Preview

Australian Society of Exploration Geophysicists

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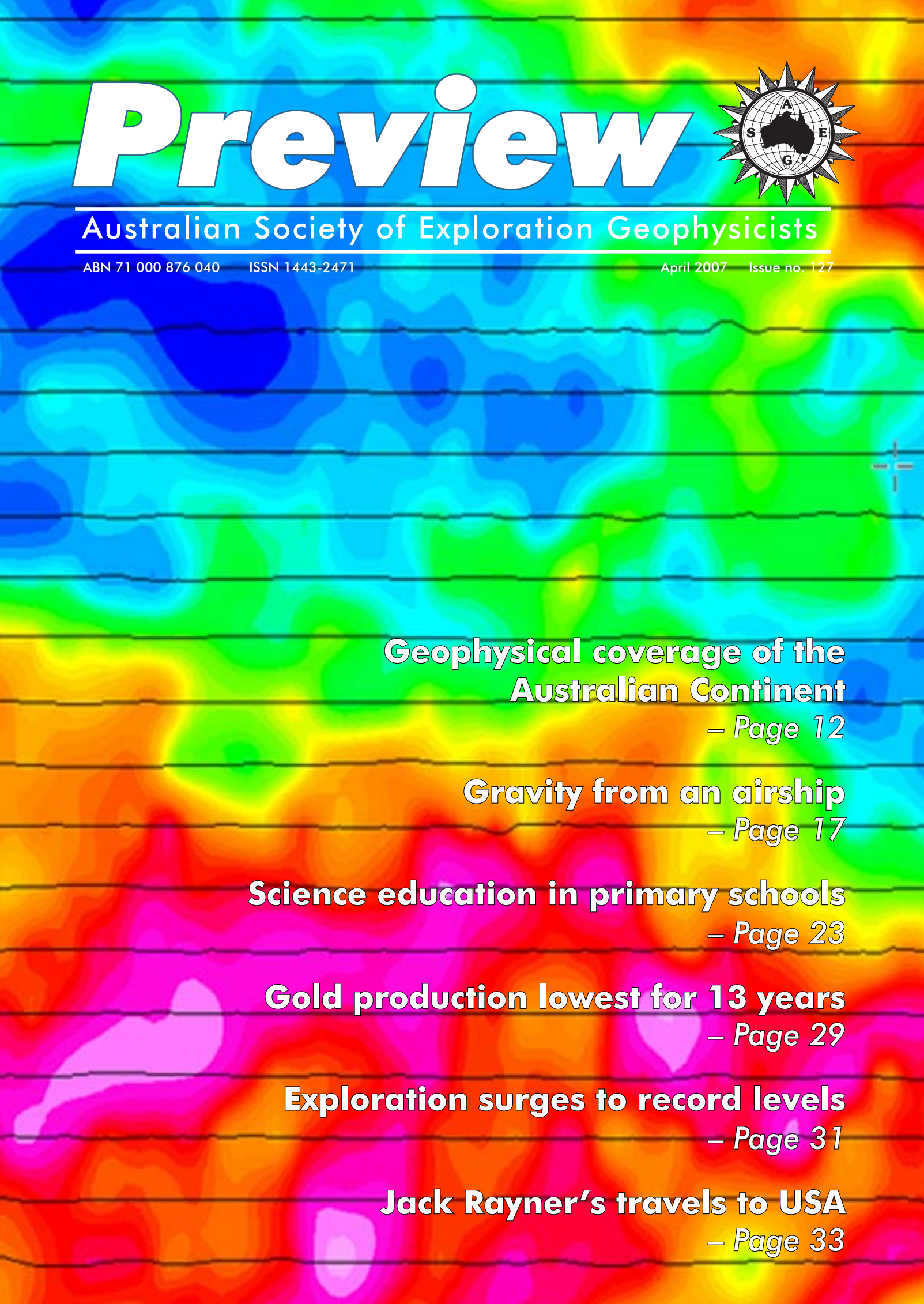
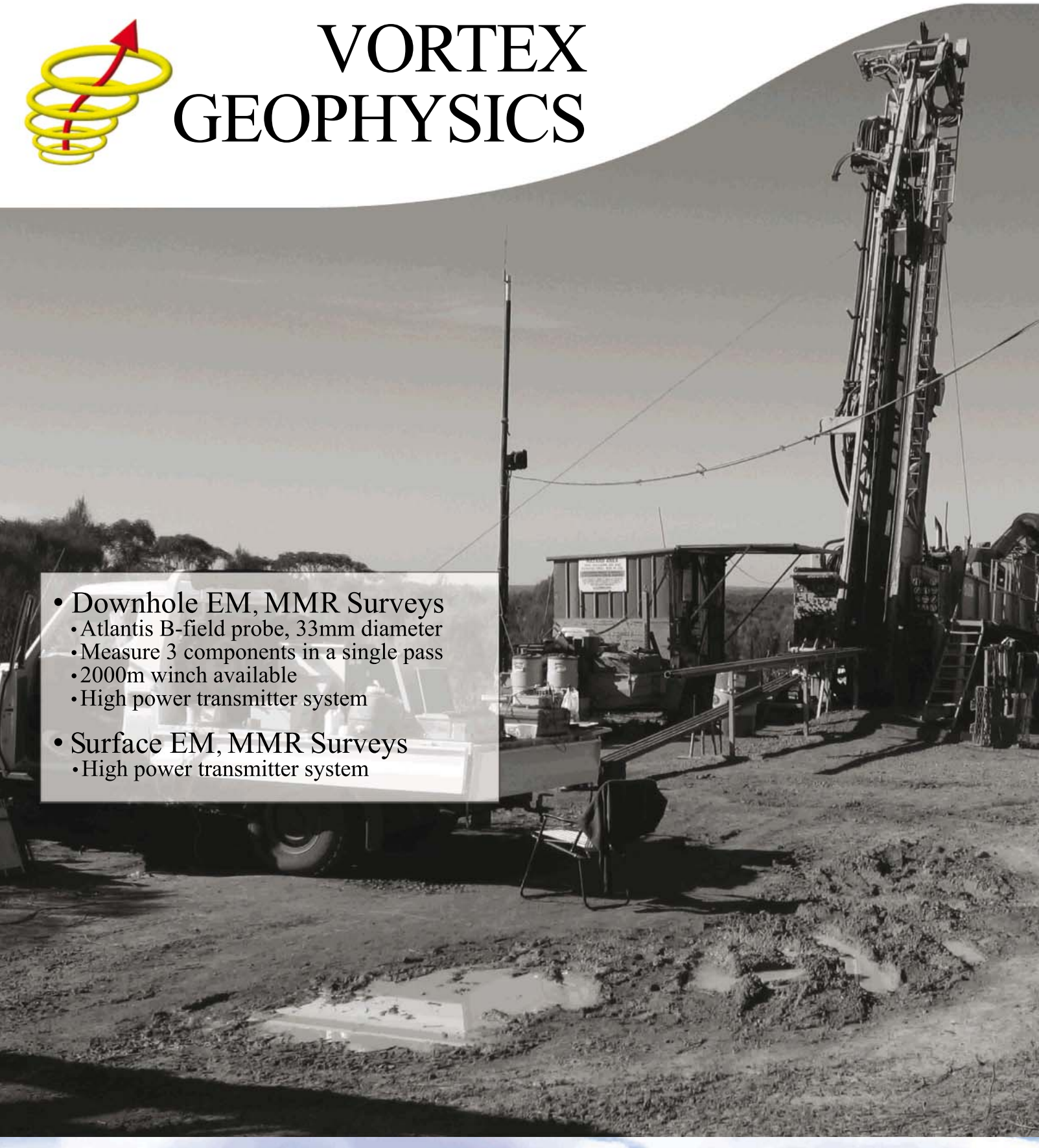


VORTEX GEOPHYSICS



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  - Atlantis B-field probe, 33mm diameter
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Atlantis borehole system

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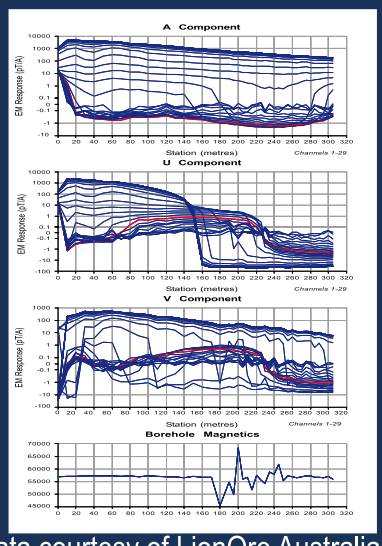

Data courtesy of LionOre Australia

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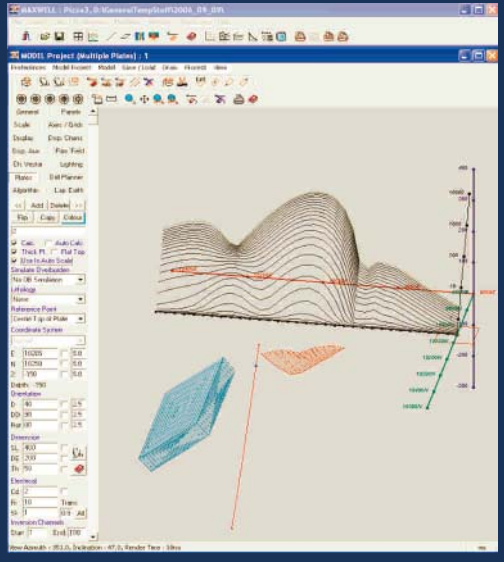

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CONTENTS

Preview is published for the Australian Society of Exploration Geophysicists. It contains news of advances in geophysical techniques, news and comments on the exploration industry, easy-to-read reviews and case histories, opinions of members, book reviews, and matters of general interest.

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Contributions

All editorial contributions should be submitted to the Editor via email at denham@webone.com.au.

The text of all articles should be transmitted as a Word document. Figures and illustrations should be transmitted as separate files, not embedded in the Word document. Photographs and line drawings should be of the highest quality and, if not created digitally, should be scanned at high resolution: photographs at 300 dpi at final size, saved as .jpg files; hand-drawn line drawings at least 600 dpi at final size, saved as .tif files. Computer-generated graphs and diagrams should be saved in one of the following formats: Excel, Powerpoint, encapsulated postscript (.eps), Adobe Illustrator (.ai), Windows metafiles (.wmf). In all cases they must be editable vector graphic files. Please contact the Production Editor for further information.

References

References should follow the author (date) system. They should be listed in alphabetical order at the end of the paper in the standard form:

Blackburn, G.J., 1981, Seismic static corrections in irregular or steeply dipping water-bottom environments: Expl. Geophys., **12**, 93–100.

Abbreviations and units

SI units are preferred. Statistics and measurements should always be given in figures e.g. 10 mm, except where the number begins a sentence. When the number does not refer to a unit of measurement, it is spelt out, except where the number is greater than nine. The words 'Figure' and 'Table' should be capitalised (first letter) and spelt in full, when referred to in the text.

Deadlines

Preview is published bi-monthly in, February, April, June, August, October and December. The deadline for submission of material to the Editor is the 15th of the month prior to the issue date. Therefore the deadline for the June 2007 issue is 15 May 2007.

Advertising copy deadline is the 19th of the month prior to issue date. Therefore the advertising copy deadline for the June issue will be 19 May 2007. A summary of the forthcoming deadlines is shown below:

Preview issue	Text and articles	Advertisements
128 Jun 2007	15 May 2007	19 May 2007
129 Aug 2007	15 Jul 2007	19 Jul 2007
130 Oct 2007	15 Sep 2007	19 Sep 2007
131 Nov/Dec 2007 Conference Handbook	14 Sep 2007	18 Sep 2007

David Denham

Eristicus on leave

Eristicus is on leave, but he asked me to mention the Productivity Commission Research Report, the Clean Coal funding, the Carbon Tax submissions to government and the Greener Homes grants. So here goes.

Productivity Commission

Overall funding for science and innovation is around $6 billion (see the figure below, taken from the report).

The Productivity Commission examined the impacts of such public support for science and innovation, and considered the prospects for improving outcomes by eliminating impediments to innovation or by changing the way government support is channelled to its various competing uses.

My reading of the key points is that the report is recommending *a re-shaping of the tax concessions for industry*, a *reduced commercialisation focus* in universities and CRCs, and a *simplification of bureaucracy* in the government.

Some of the key points of the report are:

- There are widespread and important economic, social and environmental benefits generated by Australia's $6 billion public funding support of science and innovation.
- The benefits of public spending are likely to exceed the costs but it is not possible to provide anything other than broad estimates of the overall return to government contributions.
- The net payoff from the R&D Tax Concession could be improved by allowing only small firms access to the 125 percent concession, changing the thresholds for tax offsets, amending the base for the 175 percent incremental concession and considering a narrower, more appropriate, definition of R&D.
- Strong public support of Rural R&D Corporations with a public good orientation is justified, but the level of government subsidies for *some* narrower, industry-focused arrangements is likely to crowd out private activity and produce weaker external benefits outside the supported rural industry.
- Collaboration can generate significant benefits. The CRC program is, however, only suited to longer-term arrangements. There are complementary options for business collaboration with public sector research agencies and universities that could provide more nimble, less management-intensive, arrangements.
- There are grounds for dealing with problems in the governance and intellectual property frameworks of universities, weaknesses in their commercial arms and shortcomings in proof-of-concept funding.
- However, the pursuit of commercialisation for financial gain by universities, while important in its own right, should not be to the detriment of maximising the broader returns from the productive use of university research.
- The structure of funding for higher education research has increasingly eroded the share of block grants. Further erosion would risk undermining their important role in enabling meaningful strategic choices at the institutional level.
- The costs of implementing the Research Quality Framework may well exceed the benefits. In the long run, a transition to less costly approaches, such as those that target poor performing areas, should be considered.

The whole report can be found at http://www.pc.gov.au/study/science/index.html

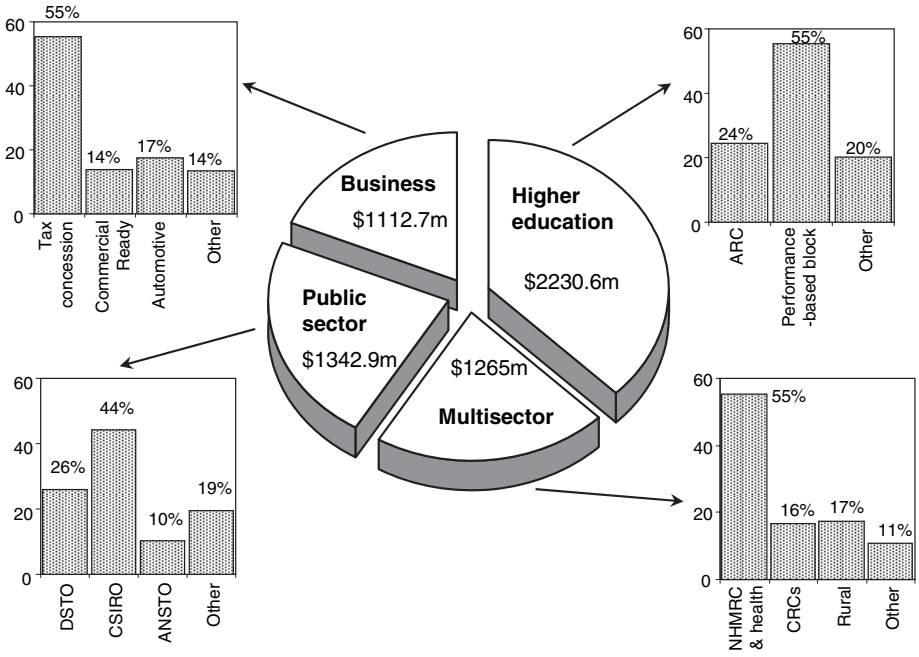


Fig. 1. Australian Government spending on science and innovation 2005–2006.

Clean Coal research funding

On 14 March Ministers Macfarlane and Turnbull announced that Victorian-based HRL Limited would receive a $100 million grant for a $750 million clean coal technology project.

The project, funded under the Australian Government's Low Emissions Technology Demonstration Fund, aims to reduce greenhouse gas emissions generated by coal-fired power stations.

The demonstration project would involve building a 400 megawatt integrated drying gasification combined-cycle power generation plant at the Loy Yang coal mine in Victoria's Latrobe valley. This aims to produce power more efficiently, at lower cost, with 30 percent lower CO2 emissions and half the water consumption of conventional brown coal power plants.

Work on HRL's IDGCC power generation plant is expected to start mid-2007

and be completed by the end of 2009, creating around 300 new jobs during construction and 36 new jobs for the plant's operation.

Carbon trading

The submissions to the Prime Ministerial Task Group on Emissions Trading are now available on the web (http://www.pmc.gov.au/emissionstrading/submissions.cfm)

There are about 200 submissions and the list of companies and institutions contributing to the Task Force read like the who's who of the leading resource industries. We have BHP, Rio Tinto, Alcoa, Shell and Santos, just to name a few.

The BHP submission encapsulates the main arguments being presented by most of the submissions:

> *'It is clear that an effective, sustained global response to the threat of climate change is required.*
> *BHP Billiton supports the development of a global, market-based mechanism for valuing and trading emissions entitlements and reductions, on the basis that it is broadly-based (geographically and across industries), efficient, and phased in such a way that industry and the economy have sufficient time to adjust.'*

With statements like these, it will be difficult for the government not to introduce some sort of carbon trading scheme in the not too distant future.

Greener Homes?

On 4 March 2007, the Minister for the Environment and Water Resources Malcolm Turnbull announced a $52.8 million Small Business and Household Climate Change Action initiative. This is to 'help households and small businesses become more energy efficient and potentially carbon neutral'.

Sounds like a sensible proposal. As the Minister stated: 'If we have greener homes, we can contribute to a cooler planet.'

However, all the money appears to be provided to 'send Australians information about climate change and how to become more energy efficient, as well as helping them calculate their greenhouse gas emissions'.

In other words, more pamphlets for the recycling bins and less trees in the forests. A very strange way to spend $52.8 million.

In this issue

So with Eristicus's instructions completed, you can sit back and read some of the wonderful things in this Preview. The airborne gravity paper by David Hatch shows real innovation, and the Primary Connections program operated by DEST and the AAS is to be commended if we really want to continue to being a smart country. Then there's the fascinating story of Jack Rayners visit to the US at the end of Word War II and an excellent review of the geophysical coverage of the Australian continent. Something for everybody – we hope!

David Denham

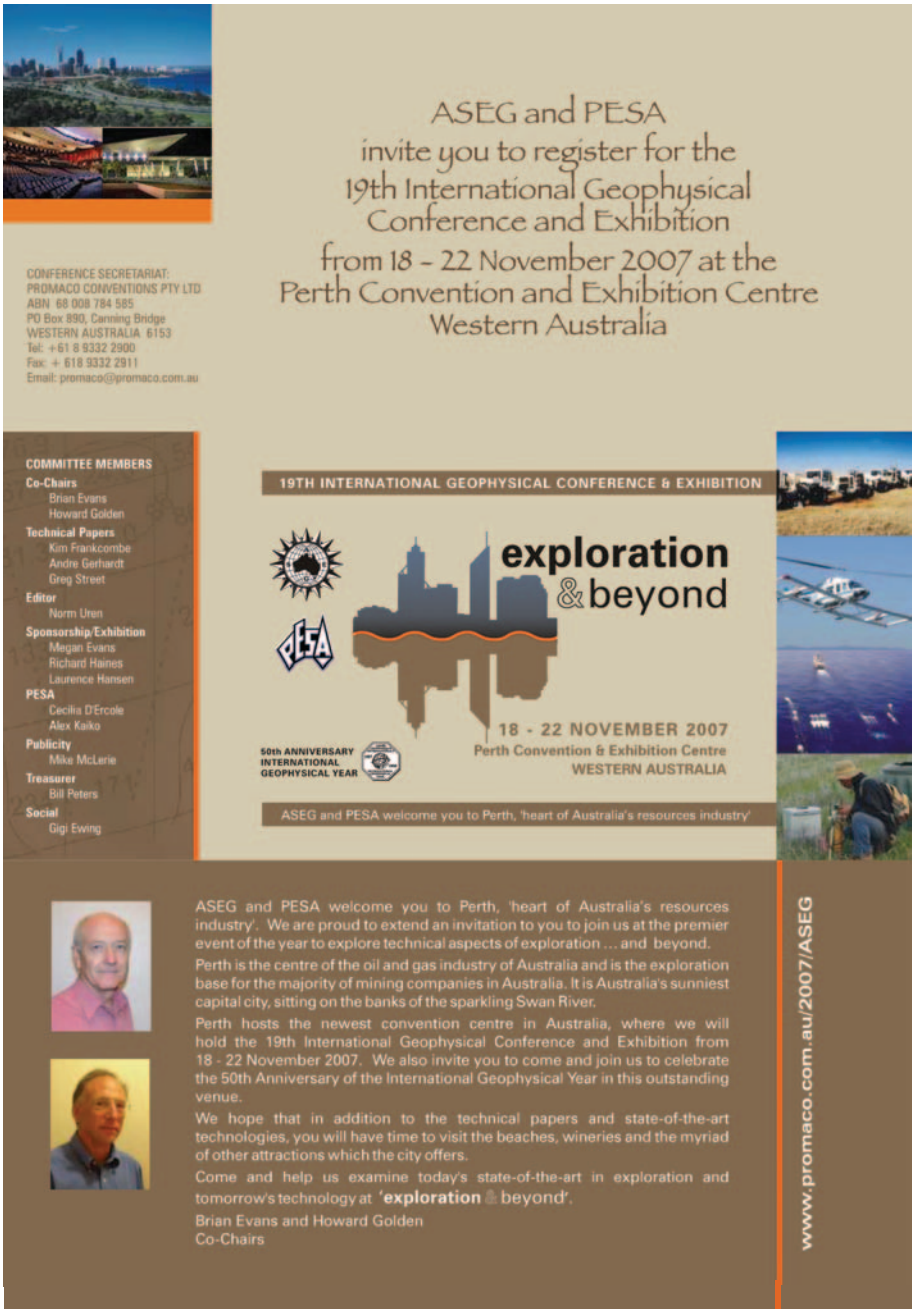
Call for Papers underway for Perth 2007 ASEG Conference

The 2007 ASEG Conference Organising Committee for the 19th International Geophysical Conference and Exhibition is expecting a scintillating range of papers and posters in a time of a booming resources sector. To that end a Call for Papers has been announced. Abstract submissions are being enthusiastically invited for papers and posters. Each submission should be associated with a technical area under the broad Minerals, Petroleum and Environmental categories. A template can be downloaded from www.promaco.com.au/2007/aseg.

