that stabilising at a lower level of 450 ppm is 'likely to be unachievable with current and foreseeable technologies'. In contrast, other economists knowledgeable in the field have suggested that a more modest target of 650–750 ppm is adequate, while more recently and in response to evidence of accelerated rates of warming, targets as low as 250 ppm have been proposed.

These large ranges give policy makers plenty of room to take decisions based on other considerations. While it would be nice to think that Governments make decisions of this kind based on long term thinking, intergenerational equity considerations and cost benefit analyses, the reality is that they – and we – are heavily influenced by immediate results and short-term cash outlays. Following the Stern prescription is going to require some hard selling.

None of the above – some of which can be regarded as nit-picking – should detract from this authoritative and invaluable reference work. Perhaps the key point is best summarised in the Postscript (page 653) thus:

> *'We should recognise the balance of the risks. If the science is wrong and we invest 1% of GDP in reducing emissions for a few decades, then the main outcome is that we will have more technologies with real value for energy security, other types of risk and pollution. If we do not invest the 1% and the science is right, then it is likely to be impossible to undo the severe damages that will follow.'*

This is a conclusion that is hard to argue against. Copies can be ordered directly from Cambridge University Press: Tel (03) 8671 1400 or www.cambridge.edu.au.

Graham O'Loghlin is a Canberra-based management consultant who used to be a scientist.

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The Last Oil Shock – a survival guide to the imminent extinction of petroleum man

by David Strahan

Publisher: John Murray, 2007, London, 292 pp.
Price: $35, ISBN: 978-0-7195-6423-9

David Strahan is an investigative journalist and documentary film-maker specialising in business and science. In this book he tackles the issue of ‘Peak Oil’. This is the point of maximum production of crude oil and occurs when half the world’s conventional oil reserves have been used. Peak Oil supporters and this book claim that globally the peak is imminent (within the next 10 years) and that then demand will outstrip supply. Natural gas will reach its production peak in the subsequent 10 years. This book is well written, researched and referenced and presented in a lucid style that covers the geological, industrial, economic, policy and personal aspects of the issue. It benefits from interviews with authoritative sources relevant to all aspects of the debate. It is a thought-provoking book that claims energy security, driven by the Peak Oil concept, is already affecting the foreign polices of governments. It also looks at the implications for an energy hungry world, with some sobering conclusions regarding the efficacy of alternate energy sources to replace conventional petroleum in transport fuels and plastics. The book’s strength is its integration of economic and political aspects into the Peak Oil question and overall it maintains an excellent balance. However, the conclusions are necessarily confronting. It is highly recommended.

The first chapter lays out a case that energy security is a significant influence on current US–UK foreign policy in the Middle East. A key piece of evidence is a speech given by Dick Cheney (as Chairman of Halliburton) to the London Institute of Petroleum in late 1999, in which he acknowledged the issue of oil depletion, the critical role of Middle East oil resources to future oil supply and the lack of access for western companies. His subsequent role as Vice-President and Head of the US Energy Taskforce, and the coincidental planning for the invasion of Iraq all implies a somewhat terrifying scenario.

The second chapter is an excellent exposition of the development of the Hubbert Curve, its use in predicting the Peak Oil in the US in 1970 and its relevance to the current world situation. Chapter 3 addresses the fundamental controversy that lies at the heart of the Peak Oil concept – ‘Is it simply a matter of investment and access to prospective lands?’ as claimed in the recent past by the International Energy Agency (IEA) or ‘Is it a case of resource depletion at the global level?’ as claimed by Peak Oil proponents. He demonstrates that currently there is little surplus capacity in existing oil production infrastructure as a result of the recent increase in demand and that in fact, globally, proved and probable oil reserves are declining. To make a material difference to reserves and supply, some very large fields would have to be discovered in areas as yet unknown. This is increasingly unlikely given exploration history over the last 20 years and the maturity of our knowledge of petroleum occurrence. Investment in improving recovery will mitigate field decline but cannot substitute for very large new oil field discoveries. He demonstrates that production outside of the Former Soviet Union (FSU) and OPEC has been at a plateau for a decade.

