Preview

Australian Society of Exploration Geophysicists

ABN 71 000 876 040 ISSN 1443-2471

December 2005 Issue No.119

Business investment in R&D highest than ever

Page 13

New products from MAGDA

Page 24

Seismic imaging of complex geological structures

Page 31

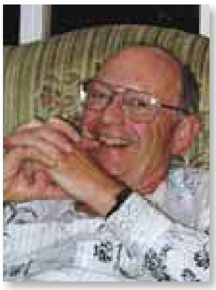
ADVERTISERS

2005 Corporate Plus Members

Velseis Pty Ltd

2005 Corporate Members

Beach Petroleum NL
BHP Billiton Minerals Exploration
Chevron Australia Pty Ltd
Earth Resource Mapping
Encom Technology Pty Ltd
Eni Australia Limited
Fugro Airborne Surveys
Geosoft Australia Pty Ltd
Haines Surveys Pty Ltd
Multiwave Geophysical Company
Normandy Exploration Ltd
Oil Search Ltd
Origin Energy Resources Ltd
Outer-Rim Exploration Services Pty Ltd
Petrosys Pty Ltd
PGS Australia Pty Ltd
Primary Industries & Resources South Australia
Professional Investment Services Pty Ltd
Rio Tinto Exploration Pty Ltd
Santos Ltd
Seismic Asia Pacific Pty Ltd
Veritas DGC
WesternGeco
WMC Resources Ltd
Woodside Energy Ltd
Zonge Engineering & Research Organisation



2005 good year for resource companies

Apart from the demise of WMC, 2005 was a good year for the resource industries. From January to December the market capital of resource companies listed in the top 150 companies on the AMEX rose steadily from $137 billion to $185 billion. This is equivalent to a 35% increase. During the same period the All Ordinaries Index only rose by 13% from about 4.06 to 4.59.

The rise in the **oil price** played in major role in the resource growth. It rose, somewhat erratically from US45 to $60/barrel, bringing record profits to the major companies.

As a result of the huge increase in demand for oil, exploration companies are taking bigger risks and are developing new fields in deeper and deeper water.

A new record will be soon be set in Australia with the development of the Stybarrow oil field located in the Exmouth Sub-basin, approximately 65 kilometres from Exmouth, off the northwest Australian coast. At a water depth of approximately 825 metres it will be the deepest oil field development ever undertaken in Australia.

The Stybarrow Field was discovered in February 2003 and together with the adjacent small oil rim of the Eskdale Field has recoverable oil reserves estimated in a range of 60-90 million barrels of oil. BHP Billiton is the operator (50 per cent), with joint venture partner Woodside Energy Limited (50 per cent). The project costs for Stybarrow are estimated to be approximately US$600 million. This expenditure includes the cost of field development and a 10 year minimum service agreement with a Floating Production Storage and Offtake (FPSO) provider.

Gold also performed solidly, increasing from US$420 to $500/oz, with some optimistic analysts predicting the demand from China and India will push the price up to US$1000 before too long! However, there are also supply problems for gold. In Australia the production of gold has steadily fallen from a maximum of 80 tonnes in the last quarter of 1997 to about 70 tonnes in mid-2005. Clearly all the easy-to-find deposits have been discovered and developed, and it is just getting harder and harder to find large new deposits.

ARC research grants announced

In November the Government announced the allocation of $370 million, on the advice of the Australian Research Council, to new research projects. The bulk of the money ($274 million) was allocated for Discovery Grants with lesser amounts made available for Linkage Grants. A total of 917 grants were awarded from a total of 3742 applications. This is less than the 1055 awarded in 2005 and also results in a lower the success rate of 24.5%, compared to the 30.9% figure for 2005. However, the average first year grant has increased from $94,340 to $103,768 and the total grant over the duration of a project now averages $298,350 compared to $282,030 for the 2005 allocation.

There is not enough space in this issue of *Preview* to analyse the geoscience-related grants. This information will be contained in the February 2006 issue. Overall the numbers are consistent with the government's *Backing Australia Ability* commitments announced last year.

Seasons Greetings

This is the last issue of *Preview* for 2005, and I would like to take this opportunity to thank our contributors, readers, advertisers, sponsors and publisher for their support during the year.

I hope you all have a relaxing Christmas, and that the New Year brings prosperity and exciting challenges for us all.