Accepted authors will be required to submit a short paper (maximum of four pages) for publication on the conference CD. Papers will be reviewed for technical content and undergo editorial review. The program will allow for informal discussion around the posters. For more information, contact the Secretariat, Promaco Conventions via promaco@promaco.com.au.

All the sub-committees are gearing up to ensure that the Conference is well supported by industry, the technical and exhibition programs are excellent, and the venue is comfortable and well-suited for the event. Added attractions in the form of DISC, workshops, and social functions are also in the planning stages. ASEG is also pleased to announce two major field trips preceding the conference opening, one to Barrow and North West Shelf and the other to the Kalgoorlie gold fields.

Next Spring will see one of the biggest geophysical events in recent memory take place in Perth. The Committee is looking forward to seeing a broad cross-section of the geophysics community in Western Australia in November 2007.



Calendar of Events 2007/2008

2007

21–25 May
American Geophysical Union Joint Assembly
Acapulco, Mexico
http://www.agu.org/meetings/ja07/

11–14 June
69th EAGE Conference & Exhibition incorporating SPE Europec 2007
Venue: ExCel London, UK
http://www.eage.org/events/

2–13 July
International Union of Geodesy and Geophysics XXIV General Assembly
Venue: Perugia, Italy
Contact**:** Secretariat, Research Institute for Geo-Hydrological Protection
Email: secretary@iugg2007perugia.it
www.iugg2007perugia.it

9–12 September
5th Decennial International Conference on Mineral Exploration (Exploration 07)
Theme: ***Exploration in the new millennium***. Exploration 07 will review the current state of the art in geophysics, geochemistry, remote sensing, data processing and integration.
Venue: Toronto, Canada
www.exploration07.com

23–28 September
SEG International Exposition & 77th Annual Meeting
Venue: San Antonio, Texas, USA
http://seg.org/meetings/calendar

27–30 September
4th International Symposium on 3D Electromagnetics (3DEM-4)
Venue: Freiberg, Germany
Contact: Klaus Spitzer klaus.spitzer@geophysik.tu-freiberg.de
http://www.geophysik.tu-freiberg.de/3dem4

2–5 October
Greenhouse 2007
Venue: Sydney, New South Wales, Australia

Contact: P. Holper, CSIRO, Tel: +61 3 9239 4661
Email: info@greenhouse2007.com
www.greenhouse2007.com

22–26 October
2007 SAGA Biennial Technical Meeting & Exhibition
Theme: Making Waves
Venue: Wild Coast Sun Resort, Durban, South Africa
Contact: events@rca.co.za
http://www.sagaonline.co.za/2007Conference/2007conference.htm

18–22 November
ASEG's 19th International Conference and Exhibition
Perth, WA, Australia
Contacts: Brian Evans
Email: brian.evans@geophy.curtin.edu.au
http://www.promaco.com.au/2007/aseg
promaco@promaco.com.au

25–29 November
5th International IAHS Groundwater Quality Conference
Venue: Fremantle, Australia
Contact: W. Whitford, Tel: 61 8 9333 6273
Email: Wendy.Whitford@csiro.au
www.clw.csiro.au/conferences/GQ07

10–14 December
American Geophysical Union, Fall Meeting
San Francisco, California
http://www.agu.org/meetings

2008

6–9 April
2008 APPEA Conference & Exhibition
Perth Convention & Exhibition Centre
Contact: Julie Hood, 07 3802 2208/jhood@appea.com.au=20

9–12 June
70th EAGE Annual Conference & Exhibition
Rome, Italy
http://www.eage.org/events/

20–25 July
19th AGC, The Australian Earth Sciences Convention 2008
Joint Geological Society of Australia and Australian Institute of Geoscientists Meeting, Perth, WA
http://www.gsa.org.au/events/calendar.html

5–14 August
33rd International Geological Congress
Venue: Oslo, Norway
Contact: A. Solheim, Norwegian Geotechnical Institute
Tel: 47 2202 3000
Email: as@ngi.no
www.33igc.org

9–14 November
SEG International Exposition and 78th Annual Meeting
Las Vegas, Nevada, USA
http://seg.org/meetings/
Contact: meetings@seg.org

15–19 December
American Geophysical Union, Fall Meeting
San Francisco, California
www.agu.org/meetings

Geophysics in Japan

The 8th SEGJ International Symposium was held at Kyoto University from 24–29th November 2006. More than 200 delegates attended from 17 countries including official representation from the European Association of Geoscientists and Engineers (EAGE), SEG, KSEG, EEGS, and ASEG. In addition a particular welcome was extended to committee members from the newly formed Vietnam Association of Geophysicists (VAG).

The theme of the meeting centred on 'Imaging and Interpretation' with over 120 papers offered on a broad range of topics from reservoir characterisation, to EM methods, processing and analysis. However the proceedings demonstrated a more specific focus on near-surface applications which were further explored in several workshops prior to the main conference. The Plenary session examined the concept of 'peak oil' in the face of growing demand and decreasing production. No obvious solutions were advanced and there is now a realisation that future exploration is likely to be restricted by a simultaneous 'peak' in the number of professionals available. In particular there is a global reduction in student numbers and increasing rates of retirement.

Delegates were hosted in numerous hotels in central Kyoto with plenty of opportunity for nightlife, shopping and fine dining. The conference language was English and there were few problems in communication at the venue. Kyoto is big but finding the 'Clock Tower' (famous for near demolition during student riots) was a relatively simple matter with an excellent transport system and some English labels. Following his Karaoke act Brian Evans is now an international celebrity while Jim Cull can at least find his way around the Kobe hot springs thanks to the guidance and local knowledge offered by Koya Suto. This was a great venue and members should take the opportunity to attend the next SEGJ event in 2009.

The ASEG official delegation included Jim Cull (International Advisory Committee), Koya Suto (International Liason), and Brian Evans (19th ASEG Conference Chair).

Fig. 1. Imaging and Interpretation in Kyoto.

Fig. 2. Wyn MacNamara, a Maiko (apprentice) girl and Jill Cull in Kyoto.

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New Members

The ASEG welcomes the following new members to the Society. Their membership was approved at the Federal Executive meetings held on 31 January and 28 February 2007.

Congratulations are in order to Christopher William Luxton from South Australia and Christopher Ian Uruski from New Zealand, who are now active members of the ASEG.

Name	Organisation	State
Graham Baines	University of Adelaide	SA
Kelvin Ashley Blundell	Southern Geoscience Consultants	WA
Richard Chopping	Geoscience Australia	ACT
Luisa D'Andrea	Rio Tinto Iron Ore	WA
Luke Andrew Garde	University of Melbourne	Vic.
Anousha Hashemi	Resource Potentials	WA
Clark Jorgensen	Big Sky Geophysics	USA
Florian Karpfinger	Curtin University	WA
Peter Richard McMullen	Fugro Airborne Services	WA
Tara Siobhan Reilly	Tap Oil Limited	WA
Matthew John Saul	Curtin University	WA
James Marsden Shadlow	Australian Worldwide Exploration	NSW
Roxey Sutherland	Mosaic Oil	NSW
Adel Vatandoost	University of Tasmania	Tas
Kate Elizabeth Wilkinson	Geological Survey of Qld	Qld
David Wilson	3D Exploration Pty Ltd	WA

Australian Society of Exploration Geophysicists, Honours and Awards 2007

ASEG members are invited to submit nominations for the next round of ASEG Honours and Awards. Nominations that are judged to be appropriate and are then subsequently selected will be presented at the 19th ASEG Conference, in Perth, 18–22 November, 2007. Details of the available awards follow:

1. ASEG Gold Medal

For exceptional and highly significant distinguished contributions to the science and practice of geophysics by a member, resulting in wide recognition within the geoscientific community. The nominee must be a member of the ASEG.

2. Honorary Membership

For distinguished contributions by a member to the profession of exploration geophysics and to the ASEG over many years. Requires at least 20 years as a member of the ASEG, except where the nominee is a recipient of ASEG Gold medal.

3. 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. The nominee does not need to be a member of the ASEG.

4. Lindsay Ingall Memorial Award

For the promotion of geophysics to the wider community. This award is intended for an Australian resident or former resident for the promotion of geophysics (including but not necessarily limited to applications, technologies or education), within the non-geophysical community, including geologists, geochemists, engineers, managers, politicians, the media or the general public. The nominee does not need to be a geophysicist or a member of the ASEG.

5. ASEG Service Medal

For outstanding and distinguished service by a member in making major contributions to the shaping and the sustaining of the Society and the conduct of its affairs over many years. The nominee will have been a member of the ASEG for a significant and sustained period of time and will have at some stage been one of the following:

- Federal President, Treasurer or Secretary,
- State President, Conference Chairman or Standing Committee Chairman
- Editor of Exploration Geophysics or Preview

6. ASEG Service Certificates

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

Nomination Procedure

For the first four award categories, any member of the Society may nominate applicants. These nominations are to be supported by a seconder, and in the case of the Lindsay Ingall Memorial Award by at least four geoscientists who are members of an Australian geoscience body (eg GSA, AusIMM, AIG, IAH, ASEG or similar). Nominations for the ASEG Service Medal and the ASEG Service Certificates are to be proposed through the State and Federal Executives with their backing.

All aspects of the criteria should be addressed, and a nomination must be specific to a particular award. To gain some idea of the standard of nomination expected, nominees are advised to read past citations for awards as published in Preview.

Nominations including digital copies of all relevant supporting documentation are to be sent electronically to:

Roger Henderson
Chairman, ASEG Honours and Awards Committee
Email: rogah@tpg.com.au

The absolute deadline for applications is 15 September, 2007

Australian Civil Honour Awards

Distinguished ASEG members may also be nominated for one of the following Australian Civil Honour Awards

- Companion in the Order of Australia (AC)
- Officer in the Order of Australia (AO)
- Member in the Order of Australia (AM)
- Medal of the Order of Australia (OAM)

Any nominations should be made directly using the following website:

http://www.itsanhonour.gov.au/about/medal_descriptions/order_of_australia.html

Antonia Bigault wins ACT Geophysics Prize

The Australian Society of Exploration Geophysicists' (ACT Branch) Prize for Geophysics was won in 2006 by Antonia Bigault, a student in the Department of Earth and Marine Sciences at the Australian National University.

Antonia studied Optometry at QUT from 1996 to 1999, and from 2000 to 2005 worked as an optometrist in Tasmania, throughout Queensland, and in the UK. Her enjoyment of outdoor activities, travel and appreciation of geological landforms led her then to pursue a degree in science at ANU, majoring in geology. This objective she achieved in 2005 and 2006, thoroughly enjoying all aspects of the course. She writes that she is keen to start work as a geologist, particularly within the exploration and geophysical fields. She is also considering doing honours, and is watching for an interesting project.

The ASEG congratulates Antonia on her success.

Australian Capital Territory – by Matthew Purss

At the AGM, which was held on 28 February, Matthew Purss was elected President, Hugh Tassell, Secretary and Leone Jones, Treasurer, for 2007.

2006 had been a successful year with seven technical talks and several joint activities with other geoscience societies in the ACT.

New South Wales – by Mark Lackie

The NSW Branch held the first meeting of the year and it's AGM in February. Mark Lackie was elected as President *in absentia* and Bin Guo was elected as Secretary. Roger Henderson continues as Treasurer and Peter Gidley as Webmaster. The 2006 President's and Treasurer's Reports are available from the Branch website.

The outgoing President Carina Simmat and the outgoing Secretary Glenn Wilson are both thanked for the efforts they made in 2006. A special thanks to Glenn for holding the fort as acting President in the later part of the year when Carina moved interstate.

In March, Iain Mason from the University of Sydney presented results from his research into imaging three dimensional ore-bodies using sparse borehole radar arrays. Presentations for forthcoming branch meetings include a look at geophysics in NSW, aspects of seismic processing and illuminating reservoirs with electromagnetics. A branch dinner is planned for July.

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

Queensland – by Emma Brand

The Queensland Branch held its AGM on Thursday the 15th of March, 2007. Nigel Fischer was re-elected as President and Emma Brand was re-elected as secretary. Binzhong Zhou stepped down from the role of Treasurer, a position that he capably filled for a number of years, to make way for Wayne Mogg. The Branch would like to thank Binzhong for his contributions as Treasurer over the years, and wish him well in his life outside the responsibilities of the ASEG. The AGM was the pre-curser to an extremely interesting talk by Natasha Hendrick on Integrated P-wave/PS-wave Seismic Imaging for Improved Geological Characterisation of Coal Environments. The presentation focused on examining the lithological information that can be extracted from the integrated interpretation of P and PS data. The Queensland Branch would like to thank Natasha, not only for the excellent presentation, but for many years of service to the ASEG, and wish her the best of luck in pursuing new opportunities in the West.

South Australia – by Luke Gardiner

After a short post-Christmas hiatus, the South Australian Branch held their AGM on the 8th of February. A new committee was voted in, with some new faces and some returning ones, including Luke Gardiner elected as President, David Cockshell re-elected as Treasurer, and Michael Hatch elected as Secretary. A large and enthusiastic crowd was in attendance for the night's guest speaker, Ian Plimer, Professor of Mining Geology at the University of Adelaide. His engaging talk on 'Failed Geophysical Exploration for Noah's Ark' highlighted the potential for misappropriation of the scientific method and the need for healthy skepticism, as demonstrated by his experiences on a recent trip to Mount Ararat. His talk was well received, and much discussed.

We thank our sponsors for technical meetings in 2006: PIRSA, BHP Billiton, Santos, Minotaur Resources, Petrosys, Zonge Engineering, Beach Petroleum and Schlumberger and hope to continue the relationship with this generous group in 2007.

The SA Branch holds technical meetings monthly, usually on a Thursday night at the Historian Hotel, from 5:30 pm. New members and interested persons are welcome. Please contact Luke Gardiner (luke.gardiner@beachpetroleum.com.au) for further details.

Western Australia – by Louise Middleton

Technical evening – 27th February 2007

27 February was ASEG WA's first technical talk for the year. Speakers included Anna Dyke from BHP Billiton on their *Falcon®: Heli-borne System results and 3D interpretation case study from the West Musgraves* and Andrew Sunderland on *A novel magnetic gradiometer: description, design issues and trial results*. Both presentations were extremely informative and well received by an audience of more than 60 people.

At this event we also presented some of our business partners with their certificates of appreciation. We extend special thanks to all our business partners: ACI Broking Services, Chevron, Down Under GeoSolutions and Geoforce for their continued support of the WA Branch of ASEG.

Technical evening – 14th March 2007

WA held another technical evening on 14 March. Speakers included Geoff Peters from BHP on *BHP Billiton Orion*

WA President, Megan Evans presenting Geoforce (L) and ACI Broking (R) with their Business Partner Certificates of Appreciation.

Happy networkers in Perth at the February meeting.

Operations – Stuart Shelf Falcon® Survey results and Tabitha Wellman, CEO of Innova Business on *How you can build an extraordinary team in a tight labor market*. It was a very successful evening with in excess of 60 people attendance.

Next Event – DISC

Concepts and Applications in 3D Seismic Imaging *by Biondo Biondi*

When: Monday, 16th April 2007
Time: (Registration from 8.00 am) 8.30 am – 5.00 pm includes lunch and refreshments
Where: The Esplanade Hotel, Fremantle
Parking: Parking is available on Marine Terrace, Fremantle for a small fee

More information is available on the ASEG Website.

Please make sure you have marked your diaries for this year's events:

16th April:	SEG DISC: Biondo Biondi – Concepts and Applications in 3D Seismic Imaging
9th May:	Workshop
13th June:	Technical Evening
8th August:	Workshop
12th September:	Technical Meeting
10th October:	Student Night
22nd November:	Annual ASEG-PESA Golf Classic
12th December:	AGM/Social/ Networking Event

Jennie Carson
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Carbon sequestration

The recent trend of acknowledging the issue of carbon dioxide build-up has led me to this month's topic of CO_2 Sequestration. Major international companies are investing large sums towards the research and development of the capturing and permanent storage of greenhouse gases. I have researched the topic and have found five websites which give a broad perspective of the work being done in this field.

United Nations Framework Convention on Climate Change (UNFCCC) http://unfccc.int/2860.php

Over a decade ago, the UNFCC was formed with the majority of the international body joining a treaty to begin international cooperation to consider what can be done to reduce global warming and to cope with whatever temperature increases are inevitable. The UNFCCC secretariat has given its support to all institutions involved in the climate change process, including the study of carbon sequestration.

The information on this website links the user to what is being done on a country-by-country basis as well as the overall joint-international efforts and goals. It is an excellent starter for a person trying to grasp the reasoning behind the effort countries, like Australia, are making to deal with increasing greenhouse gas emissions. Meetings, national reports, scientific methodology and GHG emissions data are easy to find and are sorted in a relevant order.

MIT Carbon Capture and Sequestration Technologies http://sequestration.mit.edu/index.html

The Carbon Sequestration Initiative is an industrial consortium launched in July 2000. The research examines technology assessments, economic modelling, analysis of regulatory and political aspects, and the development of a Carbon Management Geographic Information System (GIS). The site advertises an annual Carbon Sequestration Forum each autumn, as well as other activities such as the IPCC Special Report on Carbon Dioxide Capture and Storage and the Carbon Sequestration Leadership Forum.

A very interesting tool which brings the CO_2 impact across is the 'CO_2 thermophysical property calculator'. This FORTRAN code allows the user the opportunity to derive the phase, density, thermal conductivity, viscosity, etc. This tool is a great way to gain a better perspective of the issues scientists and researchers are facing in relation to the carbon sequestration issue. There are links to similar scientific and government organisations who are working with comparable goals.

http://www.fossil.energy.gov/programs/sequestration/geologic/

US Department of Energy (DOE) website has an easy to navigate page with comprehensive links to recent projects and news items. A 'quick facts' link allows users with little knowledge on the topic an opportunity to become informed on the key issues. Projects are listed in a functional database with carbon capture, geological sequestration and ocean sequestration.

In 2003, the current government gave the DOE one-billion dollars towards the development of the FutureGen project. This program takes the study of carbon sequestration away from geological storage and towards building the world's first integrated sequestration and hydrogen production research power plant. 'The project is intended to create the world's first zero-emissions fossil fuel plant and in theory, the model would be one of the cleanest fossil fuel fired power plant to date.'

http://www-old.dpr.csiro.au/index.html

The CSIRO Petroleum website is a practical page with links to career opportunities, scholarships, seminars/workshops, research and development, and patented technology. The site encompasses all the petroleum-based work currently being done by the CSIRO group. To find specific details of the carbon sequestration work completed by this organisation requires either a search of all the existing links or utilising the available search engine.

The site does a good job of quantifying the wide range of work being done by this agency but for specific searches the 'search engine' is the only way to navigate properly through the site.

Cooperative Research Centre for Greenhouse Gas Technology (CO2CRC) http://www.co2crc.com.au/

The index page of this website clearly defines the Australian-based consortium's purpose and relevant user-friendly links to the pertinent pages. The primary program, GEODISC, states that researchers have 'established that the geological features of Australia are suitable for geological storage of carbon dioxide. CO2CRC is building on these findings and plans to achieve a demonstration project within the term of CO2CRC'.

The CRC website was, by far, the most up-to-date page with updates on the recent injection testing and the drilling of a deep well for carbon dioxide testing. The organisation offers a calendar of events, potential career postings and updates of all current projects via the main page.

Geophysical data sets over continental Australia: magnetics, radiometrics, elevation and gravity, 2002–2006

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Data acquisition

In October 2002 an article titled 'Geophysical data sets over continental Australia' was published in Preview 100 (p. 48). The article was written to highlight the advances in coverage of publicly available magnetic, gamma-ray and gravity data over Australia since the first edition of Preview in January 1986. It is now timely to consider the advances in coverage over the past five years since the publication of the original article.

Since April 2002 the acquisition of magnetic, radiometric, elevation and gravity datasets by Commonwealth, State and Territory Governments and private companies has added over 2.5 million line kilometres of airborne survey data to the National Airborne Geophysical Database. This is an increase in database size of approximately 8% to December 2006. Simultaneously, more than 100,000 stations have been added to the National Gravity Database.

Magnetic, gamma-ray and gravity data sets provide vital information for mineral and petroleum explorers as well as researchers studying the geology of the Australian continent and for environmental management issues. Commonwealth, State and Territory governments have devoted considerable resources to acquiring these data sets and making them available to encourage exploration. Geoscience Australia's (GA) geophysical databases contain data acquired by governments, private industry and universities and this report summarises coverages over Australia of these data. Increased funding of the State and Territory Geological Surveys and demands for resources have been the driving factors in the recent improvement in the regional geophysical coverage of Australia.