Chapters 4 and 5 engender a sense of crisis with oil production peaking at a time of global warming. Strahan first looks at what would be required to replace transport fuels with either hydrogen or biofuels. His fundamental point is that it is simply not doable in a reasonable time – the investment in energy, in land and resources is simply too enormous and consequences unknown, even to replace the shortfall between declining oil production and demands. He also shows that energy is a much more important contributor to economic growth than is allowed for in classical economics. He makes the case that given the role of crude oil in the energy mix, any reduction in the availability of crude oil will have profound consequences for the world economy.

In Chapter 6, he shows that overall western companies are not replacing oil production with new reserves and that many are in long term liquidation as oil production companies. Some have maintained their production in the short term through takeovers or by risky investments in places like the FSU (e.g. BP). Energy analysts in the US are now predicting Peak Oil for individual companies. He claims the easy gains from the makeover of FSU oil assets have seemingly been realised. He also demonstrates that heavy oil and ‘Gas to Liquids’ projects cannot produce the volumes of oil required to replace conventional production because of any number of constraints on developing these enormous engineering projects. However, western companies only have control of a small proportion of the world’s oil production and reserves – the balance lies with national oil companies particularly in the Middle East.

In Chapter 7, he addresses the capacity of the Middle East to meet burgeoning demand. Reserve and production figures for the Middle East are notoriously unreliable. He makes a good case that surplus production capacity in Saudi Arabia is just about used up and that the stated reserves of many OPEC countries are artificially inflated as are their undiscovered resources. For example official Kuwaiti reserves are 102 billion barrels yet internal Kuwait Oil Company documents indicate remaining reserves of 24 billion barrels. He is somewhat more sanguine about official Saudi reserves. The ability of OPEC to substantially raise production to anywhere near the levels suggested in official IEA estimates is therefore seriously questioned, even assuming the financial and physical resources and the will to do so were present.

In the final part of the book (Chapters 8–11), the author examines the possible economic and political consequences and possible policy responses. Here we are in speculative territory. Short term events for whatever reason, will have disproportionate effects as they will be superimposed on a system at its limits and may obscure the underlying supply reality. Extreme price volatility and recessions will turn the ‘Oil Peak’ into a ‘saw tooth’ plateau as supply and demand fluctuates before supply inevitably falls. Prices will soar as the financial markets seek to benefit. The political consequences are similarly dramatic with increasing competition between nations for a depleting resource and the flexing of financial muscle and influence by producers. He implies that in the current activities of the US, China and Russia we are seeing the beginning of this process. His focus on policy responses is focused largely on the UK scene but, as in the global warming response, collective action by countries is required. Energy profligacy and energy driven economic growth are out. He discusses in some detail policy options all with major implications for our western life style including the idea of personal ‘Tradeable Carbon Quotas’ as a way of managing energy consumption downward.

Like global warming a few years ago, there are many gaps and assumptions in the evidentiary chain to be absolutely certain that Peak Oil is an imminent reality. However, the case is clearly building and it is being taken seriously in many quarters including the oil industry itself. Irrespective of the merits of Peak Oil it is a sobering thought that our supplies of transport fuels will be increasingly dependent upon a volatile Middle East and FSU. Australia’s oil production peaked in 2000. We can only hope our political masters are thinking this matter through.

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March			2008
2–5 Mar	Prospectors and Developers Association of Canada (PDAC) International Convention and Trade Show www.pdac.ca/pdac/conv/index.html	Toronto	Canada
April			**2008**
6–9 Apr	2008 APPEA Conference & Exhibition www.appea2008.com.au/	Perth	Australia
6–10 Apr	21st SAGEEP meeting (Symposium on the Application of Geophysics to Engineering and Environmental Problems) www.eegs.org/pdf_files/sageep08_abstracts.pdf	Philadelphia	USA
7–10 Apr	SEG Applied Research Workshop 2008 Geophysical Challenges in Southeast Asia Exploration http://seg.org/meetings/seasia_exp/index.shtml	Kuala Lumpur	Malaysia
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
July			**2008**
20–25 Jul	19th Australian Earth Sciences Convention 2008 Joint Geological Society of Australia and Australian Institute of Geoscientists Meeting www.iceaustralia.com/aesc2008/	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

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