Don't forget to enjoy the ASEG wines over Christmas and to register for the 2006 Australian Earth Science Convention.

David Denham

EXECUTIVE BRIEF

Geophysics in Korea

The ASEG and the KSEG have recently exchanged a memorandum of understanding to encourage greater levels of collaboration and communication between the members of each Society.

Formal letters of understanding were exchanged at the recent Symposium on Borehole Geophysics hosted by Chonnam National University in Gwangju (PRK) on 30 Sept 2005. ASEG was represented on this occasion by Professor Jim Cull of Monash University who also presented a keynote paper on 3D TEM logging.

The new formal links between the National Executives of each country will expand on previous successful activities involving the joint publication of conference proceedings, particularly through Exploration Geophysics.

The current publication format, substantially developed by Koya Suto and Lindsay Thomas, has been well received by the geophysical community in both Korea and Japan. It provides an opportunity for broader readership and access to technology in each country by providing Abstracts in each native language.

The KSEG also requires all authors of articles in their own Journal to provide an Abstract and Figure Captions written in English to assist with external communication. This format has also been adopted for general Conference Proceedings including the recent Gwangju volume specifically catering for international visitors.

Dr Keun Pil Park, President of KSEG and Professor Jim Cull, representing ASEG exchanging the KSEG-ASEG MOU at the KSEG special symposium on Borehole Geophysics at Gwangju on 30 September 2005.

AGM Announcement

Elsewhere in this edition of *Preview* there will be notification of our upcoming AGM, scheduled for 12 April 2006, and expect a formal notification directly via email and/or mail.

We are seeking new representatives from our members to participate on the Federal Executive and to become Chairs of the various Committees reporting to the Federal Executive.

If you wish to become more actively involved in your professional society, then I urge you to make your intentions known, and advise me of your interest in serving on the Federal Executive of the ASEG in 2006.

Howard Golden and Kevin Dodds were the ASEG's representatives at the recent **SEG conference in Houston.** They report that:

The SEG Conference was good – no record attendance (8,500) but quite upbeat.

The ASEG Conference brochures went like hotcakes and we are set to work with SEG on the 2007 ASEG/PESA Perth Conference.

As the SEG is now committed to holding one large conference outside the US each year, it is keen to do so in cooperation with the ASEG before the end of the decade.

Australian SEG members now find themselves in a re-drawn SEG district, but it doesn't affect ASEG members in any way.

Kevin and Howard will prepare a more detailed account for a later edition of *Preview*.

Cont'd from page 2

Geophysical methods are used extensively in Korea for hydrocarbon exploration, as well as groundwater and geothermal applications. However, most surveys appear to be concerned with geotechnical and geophysical engineering methods associated with the massive growth in urban infrastructure. The current initiatives will assist with a two-way transfer of skills and experience particularly relevant for sustainable development.

Jim Cull

Outlook for Geophysics, and its capacity to meet Australia's needs to 2050

We are a society of professional geophysicists with a current bank balance in excess of $800,000. Surely we are in a position to do something positive about the current state of Geophysics in Australia with a view to making it a force for the betterment of the nation by 2050.

If current trends persist, geophysics will be a science of the past, where the long term challenges prove too powerful for our already struggling profession.

- Current **recruitment** to our profession is low, where the cyclical nature and longer downward trends versus the current positive rush, does little to engender enthusiasm amongst tertiary entry-level students who have an array of seemingly more appealing professions from which to choose.
- The youth of today need to be imbued with the excitement of finding new resources to replenish current reserves. This is difficult, given the prevailing attitude of the majority of teachers at primary and secondary education levels, who remain unconvinced about the benefits of the mining industry to the health and wealth of this country. In fact, many vehemently lament that such an industry as ours exists.
- Possible solution: invest in a well structured, widely scoped and coordinated "teach the teacher" program, in conjunction with other learned geoscience societies. This program to provide training and educational material for teachers to present to both primary and secondary level students. Impress primary and secondary students with the excitement of exploration, and the tertiary geophysics student needs no convincing.

Julian Cribb, Editor of *R&D Review*, has requested a 'state of the nation' piece looking at the long term challenges facing individual societies and their relevant disciplines/areas of research.

Apart from recruitment, other areas for discussion would include the current state of skills, the adequacy of research support, infrastructure, training and investment, and specific problems facing the geophysics discipline – and the areas where geophysics could play a major role in the national future, or where for the lack of it, our nation might suffer.