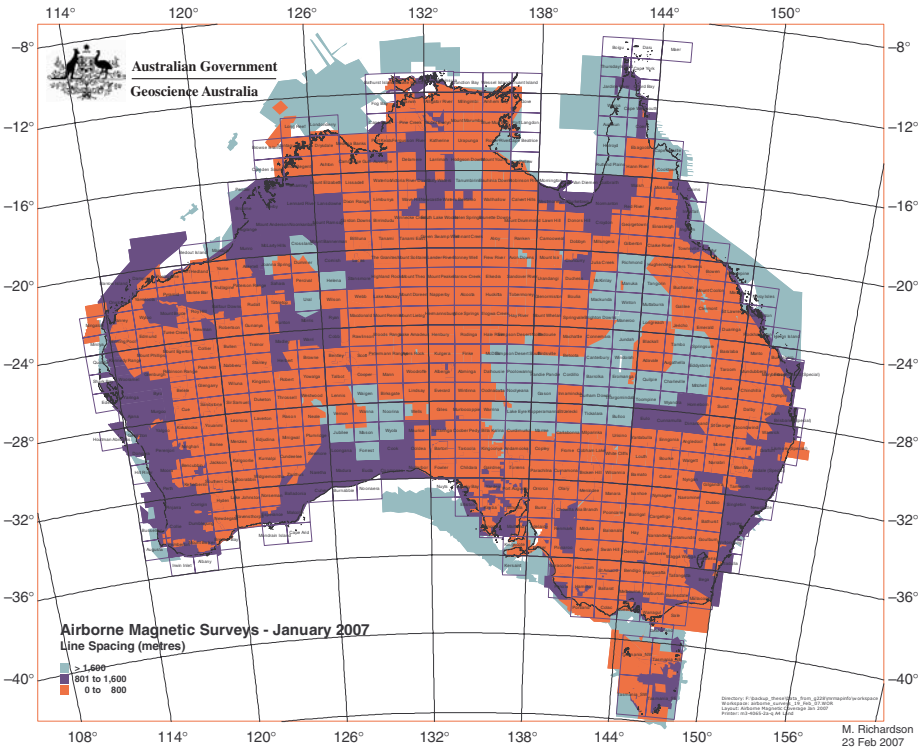

Fig. 1. Airborne magnetic coverage and line spacing of continental Australia at end of January 2007.

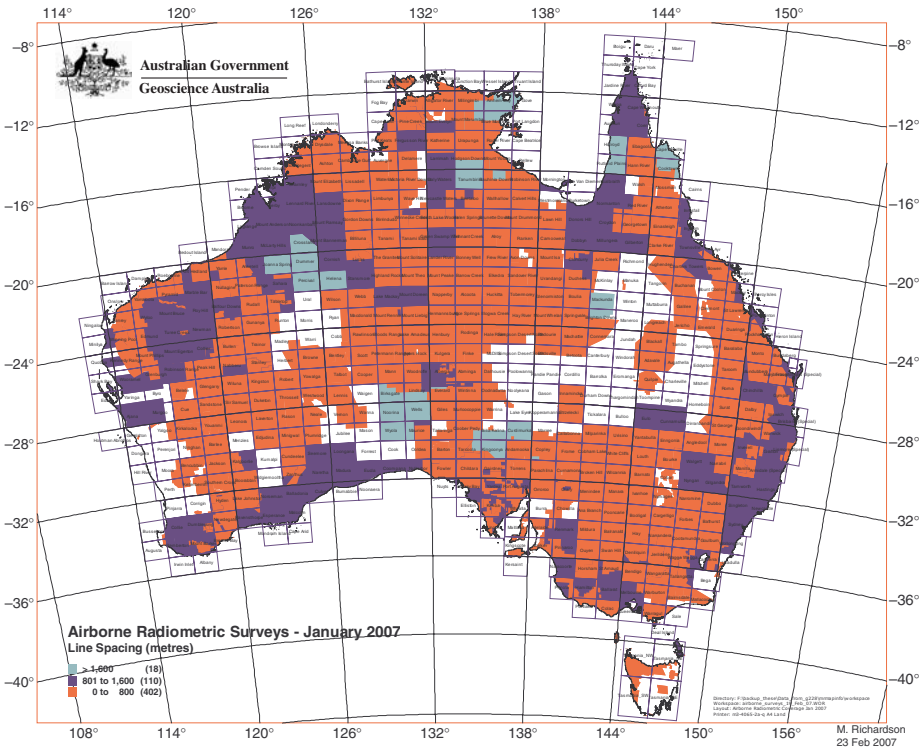

Fig. 2. Airborne gamma-ray coverage and line spacing of onshore Australia at end of January 2007.

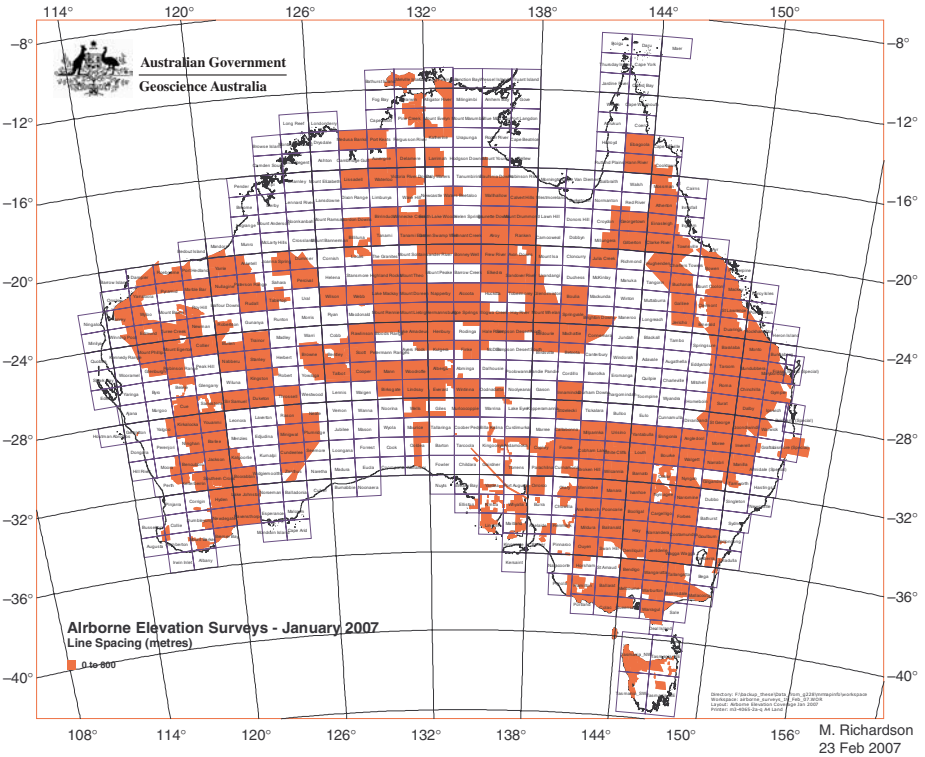

Fig. 3. Airborne elevation coverage and line spacing of Australia at January 2007.

Figures 1, 2 and 3 show the present state of coverage of magnetic, gamma-ray and elevation data over Australia at various line spacings respectively. Figure 4 shows the location of Government Surveys flown in the period 2002 to 2006. Figure 5 is a graph showing the growth in the number of line kilometres flown annually in Australia from 1951 to the present.

Tables 3 to 5 show the percent coverage of geophysical airborne data over continental Australia, and the distances surveyed through 2006.

Survey expenditure

Since the 2004–05 FY, Geoscience Australia has managed the airborne magnetic and radiometric surveys commissioned with funding provided by the States/NT and shown in Table 1.

Since the 2004–05 FY, Geoscience Australia has managed the gravity surveys commissioned with funding provided by the States/NT and shown in Table 2.

Data coverage

Since 2002 the coverage of digital airborne geophysical data acquired along flight lines spaced at 500 metres or less has gone from approximately 45% to 69% of onshore Australia, mainly due to recent initiatives by State governments.

At the end of 2006, the National Airborne Geophysical Database (NAGD) contained approximately 27,800,000 km of airborne geophysical data from over 880 surveys flown by the States/Northern Territory and Commonwealth Governments. Of this total nearly 22,300,000 km is at a line spacing of 500 m or less, approximately 4,200,000 km is at a line spacing of 1500–1600 m and the remaining 1,300,000 km is at greater than 1600 m line spacing.

The details are given in the tables below. It should be noted that:

(1) The numbers in the tables above are only approximate as not all surveys correspond to standard map sheet boundaries.

(2) The total number of line kilometres for some surveys in the database is not known. For the purposes of giving an indicative estimate of the coverage of digital survey data in the NAGD the area of the survey and the line spacing have been used to calculate the approximate number of line kilometres acquired during the particular survey.

(3) The calculation in (2) was not used in the 2002 article to calculate the total number of line kilometres in the NAGD.

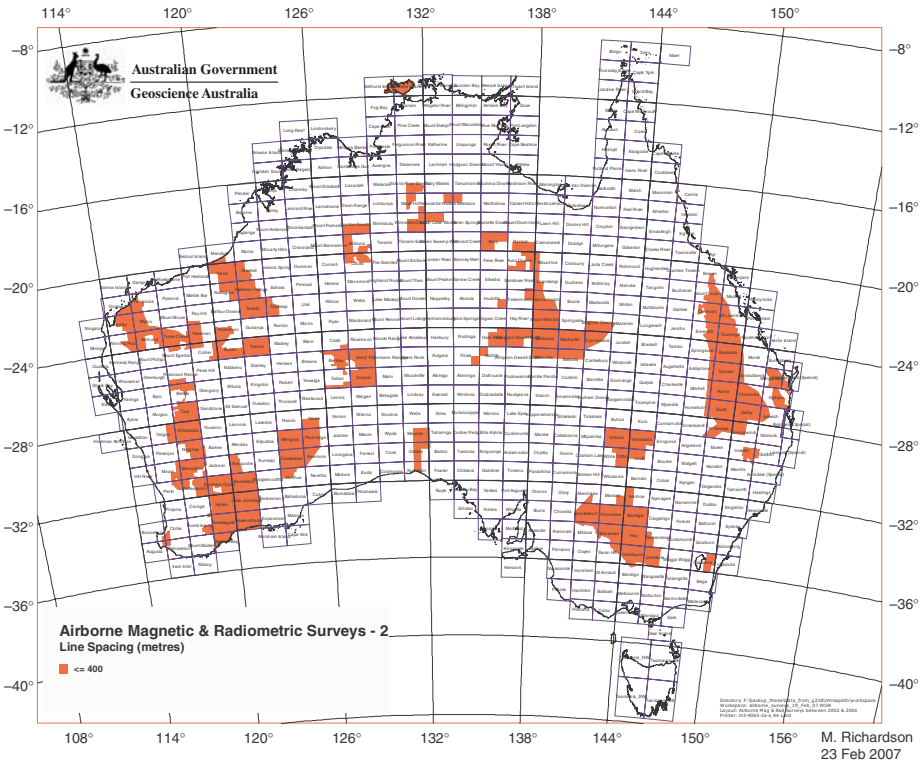

Fig. 4. Government surveys flown from 1 January 2002 through January 2007.

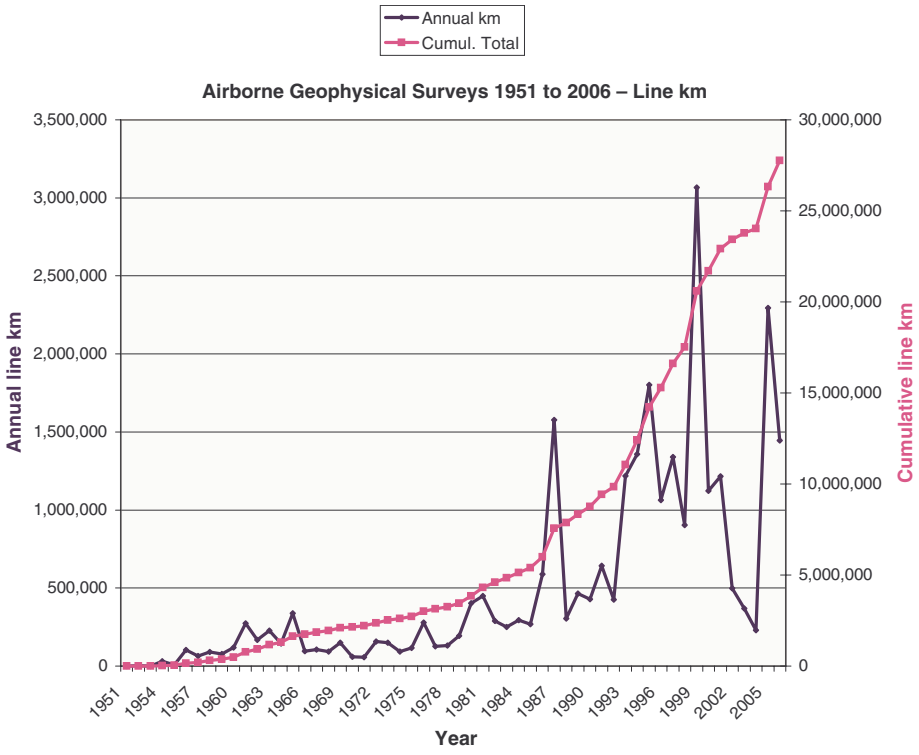

Fig. 5. Accumulation of data from State/Northern Territory and Commonwealth Government airborne geophysical surveys into the National Airborne Geophysical Database from 1951 through January 2007.

Magnetic data

The line spacing coverage of digital aeromagnetic data over onshore Australia and the number of line-kilometres acquired are summarised in Table 3.

Gamma-ray spectrometric data

The line spacing of digital gamma-ray data over onshore Australia and the number of line kilometres acquired are summarised in Table 4.

Elevation data

The line spacing of digital elevation data over onshore Australia and the number of line-kilometres acquired are summarised in Table 5.

Gravity coverage since 2001

More than 100,000 stations have been added to the National Gravity Database in the last five years from surveys conducted in all States and the Northern Territory. These data have been collected on regular grids or along individual line traverses. Most gravity surveys were conducted either:

(4) as exploration initiative projects such as the Queensland Smart State Initiative,
(5) to target specific areas as part of regional studies e.g. SA's Gawler Block, or
(6) were combined with other geophysical surveys such as seismic traverses.

The surveys conducted on a regular grid or grids usually provided a significant improvement on the pre-existing station density.

Station spacings of the regular grids varied from 4 km to less than a kilometre with the most common spacings being 4 km, 2.5 km and 2 km (see Figure 6). Traverse station spacings are generally closer than 500 m. Station positions were obtained using differential post-processed GPS techniques, which provided better quality gravity data than surrounding pre-existing data.

Australian Fundamental Gravity Network

The Australian Fundamental Gravity Network (AFGN) provides the datum and scale for gravity surveys conducted within Australia and the surrounding oceans. It consists of over 900 stations at over 280 locations as shown by the black dots in Figure 7. The first stations in the network were established in the early 1950s with the bulk of the stations established during the 1960s and 1970s.

Over the years many of these stations have been destroyed. Geoscience Australia relies on the users of the network to report on the status of the stations in the network and, if possible, to provide up to date photographs of stations that they visit. Currently there are 952 stations in the network of which 250 are known

Table 1. Airborne magnetic and radiometric surveys flown with funding provided by the States/NT since 2004–05			
State/Territory	**Survey name**	**Budget ($'000)**	**Financial year**
Western Australia	Boorabbin	494	04–05
	Hyden-Southern Cross	319	04–05
	Ravensthorpe – Newdegate – Bremer Bay	661	04–05
	Paterson North	353	05–06
	Paterson Central	440	05–06
	Paterson South – East	164	05–06
	East Yilgarn	890	05–06
	Gascoyne	542	05–06
	Ashburton	577	06–07
	Officer Basin	799	06–07
	Musgrave Extensions	553	06–07
State total		5,792	
South Australia	Ooldea	313	05–06
State total		313	
Queensland	Maryborough	317	04–05
	Bowen – Surat North	870	05–06
	Bowen – Surat South	981	05–06
	Isa West	411	05–06
	Isa South – West	869	06–07
	Isa South – East	619	06–07
	East Isa – North	684	06–07
	East Isa – South	963	06–07
	Croydon	607	06–07
State total		6,321	
Northern Territory	Tiwi Islands	256	06–07
	Tanumbirini	362	06–07
State total		618	
Tasmania	NE Tasmania	1,297	06–07
	Flinders Island	139	06–07
State total		1,436	
Grand total	**(Airborne magnetic and radiometric surveys)**	**14,480**	

to have been destroyed. Geoscience Australia has either visited or received reports in recent years confirming the existence of 181 stations, while the status of the remaining 521 stations is unknown. Any feedback on the condition of any of the stations will ensure that up to date information can be provided to users of the AFGN.

Over the past five years Geoscience Australia has conducted a program aimed at providing a more accurate and consistent Australian Fundamental Gravity Network. This program has involved the measurement of absolute gravity at 63 AFGN stations, shown by the red triangles in Figure 7, using an A10 portable absolute gravity meter. These measurements show that the current Australian gravity datum, Isogal 84, is 78 microgals (1 microgal = 1×10^{-8} m/s^2) higher than the absolute datum and that the accuracy of stations within the network is approximately 30 microgals. Geoscience Australia will be adjusting the Australian Fundamental Gravity Network and the Australian Gravity Database to the absolute datum later in 2007.

Data availability

Data owned by the Commonwealth, State and Territory Governments in the National Airborne Geophysical Databases are available from GADDS – the Geophysical Archive Data Delivery System. Data are also available from the relevant State or Territory government departments.

GADDS was released in November 2003 and has grown steadily since then. Download statistics for the period 18 November 2003 to 19 February 2007 are summarised in Table 6.

The ten most downloaded products for the same period are summarised in Table 7.

Concluding remarks

Considerable improvements have occurred in geophysical coverages of Australia since 2002, both in the extent and quality of data. State and Commonwealth initiatives fuelled rapid increases in magnetic,

Table 2. Gravity surveys completed with funding provided by the States/NT since 2004–05			
State	**Survey name**	**Budget ($'000)**	**Financial year**
Northern Territory	Birrindudu	368	05–06
	East Arunta	525	06–07
State total		893	
Western Australia	Paterson	440	05–06
	Webb	472	06–07
	Murchison	346	06–07
State total		1,258	
Queensland	Bowen – Surat	432	05–06
	Mt Isa Area A	560	05–06
	Mt Isa Area B	909	06–07
	Mt Isa Area C	835	06–07
	Mt Isa Area D	436	06–07
	Mt Isa Area E	553	06–07
State total		3,725	
Grand Total	**(Helicopter assisted gravity Surveys)**	**5,876**	

Table 3. Coverage of digital magnetic data over continental Australia at end of 2006		
Line spacing (m)	**Percentage of onshore Australia**	**Distance coverage (km) 2006**
≤500	72.0	22,335,326
>500	96.0	5,430,925

NB: Percentage coverage of onshore Australia is >100% as many areas flown at ≥1500 m line spacing have been reflown at ≤500 m line spacing.

Table 4. Coverage of digital gamma-ray data over onshore Australia at end of 2006		
Line spacing (m)	**Percentage of onshore Australia 2006**	**Distance coverage (km) 2006**
≤500	69	18,883,981
>500	51	2,875,640
No coverage	11	

NB: Percentage coverage of onshore Australia is >100% as many areas flown at ≥1500 m line spacing have been reflown at ≤500 m line spacing.

Table 5. Digital elevation coverage of Australia from airborne surveys		
Line spacing (m)	**Percentage of onshore Australia 2006**	**Distance coverage (km) 2006**
≤500	49	12,430,178

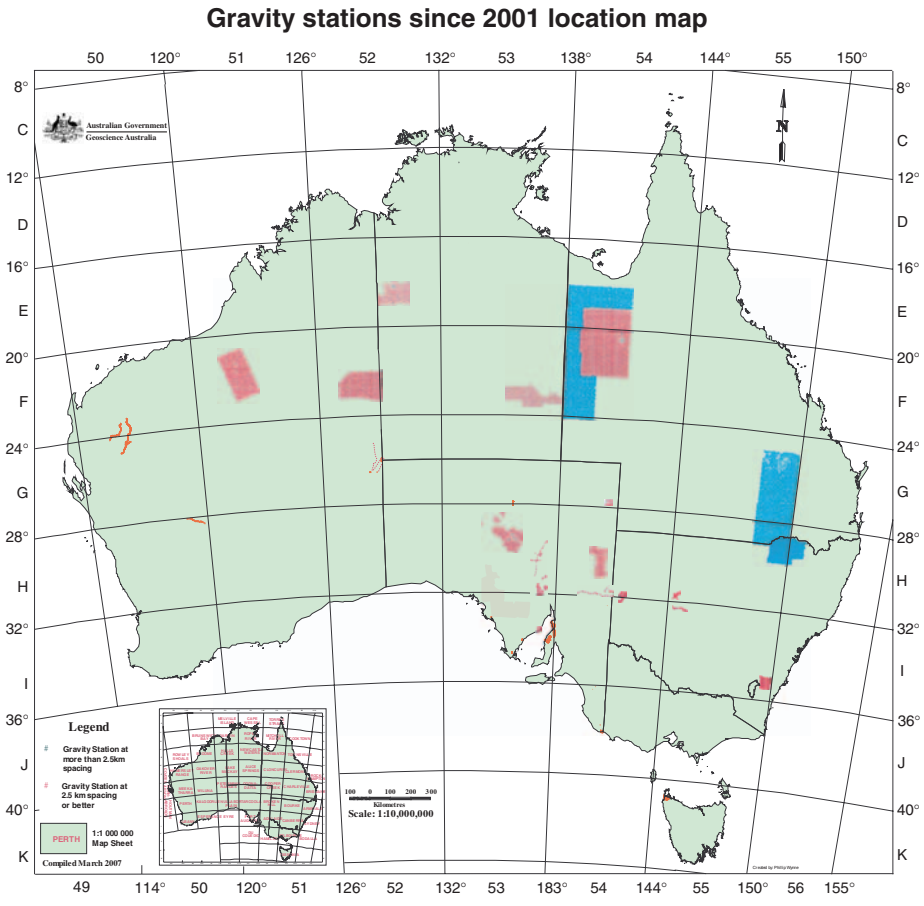

Fig. 6. Gravity Station Coverage of Australia at end of January 2007.

Continued on p. 22

Performance of the Air-FTG® System aboard an airship platform

Summary

A Full Tensor Gravity Gradiometer (Air-FTG®) system was successfully tested aboard a Zeppelin NT airship in early 2005 and is now deployed on surveys for diamond exploration in Botswana. Since implementation an extensive data set has been collected to evaluate the improvement in resolution and noise level over that observed with the same instrument in a Grand Caravan.

The airship provides two significant advantages over the fixed wing aircraft platform, i.e. a benign acceleration environment arising from the increased stability and a slow moving platform. A repeat line analysis indicates that the instrument noise in an airship is five times less than in a fixed wing platform. In a wide variety of survey conditions the airship system is able to resolve features with a wavelength of 100 m while maintaining a post-processed noise level of 1.7 E. Adverse weather conditions encountered during survey operations do not greatly influence the acceleration environment of the airship.

Introduction

The implementation of the Bell Geospace full-tensor, gravity gradiometer (Air-FTG®) (Murphy 2004) on a Cessna Grand Caravan platform for the application in diamond exploration has been investigated by several authors (Hatch 2004; Hinks *et al.* 2004). These authors concluded that although the spatial resolution and noise levels of this configuration can effectively detect kimberlites that are sufficiently large, near surface and of adequate density contrast, not all deposits of economic size and burial would be visible. As well, it was found that a significant component of the noise remaining in the fixed wing data shared the same bandwidth of kimberlite targets, which resulted in the creation of false anomalies. Therefore an improved gravity gradiometer system would not only reduce the risk of missing economic bodies, but would also reduce the cost of exploration by reducing the number of false anomalies. In order to gain a dramatic improvement in data quality, the Bell Air-FTG® system was implemented in a platform that has the ability to fly slower and more stably than a Grand Caravan.

Although the use of a lighter-than-air platform for gravity surveying has been suggested in the past, this concept has not been tested with a gravity gradiometer. One of the main advantages of this class of aircraft is that they are capable of slow flight, which will increase the resolution of the system. As well, due to the minimal amount of aerodynamic lift of an airship, it is insensitive to changes in angle of attack and is less susceptible to turbulence and manoeuvres that produce strong accelerations in airplanes and helicopters. Furthermore, due to the large overall dimensions of the airship, small scale gusts have a negligible effect on the gondola accelerations. The rigid structure of the airship allows the engines to be mounted on the hull, at a distance of 12 m from the gondola, thus reducing engine noise and vibrations experienced by the instrumentation.

The improvement in data quality from the implementation of the Bell Geospace Air-FTG® on a Zeppelin NT airship platform has been measured in two ways. First, a comparison of a series of repeats lines that were collected on the Grand Caravan and Zeppelin gave an estimate in the improvement in instrument noise prior to data processing. Secondly, a comparison was made from independent grids produced from alternate survey lines collected over a large area.

A qualitative analysis of the airship gravity data was also conducted by comparing these data with high-quality ground gravity and terrain datasets to determine the resolution and the sensitivity of the system to subtle features.

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Description of Zeppelin airship

The Zeppelin NT-07 airship that was used for the test has a rigid frame, fly-by-wire flight and thrust vector controls, and possesses the basic specifications and performance summarized in Table 1. The airship is powered by three independent 200 hp piston engines, two of which are mounted in nacelles at the sides of the airship and one at the tail, as seen in Figure 1. These engines drive fully reversible, variable pitch

Fig. 1. The Zeppelin NT-07 airship used for the test program in Germany and Botswana. It is seen mounted on a mast truck, which holds the airship secure when on the ground. The engines on the side and end of the hull can also be seen; these provide vector thrust control at low flight speeds.

propellers that can be swivelled, thus providing direct speed and lift control (side engines) and pitch and yaw control (aft engine) at the lower end of the airspeed range (between 0 and 35 kn (65 km/h)). This allows the pilots to accurately fly the prescribed flight-path in cross winds in the range of 10–18 kn (19–33 km/h) depending on variability and direction. Stronger winds parallel to the flight path have less influence on control, but will greatly reduce productivity due to reduction in speed in a headwind. The nominal survey flight speed for the test program was 60 km/h or 17 m/s which is roughly ¼ the speed of a Cessna Grand Caravan.

Unlike the original airships which used hydrogen as their lift-gas, the Zeppelin airship uses non-flammable helium. In addition, as it possesses close to neutral buoyancy, the airship remains flyable even if two of its three engines fail. The rigid frame also allows the airship to be flown back to base if the envelope becomes ruptured and internal pressure is lost, making it an inherently safe aircraft for geophysical survey operations.

The environment for flight operations in Southern Africa – high field elevation and high temperatures together with high thermal activity during daytime – provided a significant challenge for airship operations. For any airship, the static lift, which determines the height above ground that the airship is able to fly, depends on the amount of lifting gas that can be put into the envelope and on ambient and lifting gas temperatures. Figure 2 shows the lift dependency of the operational airship (including crew plus payload) in terms of possible fuel load with respect to ambient temperature and flying height for the usual field elevation in Botswana of 1200 m above sea level.

At a survey altitude of 80 m and a common summertime temperature of 35°C the airship can lift fuel adequate for a sortie of 3 hours in duration, which would severely limit daytime productivity. However, the night-time temperatures in Botswana rarely exceed 25°C, which allows a fuel load for a sortie of 8 hours. Night-flying also avoids extreme day-time thermal activity, which poses the greatest risk in an airship operation. Risks associated with night-flying have been mitigated with a variety of measures including forward illumination and a two pilot operation.

The performance of the Zeppelin airship for geophysical surveying is described in more detail by Hatch *et al*. (2006).

Noise and resolution analysis

The quantitative improvement in the noise level experienced with the airship gravity system over the fixed wing implementation has been measured in two ways. The first method employed repeat lines conducted with the Air-FTG® in a Grand Caravan and in an airship. These provided a comparison of relative noise levels for pre-processed data collected on the two platforms. The second method compares independent grids from alternate traverse lines from a large survey block.

A qualitative comparison of the airship data with high-quality ground gravity and terrain data was also conducted. The high-resolution, low noise ground gravity and terrain data were used to demonstrate the resolving power and sensitivity of the airship system to subtle features.

Repeat line analysis

Repeating the same line a number of times enables the accurate determination of system noise. However, as FTG processing techniques require a lateral distribution of data, the disadvantage is that this method only reflects the quality of the data in a relatively raw state and therefore will over-estimate noise. Nevertheless, it provides a useful comparison of the improvement of the noise measured by the instrument from one platform to another.

An 8 km line segment was repeated 10 times with the Air-FTG® system in the airship and 9 times over a 10 km segment with the Air-FTG® in a Cessna Grand Caravan. The repeat lines were stacked in an optimal way, which dropped points that are further than 100 m from the centre line of the repeats. Each line was then subtracted from the stacked line to produce a noise estimate for that line. This will be an overestimate due to vertical and lateral differences in locations of the repeats and from residual noise remaining in the reference line. The positioning error has been minimized by only using sections of lines where spatial deviations between the

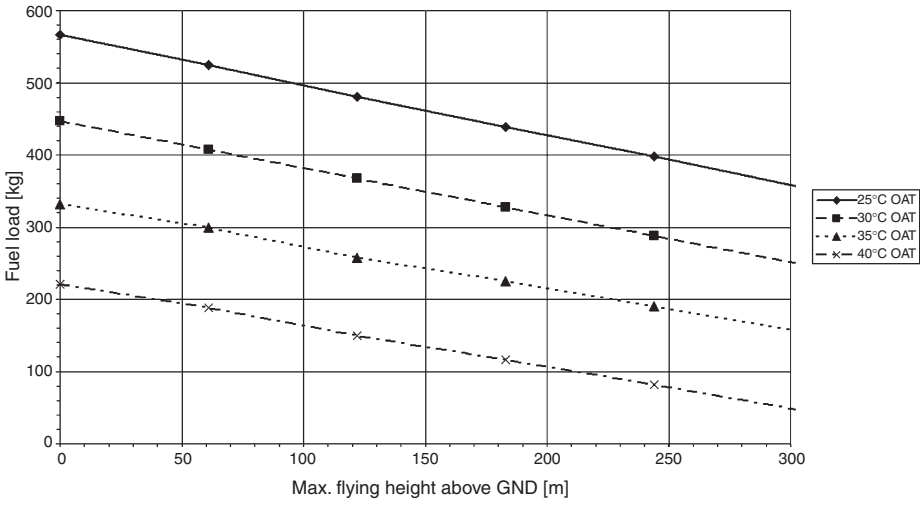

Fig. 2. Lift dependency in terms of fuel load of the Zeppelin LZ N07 airship with respect to flying height and temperature.

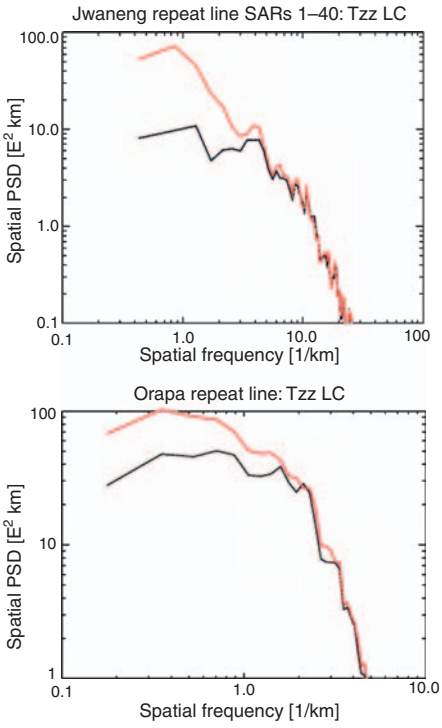

Fig. 3. PSD plots for noise (black) and signal (red) components for the repeat lines conducted with the Air-FTG® system in an airship (top) and a Grand Caravan (bottom).

reference line and individual repeats were less than 100 m.

The actual noise amplitude for each line is estimated from the difference between the test line and stacked line using the expression:

$$\sigma^2_{noise} = \sigma^2_{difference}\ n/(n+1)$$

where σ indicates standard deviation and n is the number of repeats averaged to calculate the stacked field. This is based on the assumption that all repeats have the same noise level. The same procedure was used for both the airship and Grand Caravan data.

The power spectra for the noise and signal components of the Air-FTG® system aboard the airship and Grand Caravan are shown in Figure 3. The peak noise level observed in the Grand Caravan repeat lines of 40 E^2-km is 5 times greater than the 8 E^2-km which is observed in the airship data.

Alternate line analysis

The comparison of independent grids using every other survey line allows the estimation of the noise level of a data set without the expense of collecting duplicate data. As well, the data can be subjected to the full-suite of FTG processing techniques thus providing a post-processed estimate of noise. However, this method will produce an over-estimate of the noise as the two grids are not truly redundant with the observations being off-set by half the line spacing.

The method that was used for processing the FTG data cross correlates the five independent tensor components, thereby examining the entire tensor matrix for consistencies and inconsistencies. This Multi-Component Process (MCP) does not require or involve any earth model or a single potential field model.

The grids produced from the even and odd lines are shown in Figure 4 along with the difference between these two grids. There is not a significant correlation with geological signal or terrain observed in the difference grid and its content appears to be mainly random noise. The alternate line analysis over a large survey block produced an RMS noise level of 1.7 E for the Tzz component which is likely a marginal over-estimate of the true noise level of the post-processed data.

Qualitative comparison with ground gravity and terrain

The ground gravity dataset shown in Figure 5b was collected with CG-3 and CG-5 gravimeters in Botswana at a 50 m station interval along N–S oriented lines that were spaced at 50 m. The data were terrain corrected, the vertical gravity gradient was calculated and the data then upward continued to the 80 m flying height of the airborne survey. These data were re-sampled along the flight-lines of the FTG survey to facilitate direct comparison of the two datasets. The airship FTG data were collected with a mean terrain clearance of 80 m and a flight-line spacing of 150 m flown in an east-west direction. The processed FTG Tzz response is shown in Figure 5c with the actual flight-path superimposed. The data collected on a Grand Caravan are shown in Figure 5a.

The terrain data used to correct both the ground gravity and the FTG data were derived from a recent orthophoto survey flown by the Government of Botswana. The orthophoto scenes were manually reprocessed to a lateral resolution of 10 m to reflect the elevation of the ground rather than the top of vegetation. Comparison with differentially corrected GPS elevations indicated that the orthophoto elevations were accurate to within 30 cm. The topography over the test area is essentially flat and after correction no terrain features can be recognized in any of the datasets.

Comparing the airship Tzz data (Figure 5c) with the equivalent ground gravity data (Figure 5b) one first notices the strong correlation of the major features. Although in the Grand Caravan Air-FTG® plot there is also reasonable correlation of high-amplitude, long-wavelength anomalies, there are substantial differences present. Due to relatively high-levels of noise in the Grand Caravan data, line levelling is difficult and as a result some long-

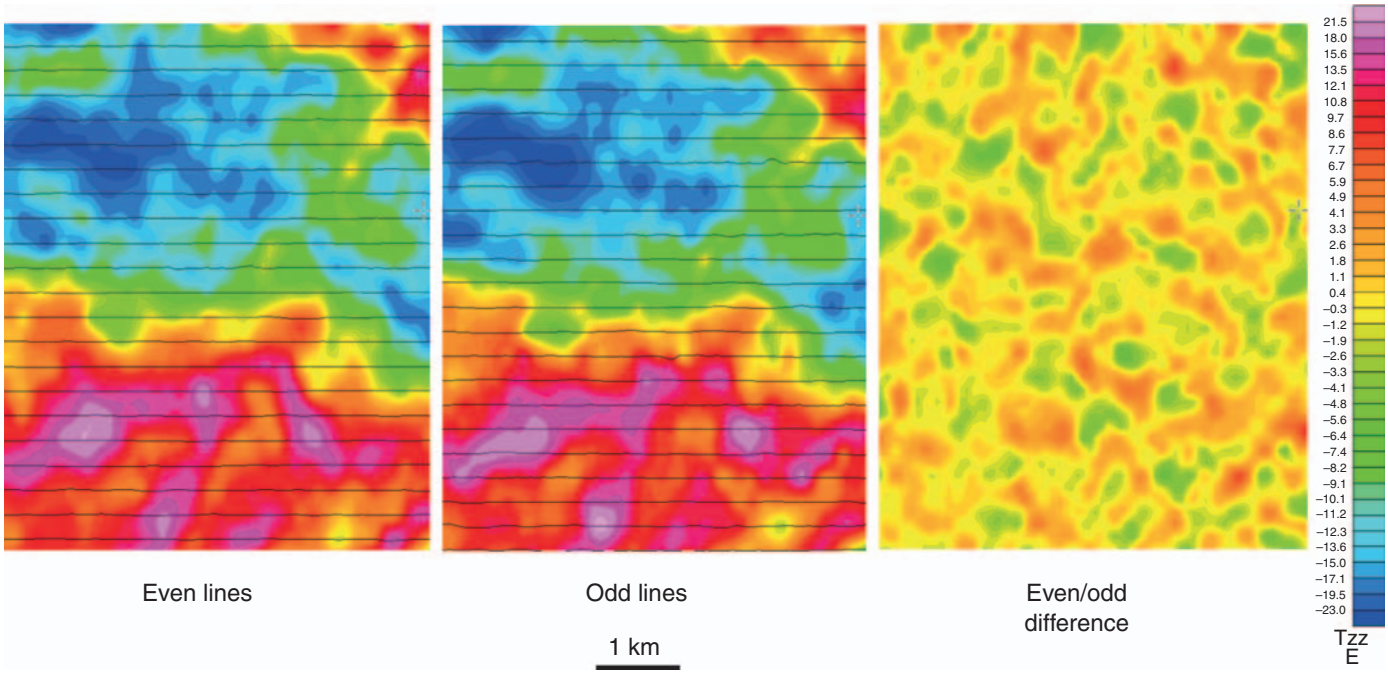

Fig. 4. Alternate line analysis of airship Air-FTG® data showing the grids calculated independently from the even and odd lines and the grid of the difference between these two.

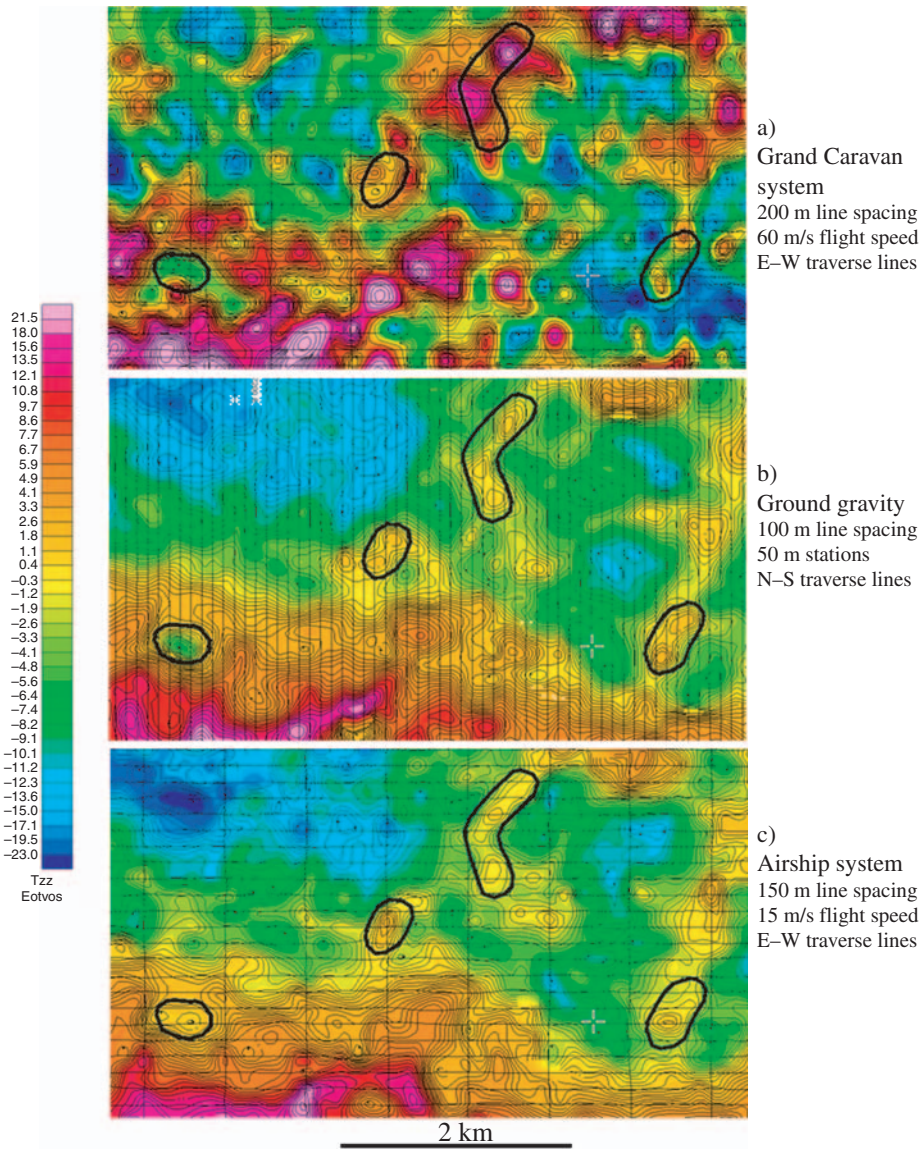

Fig. 5. (a) Air-FTG® data collected in the Grand Caravan. (b) Ground gravity data upward continued to equivalent survey height and re-sampled to the same interval of the airship data. (c) Air-FTG® data collected in an airship. The westernmost feature highlighted marks the location of a known kimberlite.

wavelength features can be distorted and others are generated which are not observed in the ground data. Line-levelling and microlevelling can be accomplished in the airship data with more accuracy and this long-wavelength distortion is greatly reduced.

Some of the subtle geological features visible in the ground data that have amplitudes less than 10E have been highlighted in Figure 5 on all of the datasets. Careful comparison indicates that most of these are well resolved in the airship data but very few are visible in the data acquired on the Grand Caravan. Of particular interest is an anomaly which is highlighted on the plots and is associated with a known kimberlite that is 2.7 Ha in size and is clearly visible in the ground gravity data. The same feature is also evident in the airship data, even though it is crossed by a single flight line. However, it is not detected with the fixed wing data despite having three lines crossing the kimberlite anomaly. The slower flight speed and lower noise level experienced by the instrument aboard an airship lessens the requirement for filtering and allows these subtle features to be detected.

The reduction of the noise levels in the airship data also greatly reduces the number of false anomalies that can have an appearance similar to those caused by kimberlites. There are several anomalies present in the Grand Caravan data that are of similar size, shape and amplitude that could be interpreted as kimberlite targets. However, as many of these features are not present in the ground gravity data they are in fact residual noise. By comparison there are very few anomalies, if any, that could be interpreted as kimberlite targets in the airship data that are not also visible in the ground gravity data.

Hueburg test area

The Botswana test site doesn't provide an opportunity for a conclusive spatial resolution test as the area is covered by flat-lying sediments (the geology doesn't provide adequate short wavelength gravity anomalies) and there is little topographic relief. An earlier test conducted in Germany was over rugged terrain for which an accurate DTM was acquired. The Air-FTG® data were acquired on a tight drape with a line spacing of 100 m in an east-west traverse direction. Figure 6 shows an image of the Tzz anomaly overlain by the DTM contoured to 50 m intervals. There is very strong correlation between DTM peaks which are 100 m wide and have been circled (white) where they correspond to a Tzz anomaly that is also 100 m wide. As well examples of closely spaced 100m anomalies that can clearly individually be seen indicates the spatial resolution for Air-FTG® data acquired on the Zeppelin would be on the order of 100 m wavelengths.

Productivity

The noise in an Air-FTG® data set is greatly dependent on the turbulence experienced by the aircraft during the time of data recording. As shown in Figure 7, an extended survey program in a fixed wing aircraft using only data with an acceptable quality produced average vertical acceleration of 31 mGal. As vertical accelerations increase, the data quality deteriorates and typically when the maximum turbulence exceeds 80 mGal the survey program is halted until conditions improve. The accelerations experienced during the airship test program averaged between 10–11 mGal for all lines in a wide range of weather conditions which included relatively high wind speeds and gusty conditions. The weather did not greatly affect the data quality of the Air-FTG® system and very few airship survey lines have needed to be re-flown due to acceleration induced noise. During adverse weather conditions flights were cancelled on the basis of safety, productivity and ability to adhere to line-keeping specifications rather than data quality concerns.

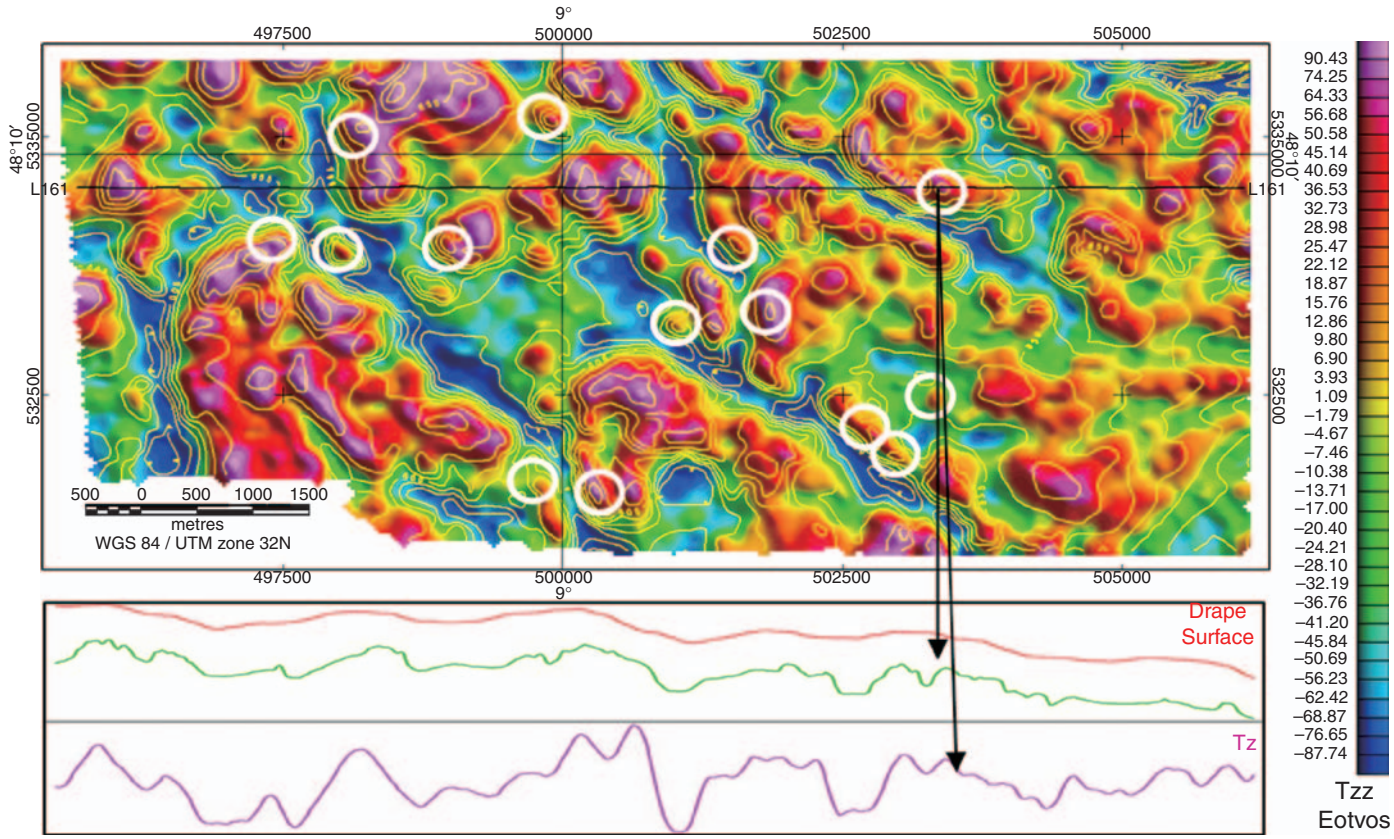

Fig. 6. Zeppelin Air-FTG® data with DTM overlay (yellow contours). DTM contour interval, 100 m. White circles where 100 m closures correspond to Tzz anomalies. Profiled drape, DTM and Tzz anomalies for Line 161 are shown in the lower half.

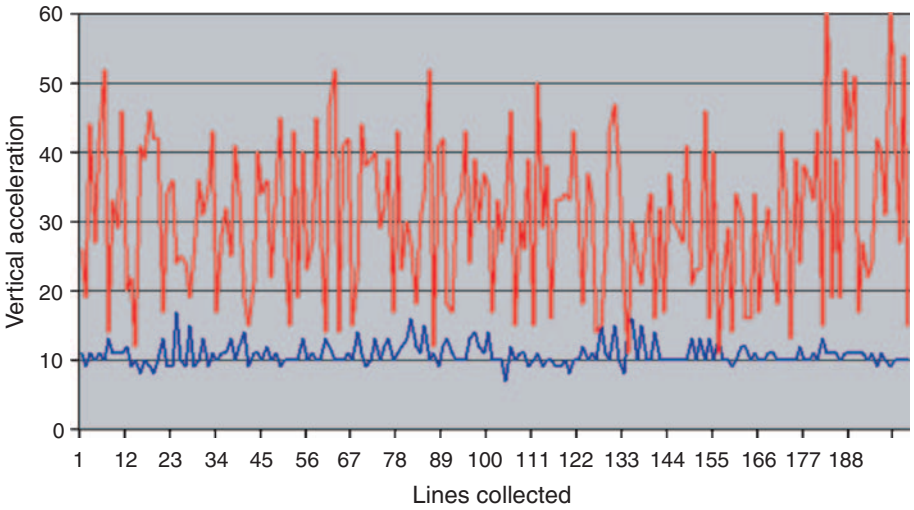

Fig. 7. Average vertical acceleration (mGal) recorded over a number of surveys lines which produced acceptable data for a Grand Caravan (red curve) and airship (blue curve).

Table 1. Specifications and performance for Zeppelin LZ N07

Length	75.1 m
Hull diameter	14.2 m
Envelope Volume	8425 m^3
Max. airspeed	60 kn (111 km/h)
Normal cruising speed	35 to 50 kn (65 km/h to 93 km/h)
Max. rate of climb	360 m/min
Max. rate of descent	300 m/min
Max. endurance	22 h
Max. range	1100 km
Design useful load	1850 kg

Conclusions

Air-FTG® data recorded in a fixed-wing aircraft moving at speeds of approximately 60 m/s has been documented with an RMS noise level between 5 to 6 E and a resolution of 300 to 400 m wavelengths. The repeat line analysis confirms that the flight characteristics of the airship result in an instrument noise level that is 5 times lower than in a Cessna Grand Caravan. The low level of acceleration within the airship is not greatly affected by varying weather conditions which results in excellent productivity and very few re-flights. The lower instrument noise enables line levelling to be more accurate and requires less strenuous filtering, resulting in a truer representation of the gravity field at both short and long wavelengths. During the test program it was observed that the Air-FTG® data acquired on a Zeppelin NT airship at a line spacing of 150 m resulted in an RMS noise level of 1.7 E with 100 m wavelength resolution along flight-lines, a significant improvement over fixed wing platforms.

This improved data quality will result in the detection of more deposits that cannot be seen in the Air-FTG® system mounted

in a fixed-wing aircraft. Further, the wavelength and amplitude of residual noise in the airship data virtually eliminate false anomalies that are present in the Grand Caravan data.

Acknowledgements

The authors would like to thank De Beers Group Services for permission to publish this paper and for the invaluable assistance provided during the roll-out of the project by many individuals at Zeppelin Luftshifftechnik.

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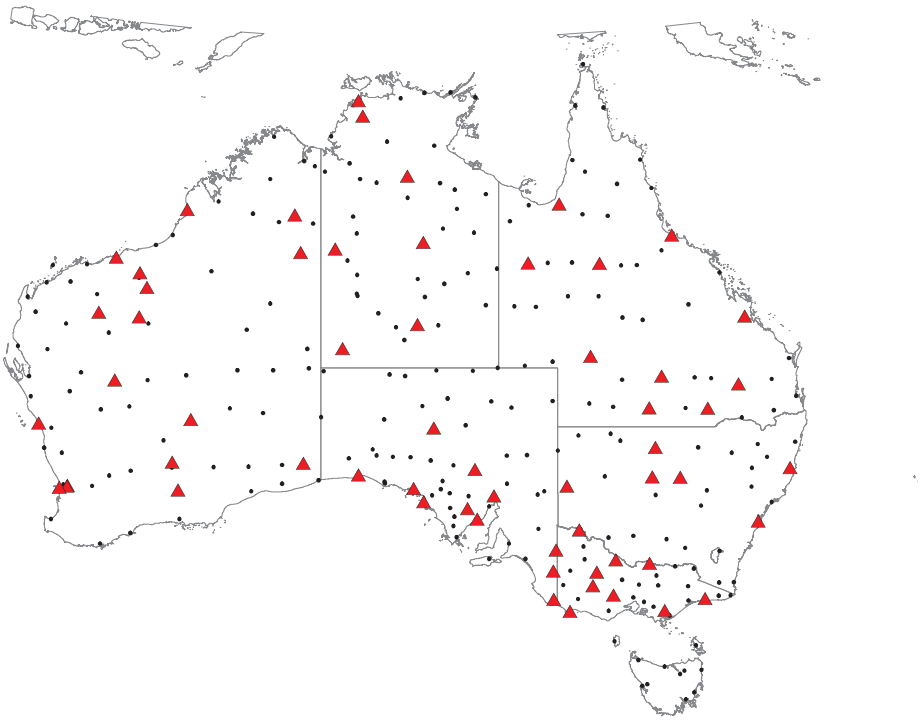

Fig. 7. Australian Fundamental Gravity Network sites (black dots) including those that have had absolute gravity measurements during the last five years (red triangles).

Table 6. Some statistics on the GADDS system			
No. sessions	**Download volume (MB)**	**No. unique datasets**	**No. datasets downloaded**
17,297	724,684.095	2,215	42,993

Table 7. The ten most popular GADDS products	
Product	**Count**
9 Second Digital Elevation Model of Australia	3,185
Gravity DB Oracle	824
Magnetic Grid of Australia 4th edn 2004 – onshore	736
Gravity DB Oracle – since 2003 Release	706
Gravity Grid of Australia 2001	696
Gravity Grid of Australia 2005	456
Magnetic Grid of Australia 3rd Edition 1999	401
Australian Bathymetry and Topography Grid June 2005 edn	303
Magnetic Grid of Queensland 2003	269
NT_Uranium_Grid_2004	264

gamma-ray, elevation and gravity data during this period. The introduction of GADDS means that for the first time, publicly available Australian geophysical data are now available to anyone at any time.

Acknowledgements

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Primary Connections – helping science regain its place in primary schools

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Introduction

Australia is facing a projected skills shortage of trained science professionals. The Australian Government Department of Education, Science and Training (DEST)'s audit of science, engineering and technology skills shows that of the 55,000 extra science professionals we'll need by 2011, we'll fall short by 19,250 (35%). This means that in the near future, science teachers may be hard to find, when we are already facing a lack of interest in the teaching of science itself.

Primary Connections, a partnership between the Australian Academy of Science and DEST, is an innovative program that links the teaching of science with the teaching of literacy in the primary years of schooling. It seeks to provide teachers with both an effective pedagogy and a resource to help bring science into the classroom. Building on students' natural curiosity, and addressing what they already know, *Primary Connections* helps develop their passion for exploring how the world works.

Reinvigorating science in the classroom

Although parents rate science third in importance after literacy and numeracy (ASTEC 1997), very little teaching time is dedicated to it. Angus *et al.* (2004) show that primary teachers spend less time on science than all other subjects except for Languages other than English (LOTE). Time allocation for science was only 41 minutes per week on average over K–7 i.e. 2.7% of total weekly teaching time.

Many primary teachers lack confidence and competence with science teaching (Yates and Goodrum 1990; Hackling and Prain 2005). There are also concerns about the adequacy of pre-service education (Lawrance and Palmer 2003) and pedagogical content knowledge (Gess-Newsome 1999). In other words, teachers are not always taught how to teach science. By providing both a professional learning program, and curriculum resources that respond to needs identified by teachers, *Primary Connections* aims to address these issues.

The Primary Connections program

The *Primary Connections* team, working with many external writers and reviewers, have published seven of their projected nineteen curriculum resource books. They cover the four national curriculum strands: Life and Living, Earth and Beyond, Natural and Processed Materials, and Energy and Change. Both the conceptual and investigating outcomes are geared for the age groups' abilities. Each book explores a limited range of concepts, for example one unit is focused on the Earth's crust, plate tectonics and earthquakes. Focusing the unit allows teachers time to engage with students beliefs and provide real conceptual change and deep understanding, as well as opportunities for developing investigative skills. Some of the unit titles are 'Spinning in space', 'Marvellous micro-organisms', 'Weather in my world' and 'Water works'. Teachers are encouraged to develop their own units on topics not covered by the published resources.

In order to give teachers the tools for effective learning and teaching, *Primary Connections* is also developing a professional learning course. The course introduces teachers to the underpinning principles of the program: the 5Es pedagogical learning model, the linking of science and literacy, the development of investigation, assessment for learning, and cooperative learning. This allows them to understand how the units are constructed, ensuring they use them to the best advantage for the students.

To date, the Academy has trained over 210 professional learning facilitators, from every state and every jurisdiction within each state. These facilitators are now developing support models for schools, presenting information sessions to teachers and principals, running workshops for schools interested in implementing the program and facilitating a professional learning program for groups of school coordinators**.** Also 65 pre-service teacher educators, from every university in Australia that provides a primary school teaching course, were given similar training. This means that student teachers will also have the opportunity to learn about the program.

Linking science with literacy

The innovation in *Primary Connections* is to explicitly explore the links between science and literacy. Firstly everyday literacies such as reading and writing are necessary skills to support the learning of scientific concepts and content. Science provides a context to explore representations through many different means, including drawing, gestures and role play (see Fig. 1).

Secondly there are the literacies of science. These can be modes of representations, such as tables and graphs, or modes of reasoning, such as evidence-based arguments. There is also a set of vocabulary that characterises science, and a set of practices, such as using models to represent the world (see Fig. 2).

5Es teaching and learning model

Primary Connections is based on an inquiry-oriented teaching and learning model (see Fig. 3). Teaching and learning progresses through five phases, modelled on the 5Es instructional model (Bybee 1997).

The *Engage* phase is designed to spark students' interest, stimulate their curiosity, raise questions for inquiry and elicit students' existing beliefs about the topic.

The *Explore* phase provides students with hands-on experiences of the topic's science phenomena (see Fig. 4), ensuring all students have a shared experience that can be discussed and explained in the *Explain* phase.

In the *Explain* phase students discuss and identify patterns and relationships within observations and develop scientific explanations. Students consider the current views of scientists and deepen their own understanding.

In the *Elaborate* phase students plan and conduct an open investigation to apply and extend their new conceptual understanding in a new context.

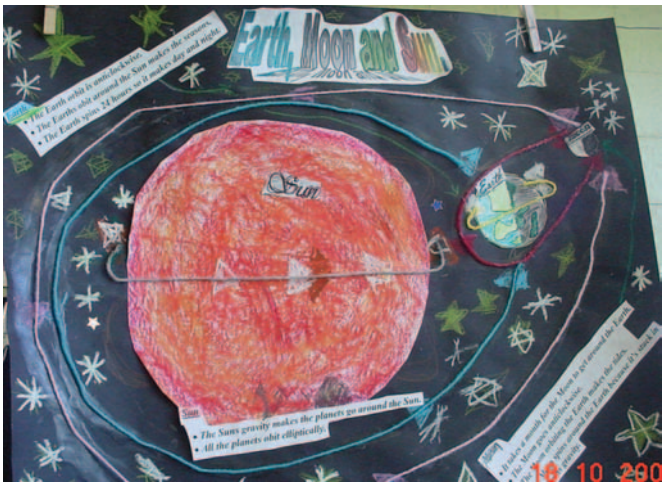

Fig. 1. Using everyday literacies to explain science.

Fig. 2. Learning the literacies of science.

Fig. 3. Elements of the Primary Connections inquiry approach.

Fig. 4. Exploring hands-on activities.

In the *Evaluate* phase students reflect on their learning journey and create a literacy product to re-represent their conceptual understanding.

Real results

Primary Connections was trialled by 106 teachers in 56 schools, reaching over 3,000 students across all states and territories in 2005. The schools were from all jurisdictions and sectors, and included schools from metropolitan, regional and rural area. The teachers completed 5 days of initial professional learning. A range of data was collected throughout the trial, including teacher and student questionnaires, case studies, and analysis of students' work samples.

Teachers' confidence with nine science and literacy teaching strategies was assessed on a five point scale. Their mean confidence scores increased significantly ($P < 0.05$) from 3.34 at the beginning of the program to 4.04 at the end of Term 2.

96 of 97 teachers said their teaching had improved. They reported an increase in the teaching of the literacies of science, the use of hands-on activities, and the use of diagnostic assessment to determine the existing conceptions of students.

The amount of science being taught in the classroom increased, with 73% of teachers teaching over an hour of science a week (vs 33% before the trial). Students responded positively to the activities and the learning approach. There was a positive impact of the program on literacy learning, with students using a wider range of forms of representation. Lastly science was given a higher status within the school (Hackling and Prain 2005).

What the future holds

Primary Connections aims to help students become more scientifically literate in an increasingly information-rich world. Scientific literacy is a high priority for all citizens, helping them to:

- be interested in, and understand the world around them,
- engage in the discourses of and about science,
- be sceptical and questioning of claims made by others about scientific matters,
- be able to identify questions, investigate and draw evidence-based conclusions, and
- make informed decisions about the environment, and their own health and well-being (Goodrum *et al.* 2001).

An aspect of helping students to become scientifically literate is to connect the learning of science to students' everyday lives and local communities. An Indigenous perspective is currently being researched to help teachers engage all students with science.

Further information about *Primary Connections* can be found on the web site: www.science.org.au/primaryconnections

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Geological Surveys of Queensland, Western Australia, Northern Territory, Tasmania and Geoscience Australia

Update on Geophysical Survey Progress (Information current at 16 March 2007)

For more information contact Murray Richardson of Geoscience Australia at murray.richardson@ga.gov.au

Table 1. Airborne Magnetic and Radiometric Surveys

Survey Name	Client	Project Management	Contractor	Start Flying	Line km	Spacing AGL Dir	Area (km^2)	End Flying	Final Data to GA	Locality Diagram (Preview)	GADDS release
Ashburton	GSWA	GA	UTS	4 Aug 06	105,840	400 m 60 m N/S	34,920	27 Dec 06	9 Mar 07	121 – Apr 06 (p. 35)	TBA
Southern Officer Basin	GSWA	GA	GPX	15 Aug 06	105,200	400 m 60 m N/S	37,330	18 Jan 06	16 Mar 07	121 – Apr 06 (p. 35)	TBA
Musgrave	GSWA	GA	Fugro	15 Jun 06	83,950	400 m 60 m E/W;N/S	27,920	10 Oct 06	30 Jan 07	121 – Apr 06 (p. 35)	Released 13 Feb 07
Isa South-West	GSQ	GA	Fugro	3 Apr 06	140,000	400 m 80 m E/W	50,100	2 Aug 06	30 Jan 07	118 – Oct 05 (p. 41)	Released 13 Feb 07
Isa South-East	GSQ	GA	Fugro	8 Aug 06	101,200	400 m 80 m E/W	35,800	19 Nov 06	TBA	118 – Oct 05 (p. 41)	TBA
Tiwi Islands	NTGS	GA	Fugro	2 Oct 06	29,300	400 m 80 m N/S	10,200	19 Nov 06	5 Feb 07	123 – Aug 06 (p. 39)	Released 13 Feb 07
North-East Tas	MRT	GA	GPX	18 Mar 07	52,000	200 m 90 m E/W	8,600	TBA	TBA	123 – Aug 06 (p. 39)	TBA
Flinders Island	MRT	GA	UTS	9 Jan 07	17,900	200 m 90 m E/W	2,900	91% complete @ 14 Mar 07	TBA	123 – Aug 06 (p. 39)	TBA
East Isa North	GSQ	GA	UTS	At end of Flinders Island Survey	113,000	400 m 80 m E/W	39,940	TBA	TBA	125 – Dec 06 (p. 32)	TBA
East Isa South	GSQ	GA	Fugro	10 Mar 07	145,900	400 m 80 m E/W	51,560	16% complete @ 12 Mar 07	TBA	125 – Dec 06 (p. 31)	TBA
AWAGS2	GA	GA	UTS	Mobilised to Broken Hill 28 Feb 07	145,350	75 km 80 m N/S	7,659,861	TBA	TBA	124 – Oct 06 (p. 15)	TBA
Croydon	GSQ	GA	UTS	16 May 07	100,230	400 m 80 m E/W	335,310	TBA	TBA	This issue	TBA
Tanumbirini	NTGS	GA	UTS	Mid June 07	69,463	400 m 80 m E/W	24,047	TBA	TBA	126 Feb 07 (p. 35)	TBA
Canning Basin	GA	GA	Fugro	20 Apr 07	102,656	800 m 80 m N/S	70,192	TBA	TBA	This issue	TBA

TBA: To be advised

Table 2. Gravity Surveys											
Survey Name	**Client**	**Project Management**	**Contractor**	**Start Survey**	**No. of Stations**	**Station Spacing (km)**	**Area (km²)**	**End Survey**	**Final Data to GA**	**Locality Diagram (Preview)**	**GADDS Release**
Isa Area C	GSQ	GA	Fugro	19 Oct 06	9,236	2 and 4 regular	68,500	100% complete @ 10 Feb 07	TBA	124 – Oct 06 (p. 29)	TBA
Murchison	GSWA	GA	Fugro	10 Feb 07	3,600	2.5 regular	24,800	77% complete @ 12 Mar 07	TBA	123 – Aug 06 (p. 39)	TBA
Isa Area D	GSQ	GA	Daishsat	At end of Isa Area E Survey	4,903	4 regular	75,460	TBA	TBA	125 – Dec 06 (p. 32)	TBA
Isa Area E	GSQ	GA	Daishsat	1 Feb 07	6,233	4 regular	97,420	53% complete @ 5 Mar 07	TBA	125 – Dec 06 (p. 32)	TBA

TBA: To be advised
Locality diagrams for the Canning Basin and Croydon surveys are shown in Figures 1 and 2.

GSWA Regional Geophysics Survey Program: March 2007 update

As stated in the Industry News section of *Preview*, Western Australia is the most active State as far as both mineral and petroleum exploration is concerned. Figure 3 shows in detail the plans of the Geological Survey of WA to improve the State's geophysical coverage. This should be viewed in conjunction with Tables 1 and 2 in this section.

Geoscience Australia

Seismic Reflection Surveys

Planning for forthcoming Isa-Georgetown-Charters Towers seismic reflection survey is in full swing. The project involves collaboration between Geoscience Australia and the Geological Survey of Queensland, Department of Mines and Energy. Geoscience Australia's involvement is under its Onshore Energy Security Program (OESP) delivering on the recent Commonwealth Government's Energy Security Initiative while the Geological Survey of Queensland's involvement is under its Smart Mining – Future Prosperity Program. The seismic operations will be supervised by Geoscience Australia staff and undertaken by ANSIR, the Australian National Facility for Earth Sounding, using Terrex Seismic Pty Ltd to undertake the data acquisition.

The survey runs from the eastern edge of the Mt Isa Inlier to the Georgetown Province, then southwards through Charters Towers to the Drummond Basin (see Figure 4) and involves the acquisition, processing and interpretation of deep seismic reflection and add-on earth imaging experiments from a series of seismic traverses that research the:

- eastern margin of the Mt Isa Inlier,
- western margin of the Georgetown Province,

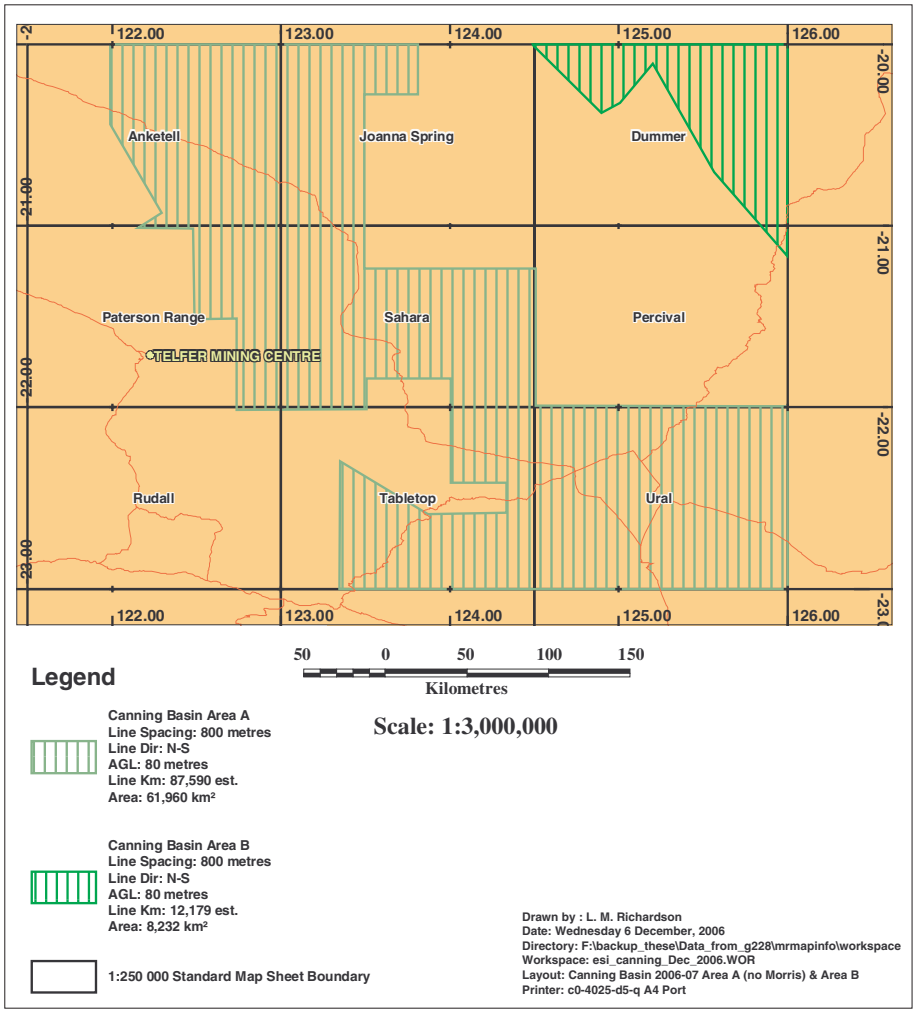

Fig. 1. Location of Canning Basin Survey in Western Australia.

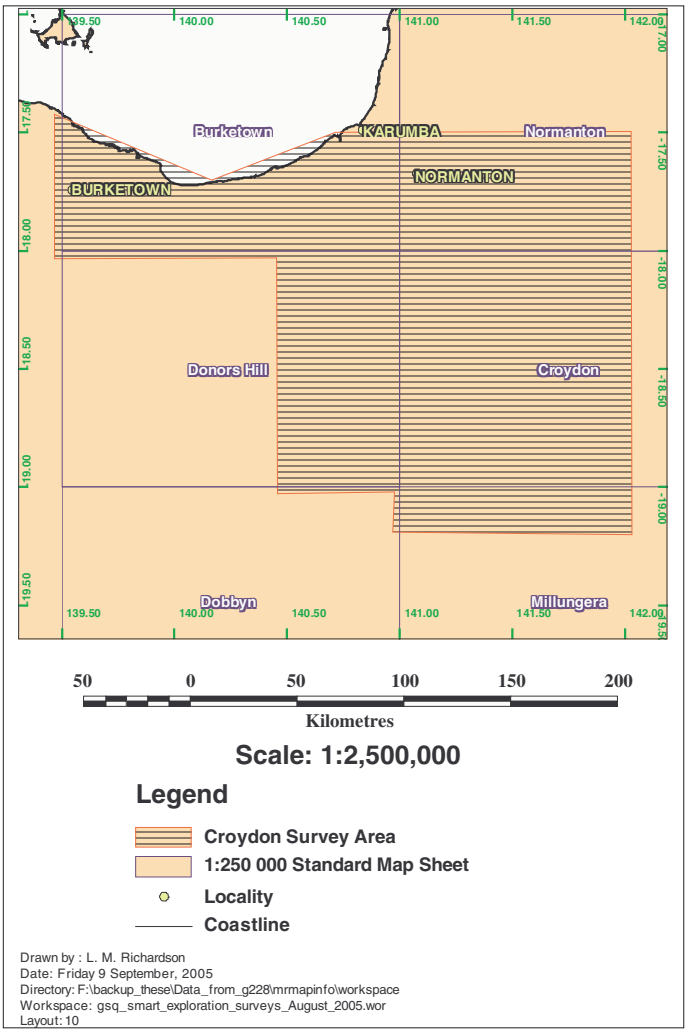

Fig. 2. Location of Croydon Survey in Queensland.

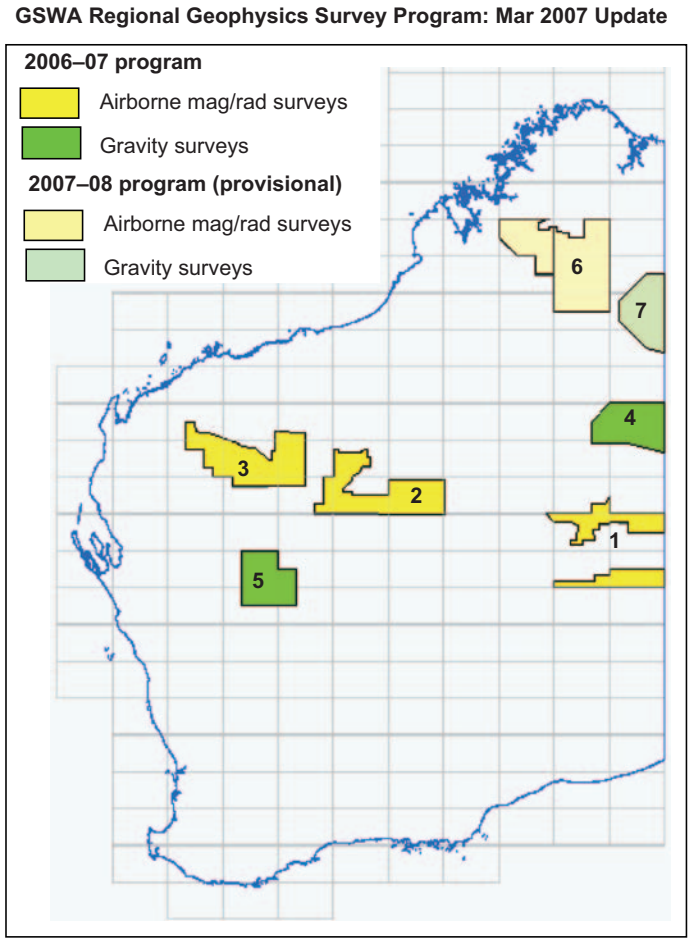

Fig. 3. Map showing locations of recently completed and planned geophysical surveys in WA.

Table 3. Details of WA Regional Geophysical Surveys

ID	Name	Specifications	Status	Start	End	Release*
Airborne Mag/Rad Surveys						
1	Musgrave 2006	400 m × 60 m; E/W; N/S	Complete	Jun 06	Oct 06	13 Feb 07
2	Officer (Trainor) 2006	400 m × 60 m; N/S	Complete	Aug 06	Jan 07	28 Mar 07
3	Ashburton 2006	400 m × 60 m; N/S	Processing	Aug 06	Jan 07	Apr 07
6	South Kimberley 2007	400 m × 60 m; N/S	Planning	Jul 07	Dec 07	Apr 08
Gravity Surveys						
4	Webb 2006	2.5 km regular	Complete	Aug 06	Sep 06	21 Dec 06
5	Murchison 2007	2.5 km regular	Acquisition	Feb 07	Mar 07	May 07
7	West Tanami 2007	2.5 km regular	Planning	Dependent on Land Access		

Information current at: 14 Mar 2007

Comments

**Dates shown are for release of final data; dates in parentheses are provisional.*

Final data releases are available by download from the Geoscience Australia Data Delivery System at www.ga.gov.au/gadds. Releases of preliminary data, generally at about 50% and 100% of the data acquisition stage, are made on the GSWA website (www.doir.wa.gov.au/GSWA) 'Maps and Images' page.

*Subscribe to the **GSWA newsletter** (subscription link located on the 'News and Events' page of the GSWA website) to keep informed of preliminary and final data release dates.*

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- relationship between the Georgetown Province, Cape River and Broken River Province and northern margin of the Drummond Basin,
- geodynamic setting of the Mt Isa Inlier, Georgetown Province, Cape River Province, Broken River Province and Drummond Basin,
- internal structure of the Georgetown Province, Cape River Province and Broken River Province, and investigates the
- relationships between crustal architecture, geodynamic setting, mineral and energy systems and geothermal systems.

This survey is scheduled to commence in April 2007 and involves the collection of approximately 1300 km deep seismic reflection data, as well as coincident gravity data and magnetotelluric data. In addition, approximately 200–250 km of seismic will be acquired by ANSIR for the AuScope Far North Queensland Project which runs from the Mt Surprise region towards Cairns, crossing the Palmerville Fault and Tasman Line.

Planning is also progressing on the Gawler-Curnamona seismic reflection survey. This survey is a collaborative project between Geoscience Australia and the PIRSA. The project aims to increase investment in energy-related exploration in SA that will lead to new

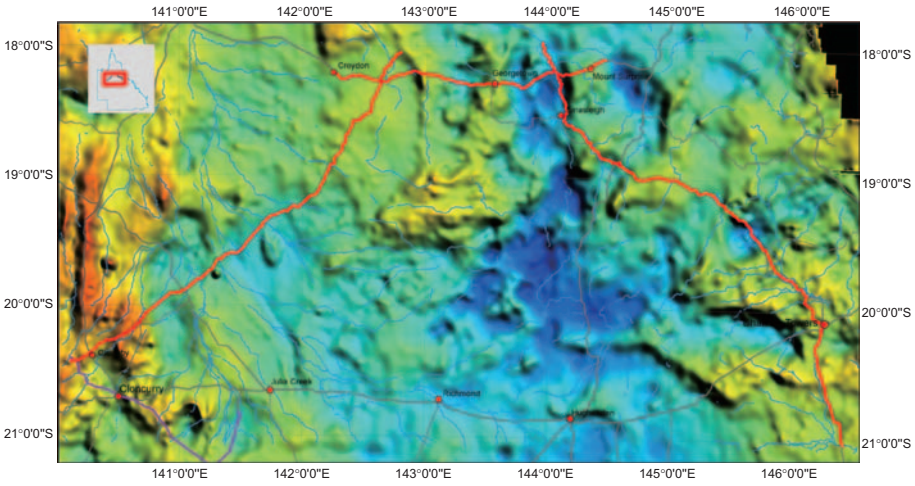

Fig. 4. Location of the proposed Isa-Georgetown-Charters Towers Seismic Survey, North Queensland. The seismic survey lines are superimposed on the Bouguer gravity map of the region.

discoveries of geothermal and onshore energy resources. It will also reduce the risks of exploration and increase efficiency of discovery process as well as creating an increase ground uptake in greenfields areas.

The ANSIR high-frequency MiniVib is currently in the Otway Basin working on a CO2CRC project to record a high resolution baseline 3D seismic reflection survey and simultaneous 3D VSP. This project will form the basis of the world's first time-lapse seismic case study of C02 sequestration within a depleted gas field. Later it moves to Western Australia to do follow-up work in the Jundee Area of the Eastern Goldfields to map Archaean stratigraphy and structure hosting mesothermal lode gold deposits in the Yandal greenstone belt, Western Australia. The MiniVib then moves to Queensland to work in the coalfields.

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Australian gold production in 2006 at lowest since 1993

Australian gold mines produced 249 tonnes of gold in 2006, down from 263 tonnes in 2005 and the lowest since 1993, when 248 tonnes were produced. These data were released in Surbiton Associates, *Australian Gold Quarterly Review*, which was published in March 2007. Figure 1 shows the quarterly production numbers from 1986 onwards.

Annual production peaked at 313 tonnes in 1997 and has been steadily declining following the 82 tonne quarterly peak in the fourth quarter of 1997.

Australia is now third in the world rankings of gold producing countries. South Africa is still first with 275 tonnes, but the US has moved into second place with 252 tonnes. However, according to Sandra Close of Surbiton Associates, China is likely to make a big impact by lifting production by 20 tonnes to an expected 260 tonnes in 2007. Figure 2 shows how both Australia and South Africa have fared since 1970.

The decline in South African production is dramatic, falling steadily from 1000 tonnes in 1970 to the 275 tonne level in 2006. This decline is mainly due to the gold being harder to extract, but the affect of AIDS on the workforce is now also thought to be significant.

In spite of predictions a few years ago that Australia would overtake South Africa, this has not yet happened.

However, the news is not all bad for Australian gold miners because according to Sandra Close the value of Australian gold production for 2006 increased by almost 30% to A$6.4 billion, following the increase in the average spot price of gold from $600 in 2005 to $800 an ounce in 2006.

The Kalgoorlie Super Pit retained its place as the largest Australian producer just ahead of Telfer for the full 2006 year, but Telfer was the largest producer in the December quarter with a 5.2 tonne production as compared with 5.1 tonne from the Super Pit.

Table 1 shows the annual production numbers from the top five producers.

It is noteworthy that the only Australian-owned company in the top ten is Newcrest. Placer Dome's takeover of AurionGold in 2006 has lifted foreign control of the Australian gold industry to 70%, according to Surbiton Associates.

It would appear that there are good opportunities for boosting gold exploration, particularly as the price of gold remains firm. The prize for finding a large deposit is very attractive.

Rig numbers rise world-wide

The number of rigs drilling for oil is a good indicator of the health of the petroleum exploration industry. Baker Hughes Inc. has for many years compiled a count of active rigs and in Figure 3 we have plotted the data from 1975 through 2006 and also included two months of 2007.

As might be expected the number of rigs correlates well with the price of oil over the last 30 years. Perhaps the most remarkable statistic to come out of these plots is that the US by itself has accounted for approximately 50 percent of the world's oil rigs since 1975, even though it only occupies about 5 percent of the Earth's land surface and currently has reserves of less than 3 percent of the world's total.

The logical conclusion that has to be drawn is that there should be opportunities for a lot of successful drilling in other parts of the planet for some considerable time.

Mineral and Petroleum exploration continue to surge in December quarter

Minerals

Exploration powers ahead

Figures released by the Australian Bureau of Statistics in March 2007 show that the trend estimate for total mineral exploration expenditure increased by 9.5% in the December quarter of 2006. The trend estimate of $416.1 million is now 40.6% higher than the December quarter 2005 estimate The level of actual expenditure when it is CPI adjusted is at $288 million, very close to the CPI adjusted record peak of $289 million, reached in the June quarter of 1997, and is the second highest on record.

Figure 4 shows the expenditure estimates from December 1998 through December

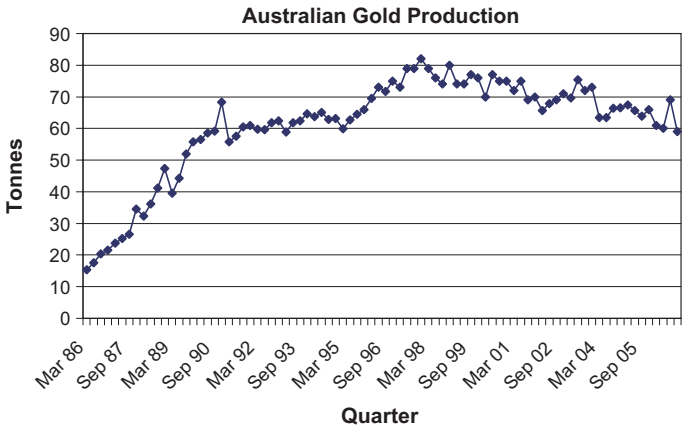

Fig. 1. Quarterly gold production in Australia for 1986 through 2006. Notice the general decline since the peak of 82 t in the last quarter of 1997.

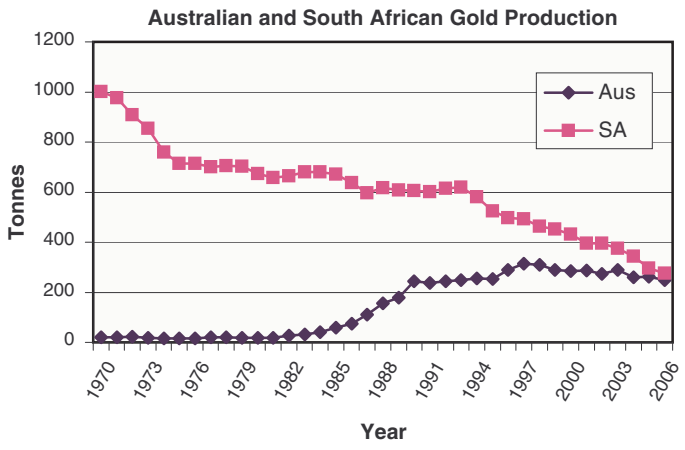

Fig. 2. Annual gold production in Australia and South Africa from 1970 through 2006.

Table 1. Top five gold operations in Australia for 2006		
Operation	**Tonnes**	**Owners**
Super Pit – JV	21.0	Newmont Mining Corp 50%, Barrick Gold Corp 50%
Telfer	20.6	Newcrest Mining Ltd
Kanowna/ Paddington*	15.7	Barrick Gold Corp
St Ives/Lefroy	15.5	Gold Fields Ltd
Sunrise Dam	14.4	AngloGold Ashanti Ltd

**Two plants*

2006. Both the trend and the seasonally adjusted numbers are powering ahead.

Figure 5 shows the longer term trends from March 1986. It indicates that in real terms (CPI adjusted) the expenditure levels have almost reached those of 1997.

The largest contribution to the increase this quarter was in Western Australia where investment increased by $21.7 million or 12.2% to a record $217.3 million. WA was followed by Queensland at $73.7 million and South Australia at $59.1 million. All states except Tasmania showed increasing expenditure levels this quarter and WA again dominated the scene by attracting 48 percent of the total investment.

A very good sign was the increase in Greenfield investment. This jumped by 16 percent from the September quarter to $160.2 million, while the Brownfield investment only increased by 11 percent to $288.0 million. So the Greenfield expenditure is at a high of 36 percent of the total expenditure. And we need this to discover new deposits.

The trend estimate for metres drilled increased by 7.5% this quarter. The current estimate is now 28.0% higher than the December quarter estimate for last year. In seasonally adjusted terms, total metres drilled increased by 7.0% in the December quarter 2006 to 2183 km. However, the actual metres drilled decreased by 6.7% to 2099 km. Drilling in areas of new deposits increased by 10.8% to 900 km and drilling in areas of existing deposits decreased by 16.7% to 1199 km.

Clearly, the mineral exploration boom shows no signs of slackening off.

Petroleum

Record levels of expenditure

The petroleum sector also turned in a very impressive performance and exceeded the

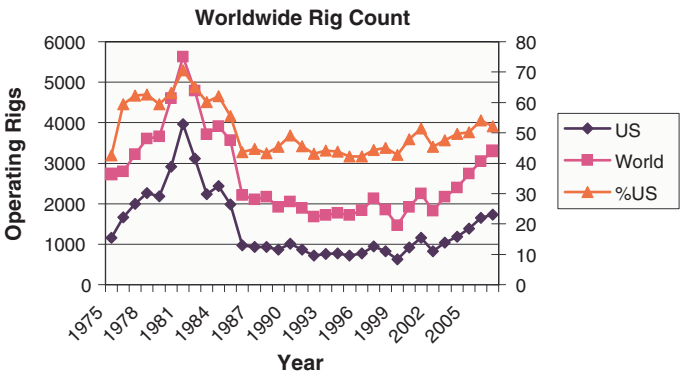

Fig. 3. Plot of Baker Hughes worldwide rig counts for 1975 through February 2007. Notice how the US percentage of total rigs has stayed within 50 ± 10% for most of the period covered (see secondary axis).

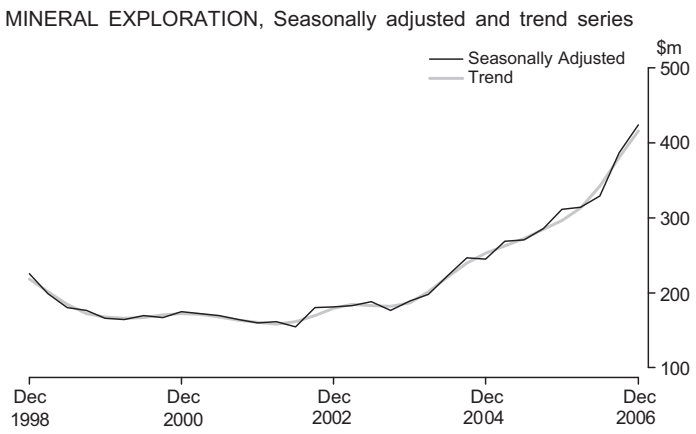

Fig. 4. Trend and seasonally adjusted quarterly mineral exploration expenditure from December 1998 through December 2006 (provided courtesy of the Australian Bureau of Statistics).

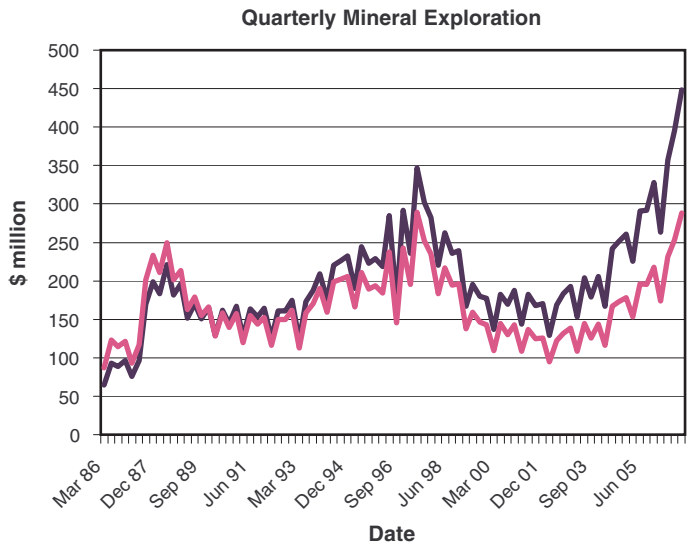

Fig. 5. Quarterly 'actual' mineral exploration expenditure from March 1986 through December 2006 (from ABS data). The black curve represents actual dollars spent and the purple curve shows the CPI adjusted number to 1998/99 levels (ABS data).

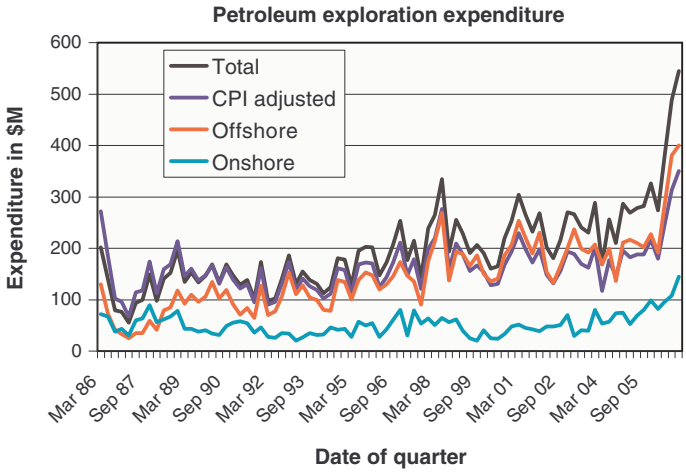

Fig. 6. Quarterly petroleum expenditure from March 1986 through December 2006. The individual offshore and onshore numbers are actual numbers spent at the time, not CPI adjusted. The black graph shows the contemporary dollars spent and the blue curve shows the CPI adjusted number to 1989/90.

record levels achieved in the September 2006 quarter.

Expenditure on petroleum exploration for the December quarter 2006 increased by $55.9 million (11.4%) to a new record of $544.5 million.

Expenditure on production leases increased by $3.8 million or 2.9%, to $135.1 million while exploration on all other areas increased by $52.0 million or 14.6% this quarter to $409.3 million. Therefore the government's policy of encouraging exploration in new areas appears to be paying off well.

There was an increase of $19.2 million (5.0%) in offshore exploration to $400 million, while onshore exploration expenditure increased by a massive $36.7 million (34.0%) to 144.5 million. Figure 6 shows the very encouraging trends.

In the December quarter 2006, Western Australia had the largest increase in petroleum exploration expenditure of $56.2 million (19.4%) to $346.1 million, followed by Queensland with an increase of $20.4 million (56.4%) to $56.6 million. Northern Territory had the largest decrease of $26.2 million (25.8%) to 75.2 million.

As for the mineral statistics Western Australia dominated with a massive 64 percent slice of the national cake. No wonder Perth is booming!

Exploration frenzy as Uranium heads for $US100

As the spot price for uranium (U_3O_8) heads for $US100 a pound, an exploration frenzy is taking place in Australia. From October 2006 to March 2007 the price rose from $US55/lb to $US90/lb. Paladin's share price has benefited substantially, with its market capital rising from $1.6 billion in March 2006 to $4.6 billion in March 2007. It now plans to be the world's fourth-largest uranium producer by 2010.

At the same time uranium exploration programs have expanded dramatically. In March 2007 alone there were at least 18 announcements to the ASX by 16 companies hunting for uranium. Most of these companies are small, but they are searching throughout Western Australia, South Australia and the Northern Territory. Table 2 gives a flavour of the work being undertaken. Notice the focus on palaeo-drainage channels. The ASX media releases are the sources for this information.

Table 2. Snapshot of uranium exploration in Australia in March 2007

Company	Project
Arafura Resources Ltd	Arafura has created a dedicated uranium exploration company, NuPower Resources Limited. It is working on three projects covering 10,000 km^2 at Lagoon Creek, Lucy Creek and the Aileron Basins. At ***Lagoon Creek,*** which is 400 km east/north east of Tennant Creek, the highlights announced include: • Significant uranium mineralisation intersected in 12 of 23 drill holes. • Best intercept of 5 m at 0.18% (3.9 lb/T) U_3O_8 • Individual 1 metre RC drilling samples assay up to 0.42% (9.1 lb/t) U_3O_8, and 1.57 g/t gold. At ***Lucy Creek,*** which is 265 km northeast of Alice Springs, a program of ground work, in combination with aerial radiometric imagery has identified significant uranium mineralisation, with grading up to 565 ppm U_3O_8 in selected samples. The uranium anomalies are associated with a 30 m thick sequence of deeply lateralised tertiary sediments. The ***Aileron Basins*** include 5,000 km^2 of land holdings in five tenements, situated 135 km north of Alice Springs. Initial exploration of the area identified a number of individual prospects in the intrusive complex, which contain significant grades of uranium mineralisation.
AusQuest Limited	AusQuest Ltd has scheduled surface sampling to start in early April within its ***Sylvania Project***, located south of Newman, WA, following encouraging results from a helicopter-borne radiometric survey over the project. The significant improvement in uranium anomaly definition provided by the low-level detailed helicopter survey will allow follow-up mapping and sampling to be focused in the best areas. A total of thirteen areas were surveyed, covering 80 km^2. According to AusQuest, uranium anomalies occur both within the granitic bedrock and over calcretes within the main palaeodrainages.
Catalyst Metals Ltd	Catalyst has acquired a new landholding covering multiple uranium-channel airborne radiometric anomalies in the Gascoyne region of WA. The new Koonana Hill exploration licence expands the area of the ***Minnie Creek Project*** to 1220 km^2. The anomalies occur in geological settings prospective for both palaeochannel and primary hosted uranium mineralisation. Several areas prospective for palaeochannel uranium mineralisation in calcrete have been outlined by airborne radiometric surveys.
Compass Resources	A scoping study has indicated that development of Compass Resources' ***Mt Fitch*** Uranium resources in the NT is economically viable on a stand-alone basis in the current uranium demand and price environment. A program of additional drilling, sampling and process engineering test work will now continue to refine and optimize concepts and collect more data for a definitive feasibility study. Development of ***Mt Fitch*** would provide the first step in the Compass plan for producing uranium from a number of potential resources in its large tenement holding including the Rum Jungle area.
Elkedra Diamonds	Elkedra Diamonds has made an in principle decision to spin-off its uranium and base metal prospects in the ***Georgina Basin*** into a new company. The new company's tenement package is expected to comprise approximately 8,000 km^2, nearly all of which is located in the Northern Territory. Work undertaken by Elkedra, while exploring for diamonds in the Georgina Basin and other available exploration data have confirmed the 8,000 km^2 tenement package contains highly prospective uranium and base metal targets, which warrant further exploration.
Epsilon Energy	Epsilon Energy has announced the grant of a number of exploration licences at its ***Balladonia Uranium Project*** in WA and its ***Pandanus West Project*** in Queensland. The approvals pave the way for drilling programs to commence at both projects. According to Mr Gauci the CEO of EE, uranium in the Balladonia province is sourced from the adjoining radiogenic granites of the Yilgarn Craton, transported via oxidized groundwater and deposited within porous sandy sediments or the extensive lignites within the identified palaeochannels. He believes this region of the Eucla Basin has the potential to host a major uranium deposit similar in style to the 21,000 tonne Beverley uranium deposit or the 47,000 tonne Mulga Rock uranium deposit.

(Continued)

Table 2 (continued)

Company	Project
	The ***Pandanus West Project*** lies within the Georgetown-Townsville Uranium Field, in Queensland, which has been the subject of widespread and successful uranium exploration. "We will start drill testing anomalies there in the June Quarter." he said.
Eromanga Uranium Ltd	Eromanga has discovered a palaeochannel system stretching more than 100 km in length in the far north of South Australia. This will be drill tested as early as mid-year in an area between the township of Marree and the operating Beverley uranium mine. The early success for Eromanga came after the company flew a 4,000 line-km EM survey across the ***Marree Project*** using an advanced aerial survey system designed to better identify palaeodrainages in which sandstone hosted uranium deposits can develop. "The new "REPTEM" system used by Eromanga has more stable flight and therefore improved data quality compared to the internationally respected HoistEM system." According to Eromanga's Managing Director, Kevin Lines. "Surface sampling of outcrops conducted in parallel with the survey, had identified non-economic secondary uranium mineralisation - occurrences which importantly, confirmed that uranium sourced from the adjacent ranges had flowed into, and been deposited within the ***Marree Project*** area," he said. The company would complete similar airborne EM surveys over its projects at ***Billa Kalina***, 70 km northwest of Olympic Dam; at ***Kingoonya*** further to the west; and in the Northern Territory, at ***Abminga***, just inside the border with SA.
Goldstream Mining NL	Goldstream has recommenced a drilling program targeting uranium in palaeochannels at its ***Mt Woods*** tenements south of Coober Pedy. The four holes drilled into palaeochannels are outstanding from Goldstream's 2006 uranium drilling program. The current round of drilling will advance the testing of the uranium palaeochannel concept and assist with refining the model for future exploration.
Halcyon Group Ltd	Halcyon has received positive indications that the ***Lake Marmion Uranium Project***, located approximately 130 km north of Kalgoorlie in WA, could host near surface uranium deposits, with surface samples from initial sampling programs having returned up to 140ppm U_3O_8. The company expects the first main tenement, ELA29/634, with an area of 208 km^2, in the project to be granted next month, allowing an aircore drilling program to start soon after to further test the better surface sample sites. Halcyon will continue the surface sampling program on the ***Lake Marmion Uranium Projec***t or geophysical surveys to better define the palaeochannel system, prior to test drilling.
Marathon Resources	Marathon has intersected further significant uranium mineralisation in the western part of its ***Mt Gee*** deposit in Northern Flinders Ranges of South Australia. The Mt Gee deposit, has an Inferred Resource of 45.5 million tonnes of uranium mineralisation, and is one of Australia's largest undeveloped uranium deposits. The new drill results are part of an extended program to upgrade the resource definition of the Mt Gee deposit from inferred to indicated and/or measured category.
Mindax Ltd	Mindax reported encouraging results from water sampling conducted throughout the Yilgarn ***Avon Uranium Project*** in Western Australia during February. A sample from the Lake Campion project area measured 1128ppb U, the highest value to date from the Project and directly comparable to the 1200ppb U historically reported from waters within the Yeelirrie uranium orebody. Planning is well advanced for a follow up drilling program in April. The results reinforce the high uranium contents of the upper Salt River palaeochannel, and their exploration is focused on identifying sites where uranium may have been deposited. The company has applied for tenure over 664sqkm in two licences covering palaeochannels draining into Oneabunga (Lake Burnside), north of Lake Carnegie. The drainages extend more than 88 km in length. Mindax is conducting exploration programs at five uranium-gold projects in the Sandstone region of Western Australia. The company, in joint venture with Quasar Resources, is simultaneously investigating uranium in ground waters within the 3,000 km^2 Yilgarn ***Avon Uranium Project*** in the WA Wheatbelt.
Pegasus Metals	Pegasus has engaged Fugro Airborne Surveys to fly new radiometric and magnetic surveys for the company's three Western Australian uranium projects at ***Hooley, Horse Well*** and ***Gifford Creek***, all located in the Ashburton-Gascoyne region of the state. The surveys will cover all the Pegasus uranium project areas at detailed 50 m line spacing. Previous explorers flew at reconnaissance 400 m to 500 m line spacing. The total survey will comprise approximately 5,630 line km, of which about 4,720 line-km are directly over Pegasus project areas.
Southern Uranium Ltd	The underwritten Southern Uranium IPO, which includes Chinese investment giant CITIC Australia Pty Ltd and Talbot Group Holdings Pty Ltd, is expected to raise $14 million to explore the company's uranium projects covering more than 10,000 km^2 of the Gawler Craton, later this year.
Thundelarra Exploration Ltd	Thundelarra Exploration Ltd has entered into a Tenement Swap Agreement with Canadian listed Aldershot Resources Ltd. The terms of the agreement are that Aldershot will exchange its Mt Wedge tenement located in the Ngalia Basin area in the Northern Territory for five tenements held by Thundelarra located in the Yuinmery area in the Murchison Region of WA.
Toro Energy	Detailed exploration of one of South Australia's prime Gawler Craton uranium projects has started, with Toro Energy undertaking drilling in palaeochannels in the ***Warrior Project***. An initial program of 200 air-core holes (approximately 10,000 m) is planned, with the objectives of scoping the potential of previously identified mineralisation and defining possible extensions at the ***Warrior Project***, in preparation for more formal resource definition work to be commenced later in 2007. Based upon ongoing successful results, Toro plans to spend more than $3M over the next four years on the project.
Venture Minerals	Venture Minerals has confirmed its intention to fast track further diamond drilling at the ***Churchill Dam Project*** in SA following the initial success of recent diamond drilling at the project. This initial drilling consisted of two diamond drill holes drilled, approximately 1.7 km apart, with both holes confirming the presence of substantial zones of altered Gawler Range Volcanics, which are the preferred host rocks. Venture believes the brecciation and alteration style intersected in the first two holes to be consistent with mineralised Iron-oxide-Copper-Gold-Uranium (IOCGU) systems within the Olympic Dam IOCGU province of South Australia. In addition, Venture has now committed to extend its detailed ground based geophysical survey to cover the entire 17 km long regional anomaly, in order to delineate additional drill targets within the interpreted caldera structure. This is expected to start in April 2007.

Jack Rayner in America, 1945

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The background

In September 1944 the Curtin Government established the Mining Industry Advisory Panel chaired by Harold Raggatt. The panel also included Jim Keast, Lindsay Clark, G. B. O'Malley (AusIMM), and union representation. The Panel's brief was to examine the history of the mining industry, its developments during the war and to make recommendations that would lead to a sound post-war Commonwealth mining policy (Rayner and Wark 1972). Among other things the Panel, through Raggatt, and also the AusIMM, recommended the formation of a Commonwealth Geological Survey. The Panel also recommended that Harold Raggatt and my father, Jack Rayner, should visit the USA and Canada to investigate the organisation of national geological surveys and recent developments in geophysics. The RAF Air Transport Command's authorisation for Jack to fly to the USA in May 1945 stated that:

> *'Mr Rayner is required to make investigations in the United States and Canada in order to gain the necessary information for the Mining Industry Advisory Council to complete its report on Australian Mineral Resources.'*

I hold the complete set of Jack's technical diaries for the trip plus a number of the documents he collected on the way, his letters home to his wife, Phyllis (Phyl), in Canberra, and her letters to him. In preparing this article I have made extensive use of the diaries, and have quoted from them as much as possible, so as to reflect Jack's thinking at that time.

In 1945 Jack was 39, and had had extensive experience in geophysics, beginning with the Imperial Geophysical Experimental Survey (IGES) of 1929. He was then employed by the NSW Mines Department and was simultaneously the geophysical consultant to the Aerial Geological and Geophysical Survey of Northern Australia (AGGSNA) through the 1930s before moving to the Mineral Resources Survey in Canberra during the war years as chief geophysicist. In 1946 he became Chief Geophysicist of the newly formed Bureau of Mineral Resources, Geology and Geophysics (BMR), and ultimately its Director during the 1960s. He was equally at home with theoretical work or in the field: a hard-working, serious individual, as his passport photograph of 1945 in Figure 1 suggests. However, a lively spouse and two young children were busy educating him about how to loosen up a bit.

The trip

Jack and Harold left Sydney on 13 May 1945 on a partially converted Liberator bomber and travelled via, New Zealand, Fiji, Canton Island and Pearl Harbour to San Diego. With meticulous detail Jack writes to Phyl that the flying time was 41 hours 13 min and the stopping time on the way was 10 hours 27 min.

> *'Thus we spent two days and nearly three nights on the trip, ...we all found sitting up all that time in rather cramped positions with scarcely any sleep at all, a pretty grim experience.' (Letter 3, 24/5/45)*

Phyl was most apprehensive about the trip and so to allay her fears he wrote:

> *'It [the Mae West life jacket] seems a most effective device and one could bob about in the water indefinitely eating chocolate and swigging the brandy in one's pocket.' (Letter 1, 13/5/45)*

Having reached the USA, Jack and Harold criss-crossed the country a number of times, sometimes together, but often on separate missions. Raggatt concentrated on geological matters and the organisation of national geological surveys while Jack concentrated on the geophysics. Figure 2 shows the main elements of Jack's journey.

Initially he and Raggatt flew from San Diego to Washington following 'The Southerner' route travelling on a 'Mainliner' (DC3) with its spacious cabin (Figure 3). All of the later travel was by train. Their main base was the Office of Australian War Supplies Procurement in Washington.

Jack's first trip was from Washington to New York and Boston and return followed by a long rail journey to Tulsa and Houston, to look at aspects of the oil industry, returning via St Louis and Pittsburgh. The third trip took him through the Adirondacks in up-state New York, to look at aeromagnetic surveys, and then on to Ottawa, Toronto and Noranda, and return. The final trip took him to Denver and Colorado Springs, then through Wyoming to look at seismic work, and on to Los Angeles, a detour out to the Grand

Fig. 1. Passport photo of Jack aged 39, just prior to departure to the USA, May 1945.

Fig. 2. Map of North America showing Jack's trip.

Canyon, and finally back to San Diego and home on 11 September 1945.

The scope of the topics investigated by Jack was quite remarkable:

- Oil prospecting and seismic reflection equipment, through such companies as the Seismograph Services Corp. and the Heiland Research Co,
- Gravity surveys and gravimeters, e.g. Frost Gravimetric Surveys, Tulsa,
- Magnetic surveys, particularly aeromagnetic techniques employing fluxgate magnetometers in the Adirondacks,
- Geomagnetism with Fleming, the head of the Department of Terrestrial Magnetism at the Carnegie Institution, Washington,
- Seismology and the Jesuit network of stations, and talks with Fr Macelwayne in St Louis,
- Well logging, including neutron activation techniques, with R. E. Fearon and Schlumberger,
- Radioactivity, North American surveys and Geiger counters,
- Fluorescence of minerals, inspired by his work on the King Island. Scheelite,
- Mining and ore processing techniques,
- Rock bursts and their monitoring,
- Electrical methods with an emphasis on Electromagnetic (EM) techniques as illustrated in Figure 4,
- Aerial photography and the Trimetrogon system employed by the USGS,
- The organisation of national geological surveys, and
- University courses in geophysics and the field training of geophysicists.

This list shows clearly the seeds of many of the themes that were to be developed by the nascent BMR.

The diaries and letters contain not only a wealth of technical information but also a range of observations about life in North America in 1945, including:

- Records of the extensive network of contacts and friends he established with national organisations, major companies, equipment manufacturers and universities,

Fig. 3. Interior of a 'Mainliner' aircraft (DC3) operated by United airlines, taken from publicity material, 1943.

Fig. 4. Electromagnetic equipment in use with staff dressed for the field (Rayner 1946, p. 30).

- Observations on the social conditions and the discrimination shown towards the 'negro' population,
- Descriptions of the countryside, wildlife and cities that he saw: '*Washington is a bit like Melbourne'* (Letter 4, 1/6/45),
- Comments on air and train travel,
- Places visited such as: Niagara Falls, Yellowstone Park, the Grand Canyon and Pikes Peak. Figure 5 is taken from the brochure for the cog railway that went to the top of Pikes Peak near Denver, and shows typical workers clearing snow, and
- Descriptions of the hotels he stayed at, museums visited, memorable meals (*Mint Juleps at the Tulsa Country Club with Gerald Westby*, *head of SSC*) and the hospitality of the people he met.

Several entries give something of the flavour of these observations.

In Washington Jack visited the US Geological Survey (USGS) and was taken to lunch by the Director, Dr Wrather, at the Cosmos Club

> *'which is old and solid like the Melbourne clubs, but women appear to be admitted, at any rate to the dining room' (Letter 4, 1/6/45)*

a comment that says a good deal about Melbourne clubs of the time.

He also noted that:

> *'One thing that surprised me was the large number of negroes I saw in Washington...about 150,000... the inhabitants blame the Roosevelt administration for attracting the negroes by giving them good treatment and a measure of equality. In the South, although the negroes have a vote, and are theoretically equal, in practice they get a pretty thin time. In Washington they can travel on any part of the street car but as soon as it crosses the border into Virginia, ...they have to go to the rear.' (Letter 4, 1/6/45)*

In New York, Jack and Harold met Maurice (Maurie) Mawby, then director of research with the Zinc Corporation, and Cook who ran the Lakes Entrance oil extraction program. He remarks that:

> *'NY was quite memorable as Maurie, acted as bear leader to the rest of us, and a terrific week it was'. (Letter 5, 11/6/45)*

OPENING COG ROAD IN THE SPRING

Fig. 5. Typical workers taken from the brochure for the Pikes Peak cog railway, 1945.

They dined at Swiss, Scandinavian, and Russian restaurants, visited a '*leg show*' and watched an '*ice extravaganza*' at the Rockefeller Centre (Letter 5, 11/6/45).

He was in Denver on VJ day and records a little grumpily that:

> *'Denver went fairly wild last night. Stood on [the] corner for a time and watched the stream of tooting cars go past. Got no sleep before about 3.30 am that night owing [to] the noise. A drum and bugle band made a din in the lounge of the Brown Palace [his hotel].' (Diary 4, 14/8/45)*

The letters from Phyl to him reveal a good deal about living in Canberra, in 1945, with its 10,000 people, two small children, an ailing mother and one of the hardest winters on record:

> *'In the mornings I have to chip the ice off the inside of our bedroom windows.' (Phyl to Jack, Letter 4, June '45)*

It is clearly not possible in this article to describe the full range of Jack's technical activities. The following paragraphs, however, aim to give some impressions of the nature of his work.

Exploration for petroleum

One of the main objectives of the trip was to pay particular attention to developments in the exploration for petroleum. Jack and Harold concentrated much of their attention on the seismic and gravity work being undertaken in parallel with the geological programs on the sedimentary basins in Wyoming and Montana, as they believed that they may represent similar conditions to those likely to be encountered in Australia (Raggatt 1968). They also visited Okalahoma and Texas and were highly impressed by the level of activity and the results being achieved. Figure 6 taken from the final Report, shows the massive increase in activity, particularly in seismic work, between 1935 and 1945.

Jack spent several days in Tulsa with the Seismograph Services Corporation (SSC).

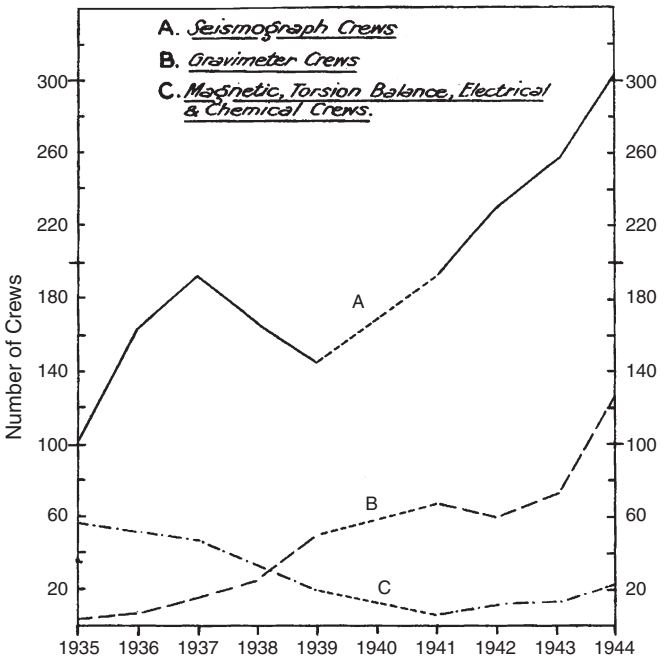

Fig. 6. Graph showing the 'trend of geophysical exploration and methods used in [the] USA' (Rayner 1946, p. 13).

Fig. 7. Front cover of SSC's brochure for 1945 showing a 'modern recording vehicle'.

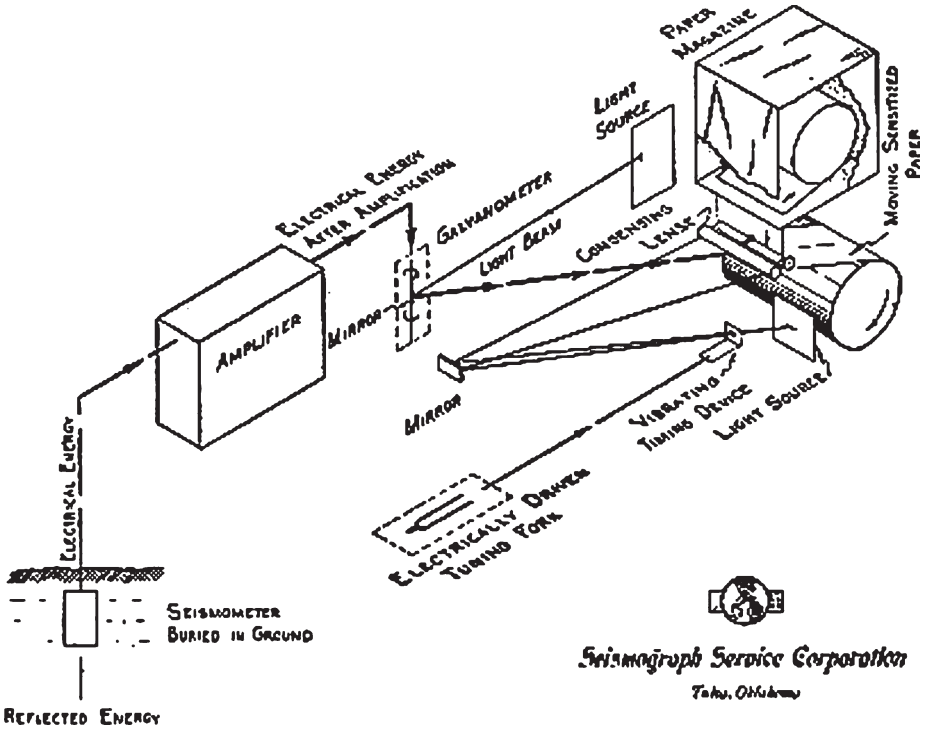

Fig. 8. Block diagram of SSC's seismic recording system, taken from the SSC brochure.

On 9 July he met the president of the company, Gerald Westby, who flew him in his private plane ('*a 4-seater with radar*') to visit one of SSC's seismic field parties. He describes the drilling operations ('*rotary drill down to 40–50 ft*'), the shooting truck ('*...were using about 10 lb charges*'), the work of the surveyor, and the recording truck (*'..using a 12-channel system'*).

> *'The shot holes were 1/4 mile apart, and geophones about 120 ft apart.'*

After lunch he '*discussed the weathered layer velocity corrections*' (Diary 4, 9/7/45).

Figure 7 shows the front cover of SSC's brochure for 1945 showing a 'modern recording vehicle', while Figure 8 from the same brochure is a block diagram of SSC's seismic recording system.

As a follow up to the trip, in 1948 Jack and Bob Thyer purchased a full set of seismic equipment: a Heiland 12-channel reflection seismic system. Figure 9 from the Heiland catalogue of 1945 shows the truck-mounted recording equipment with Jack's annotations. The system was initially trialled on the Coorabin Coalfield near Oakland, NSW.

In 1949 the first reflection survey for petroleum was undertaken in the Roma area with Jim Dooley as party leader (Wilkinson 1996, p. 85).

Jack spent several days with C. E. Heiland, the CEO of the Heiland Research Corp. They discussed Heiland's approach to gravimeters, the company's expertise in reflection seismic instrumentation and techniques, ratiometer gear, and the company's planned move into EM techniques,

> *'Heiland was anxious that I should send him my ideas concerning the development of such equipment,' (Diary 5, 20/8/45)*

presumably on the basis of Jack's early work with the IGES on EM.

He spent a day with Heiland going around the geophysics department of the Colorado School of Mines, where Heiland was a professor. His diary records the visit in great detail down to the level of how the student workbenches were set up. He also:

> *'spent a good deal of time with Heiland adjusting two Schweydar seismometers [which] were quite similar to that described in the IGES reports.' (Diary 5, 21/8/45)*

He later told me that the strong personal friendship that he established with Heiland was of enormous help in the early days of the BMR.

Gravimeters

Jack was greatly impressed by the developments of gravimeters that had taken place during the war years, particularly compared with his earlier struggles with torsion balances and gradiometers. For example, on 11 July he visited C. H. Frost Gravimetric Surveys in Tulsa and met the CEO, Frost. At this time the company had built about 45 gravimeters and had 10 parties operating in the field. His diary describes Frost's approach:

> *' the beam is flat and fits fairly snugly into [a] box to give air damping...period about 18 secs.... A null method is used, the reading at the second station being brought back to that [at the] first station by twisting [a] dial. [The] precision is usually about ± 1/100 milligal. [It] can be taken anywhere in [the] World without internal adjustment. Can range over 50 milligal without external adjustment. Heating wire surrounds the inner instrument. Thermostat keeps temperature constant to within 1/50°C. Total weight about 30 lb. Saw the instrument mounted in the back seat of an ordinary sedan car (as shown in Figure 10). Can do about 12 stations per hour and 40–80 stations per day.' (Diary 4, 11/7/45)*

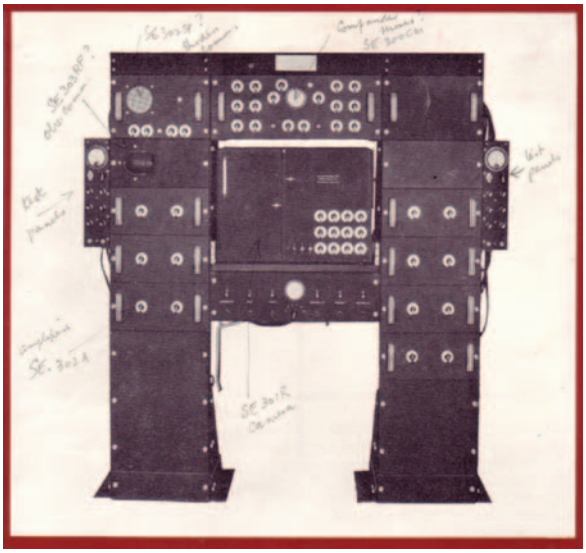

Fig. 9. Heiland 12-channel truck-mounted seismic recording system taken from the Heiland brochure, 1945 with Jack's annotations. The 12 amplifiers, two to a panel, plus a spare, are down each side of the unit while the oscillograph recorder is in the centre of the console.

Fig. 10. 'Gravimeter mounted on tripod in reading position. The instrument determines variations in gravity of the order of 1 part in 30,000,000' (Rayner 1946, p. 2).

Uranium and Radioactivity

On 10 July, Jack visited R. E. Fearon of Well Surveys Inc. Fearon, in 1938, had proposed using neutron activation as a way of logging bore holes (Green and Fearon 1940). According to Jack, Fearon had:

> *'done a lot of working and thinking in the radioactive field. He demonstrated neutron logging where: 'a radium beryllium mixture is used to generate the neutrons. Detection is done by means of a high pressure ionisation chamber'. (Diary 4, 10/7/45)*

Jack also writes that they:

> *'Discussed the Uranium bomb, and Uranium power. [Fearon] believes both [are] possible. Power could be used either for heating water internally without the use of boiler tubes, or by polymerisation of methane to petroleum'. (Diary 4, 10/7/45)*

Given that this was the 10th July, and that Hiroshima was 6th August, it is interesting to note the level of awareness of such things within the scientific community at this time.

He then had dinner at Fearon's home where they:

> *'Discussed radioactivity, geophysics and Australia. Fearon considers that [the] vast quantities [of] uranium needed for fuel and [that the] only sources are the large masses of igneous rocks with a rather high radioactive content.' (Diary 4, 10/7/45)*

One wonders whether he could have predicted the use of hot igneous rocks for geothermal applications.

Later in his Report he writes;

> *' ...there is a good deal of long range research in connection with Uranium ores. For instance, systematic work is being carried out to investigate the radioactivity of the rocks of North America. Much of this activity is related to the atomic bomb project and is veiled in considerable secrecy.' (Rayner 1946, p. 8)*

The 10th July was also significant for Jack as it was the day when he finally found, and purchased for $57.50 the Lionel electric train set for his then 4 year-old son, which I still have. He and his spies had searched high and low through most of the major cities of the USA, and he later claimed that he had had far more trouble finding the train set than any piece of geophysical equipment[1].

[1]He typically spent about $1.50 for a meal so the train was a significant expense.

Iron ore in the Adirondacks

On 19th July Jack travelled to Gouveneur in New York State to meet H. E. Hawkes of the USGS and Arthur ('Bud') Buddington, Professor of Geology at Princeton, who had been seconded to the USGS. Hawkes and Buddington, had pioneered aeromagnetic surveying, by the USGS in 1944 with Bud often flying in the aircraft as observer. When Jack met them they were conducting ground-based magnetic surveys of the iron ore deposits in the Adirondacks in order to validate the aeromagnetic results.

In his report Jack summarised the work as follows:

> *'All of these magnetic surveys were made on the ground using normal instruments [dip needles and variometers]. However, for some years the possibility has been discussed of speeding up such work by carrying continuously recording magnetic instruments in aeroplanes. It is now known that this method was perfected during the War by the U.S. navy in an attempt to detect enemy submarines., and the technical details are still veiled in some secrecy. It is of interest to note that the author saw this type of magnetic survey from the air being tested by officers of the*

> *USGS in the Adirondack Mountains. Records from the magnetic instruments [fluxgate magnetometers] were inspected and there were marked indications of points where the plane, flying at 1000 ft, had passed over the known ore bodies. It is expected that more will be heard of this method for prospecting iron ore and for other exploratory problems.' (Rayner 1946, p.7)*

Jack was never one to make hasty judgements or outlandish claims, and the last sentence is entirely typical of his considered cautious approach. Such statements used to drive the ever-enthusiastic, volatile Phyllis mad!

Organisation of national geological surveys

In addition to the technical aspects of what he saw, Jack and Harold were very interested in the structure of national geoscience institutions, the scope of their activities, and their relationship to the state level organisations. To see how these intuitions operated, they visited the USGS and spoke with its director, Dr Wrather, who said that the USGS currently undertook little geophysical work, but were about to expand significantly into the area, as they regarded geophysics as the way of the future. They also talked with, Dr Sayers of the U.S. Bureau of Mines, and visited the Division of Geophysics in Baltimore, which was then the principal government employer of geophysicists. These visits, together with a later one to the Bureau of Mines and Geology in Ottawa, were of enormous assistance in determining the scope and organisation of the future BMR, and its relationship to the state geological surveys. For instance in Ottawa they:

> *'Discussed the Dominion verses [the] Provinces problem. They have a variety of arrangements. [They] have full control of some functions [and] do reconnaissance almost anywhere, [but] do little detailed work in strong provinces like Ontario, Quebec and B. Columbia.*
>
> *Frogs legs for dinner v. good.' (Diary 4, 24/7/45)*

In the final report Jack concludes that:

> *'Geophysical work in Australia should be carried out by a Commonwealth Government organisation located in whatever centre permits the readiest access to the mining fields and offers the best facilities for technical research and development. Such a central body would be large enough to command the best equipment and permit the necessary specialisation and research within its staff. However... there is plenty of work for all, and should any of the State Mines Departments desire to carry out geophysical work, then such work could receive much assistance from the technical resources of the Commonwealth organisation.' (Rayner 1946, p. 25)*

Conclusions

In this article I have endeavoured to give some indication of the state of exploration geophysics in North America in 1945, and the impetus it had received through the War Years, and some taste of the social conditions of the times. It has also sought to highlight the critical importance of this trip by Jack and Harold with respect to the formation of the BMR and its geophysical program. To leave the final word to Jack:

'It is considered that in Australia regional magnetic and gravimetric surveys should be made over the large basins, and that the seismic method should be used to follow up any indications, and also to check some of the geologically mappable structures for position, size and closure at depth.' (Rayner 1946, p. 26)

References

During the trip Jack filled five technical diaries, which I refer to by Diary number and the date of the entry.

I refer to the letters, between Jack and Phyl by the letter number and the date on the letterhead, although many letters were written over a number of days.

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The Mechanics of Earthquakes and Faulting (2nd edition)

Christopher H. Scholz

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RRP: $130, ISBN: 0521655404

'*Understanding the basic strength properties of rock has been a practical pursuit since ancient times, both because of the importance of mining and because rock was the principal building material.*' The Mechanics of Earthquakes and Faulting describes the connectivity between earthquake mechanics and faulting. It is neither a text on faults for the geologist or a manuscript on seismology for the geophysicist. Rather, seven distinct chapters provide a comprehensive multi-disciplinary review of existing theories on earthquakes and faulting.

Brittle fracture, restricted to an area of the lithosphere known as the schizosphere, is the topic of Chapter 1. The importance of scale is considered and related to different theories of-, or conditions for- crack propagation. The chapter includes an interesting discussion relating experimental results which use a single crystal containing microscopic flaws, with actual observations of failure in rocks where flaws can be greater in size than the grain diameter. The physical and physiochemical role of water, ubiquitous in the schizosphere, is also covered.

'*Once a fault has been formed its further motion is controlled by friction...*', the topic of Chapter 2. Stick-slip friction, wear and interactions between asperities on the sliding surfaces are all covered. Interestingly, it is argued that a single friction criterion, such as Byerlee's law can be used regardless of lithology or temperature.

'*Brittle tectonics may be considered on two timescales, in which earthquakes are the short timescale phenomena and faulting is the long timescale process.*' Chapter 3 covers the mechanics of faulting. The formation and growth of faults and interactions amongst populations of faults are all covered. Scholz argues that faults are not a continuous surface and that they consist of a number of disconnected sub-faults which do not always align in a single plane. The sub-fault structure has important implications for the length, and hence size of earthquakes that a fault can support. For example, the North Anatolian Fault in Turkey is more segmented than the San Andreas Fault and therefore tends to rupture in shorter (i.e. smaller) earthquakes.

The topic of Chapter 4 is the mechanics of earthquakes and is a natural progression from the mechanics of faulting. The chapter discusses applicability of the two models for rupture mechanism in unstable slip. That is, brittle fracture as introduced in Chapter 1 or stick-slip friction as introduced in Chapter 2. These two models are useful for exploring the system but unfortunately cannot be applied to most observed earthquakes due to complexities that both idealised models fail to capture. The problem is exasperated by the fact that recorded data of seismic wave propagation is typically insufficient to re-construct all the processes that take place during an earthquake. The best that can usually be achieved is an interpretation of main slip propagation. An alternative approach to studying earthquakes is to use the more familiar parameters such as magnitude, seismic moment and focal mechanism. These are discussed and scaling relationships relating them to other properties of an idealised rupture plane introduced. Note that a distinction is necessary between small earthquakes, whose width is less than that of the schizosphere, and large earthquakes whose width equals that of the schizosphere. The large earthquakes require a greater length-to-width ratio to accommodate the same area. The chapter includes a number of case studies discussing well studied events such as the 1992 Landers earthquake and the 1994 Northridge event. It concludes with discussions on earthquake sequences and interactions between earthquakes such as Coulomb stress changes and mechanisms for time delay.

Chapter 6 deals with the seismic cycle and introduces the four main phases of crustal deformation: pre-seismic, co-seismic, post-seismic and inter-seismic. The chapter also describes different models of strain accumulation and introduces three models for earthquake recurrence: perfectly-periodic, time-predictable and slip predictable. Naturally, the applicability of these recurrence models has important implications for earthquake forecasting, the first true fault specific studies of which are only just becoming available for the Nankaido earthquakes of Japan and the Parkfield region of California. Particular emphasis is given to incorporating information from the geological record due to the inability of historical records to capture the complete seismic cycle in most regions.

Seismotectonics, the topic of Chapter 7, refers to the study of earthquakes as a tectonic component. This chapter describes the role of seismic and aseismic faulting in a variety of tectonic settings. A fascinating analysis of the global distribution of seismic moment release is provided. It demonstrates that roughly 1/4 of all seismic moment released in the period 1904–1986 came from a single earthquake, the 1960 Chile event. It shows that 85% of global moment release can be attributed to subduction zone events and 95% to shallow plate-boundary earthquakes. Subduction zone earthquakes, oceanic earthquakes, continental extensional regimes, intraplate earthquakes, deep earthquakes and slow tsunamigenic events are all discussed in separate subsections. The section on intraplate earthquakes makes particular mention of the 1968 Meckering and 1988 Tennant Creek Australian earthquakes in recognition that such events are typical of intraplate regions. That is, they occur on faults that are later identified as hosting repeated events but had previously been unidentified because local erosion rates exceed scarp growth.

The final chapter covers earthquake prediction and hazard analysis. A distinction is drawn between an immediate alert (0–20 s), short term prediction (hours to weeks), intermediate-term prediction (1 month to 10 years) and long-term prediction (stated as 10–30 years at the start but later extended to a few hundred years). The term

prediction in this context represents an accurate forecast. The long-term prediction techniques are cast in terms of the usual candidates: recurrence relationships, scaling laws and Poison processes. Intermediate precursors are dominated by seismicity or changes in seismicity. For example, some authors have reported links between increases in seismicity followed by a quiet period and then an earthquake. Others have provided examples where pre-earthquake seismicity has clustered around the edges of a yet to occur rupture. Non-seismicity intermediate precursors include changes in the V_p/V_s velocity ratio which has been linked to changes in void space through dilatancy. The discussion of short-term precursors includes a number of observed phenomena, some of which have not been conclusively linked to earthquakes. These include peculiar weather such as unusual rainfall or fog, uplift and/or subsidence of the ground and anomalous behaviour of animals. Foreshock analysis can also play a part in short-term earthquake prediction.

The Mechanics of Earthquakes and Faulting gives an impressive overview of existing theories. Arguable, the most notable conclusion is that the entire schizosphere is in a self-organised critical state that is everywhere near failure. The text is supported by a large number of black and white images and includes a colour plate section in the centre of the book. Many of the b/w images are re-reproduced from the original papers which introduced the theories. Unfortunately, I did find some of them difficult to understand, either because they could do with re-drafting or because they warranted extended captions. However, this is a small criticism of an otherwise outstanding addition to the earthquake section of any library. I recommend this text to those who have an interest in learning more about earthquake processes. It is particularly relevant to graduate students or researchers but could also be expanded to undergraduates if desired.

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