Should you have any passionate beliefs about a solution to our current predicament, I'd be most interested to hear from you.

Both Julian's request (above) and the notice of Projects of Special Merit from Jenny Cole of the SEG (as below) arrived within days of each other.

The Projects of Special Merit program is intended to advance geophysics today and inspire geoscientists for tomorrow by providing critical funding for projects that further the professional development, student support and youth outreach goals of the SEG Foundation. Applicants from around the world are encouraged to apply for that financial boost they need to get their project off the ground. Proposals should address issues, problems or opportunities related to the Foundation's mission, which is: ***to encourage and support scientific, educational and charitable activities of benefit to the general public, to geophysicists and to the geophysical corporate community***.

Guidelines and Applications for the Projects of Special Merit program are now available online at **http://foundation.seg.org**. The program is open to SEG Sections, Student Sections, Universities, and Individuals across the world. A sample list of 2005 funded projects is included below.

- Summer of Applied Geophysical Experience Field Camp, SAGE (Student Support)
- AAPG/SEG Spring Student Expo, University of Oklahoma (Student Support)
- Planetary Geology and the Early Earth, Advances in Earth Science Research Conference 2005, Carlton University (Student Support)
- SEG/AAPG Boy Scouts of America National Jamboree (Youth Outreach)
- Univ. of Novosibirsk Student Group – Popularization of Geophysics in Schools (Youth Outreach)
- Geologic Animations for Outreach in Museums and National Parks, University of Colorado (Youth Outreach)
- An Educational Seismic Network: Tomographic Imaging for the Gulf Coast Lithosphere, Louisiana St. Univ. (Youth Outreach)

Perhaps the ASEG could implement a number of such innovative ideas as listed by Jenny, which would go some way in reaching out to the youth of today to become the geophysicists of tomorrow.

Terry Crabb

2006

24 March
BMR-AGSO-GA 60th Anniversary Dinner
Venue: Hellenic Club, Woden, ACT
An informal reunion for past and present staff, AusLIG and State Geological Survey colleagues
Email: johnbain@tpg.com.au

2-6 April
SAGEEP '06: 19th Annual Symposium on the Application of Geophysics to Engineering and Environmental Problems
Organisers: Environmental and Engineering Geophysical Society
Venue: Seattle, Washington, USA
Email: staff@eegs.org
Website: www.eegs.org

19-21 April
AAS Elizabeth and Frederick White Conference
Theme: Mastering the data explosion in the Earth and Environmental sciences.
Venue: Shine Dome of the Australian Academy of Science, Canberra
Website: http://rses.anu.edu.au/cadi/Whiteconference

1-7 May
Australian Institute of Geoscientists 25th Anniversary Conference.
Theme: Outcrop to orebody – applied geoscience in exploration and mining.
Presentations will integrate modern theory, practice and procedure in the exploration and mining industry.
Website: http//:www.aig.asn.au/aig25.htm

7-10 May
2006 APPEA Conference
Venue: Gold Coast Convention & Exhibition Centre, Qld.
Deadline for receipt of Abstracts: 1 September 2005
Website: http://www.appea.com.au/conference/CallforPapers2006.pdf

12-15 June
68th EAGE Conference & Exhibition
Venue: Vienna, Austria
Contact: http://www.eage.org/conferences/

2-6 July
The Australian Earth Sciences Convention 2006
ASEG, in collaboration with GSA; ASEG's 18th International Conference and Exhibition, and GSA's 18th Australian Geological Convention
Venue: Melbourne, Vic.
Website: www.earth2006.org.au

1-6 October
SEG International Exposition & 76th Annual Meeting
Venue: New Orleans, Louisiana, U.S.
Contact: http://seg.org/meetings/calendar

16-28 November
8th International Symposium on Imaging and Interpretation
Sponsored by SEGJ, Co-Sponsored by ASEG, KSEG, SEG, EAGE and EEGS.
Venue: Kyoto University, Kyoto, Japan
Abstract deadline: 12 May 2006
Website: http://www.segj.org/is8/
Email: segj8th@segj.org

2007

18-22 November
ASEG's 19th International Conference and Exhibition
Venue: Perth, WA
Contact: Brian Evans
Email: brian.evans@geophy.curtin.edu.

Momentum gathers for Earth Sciences Convention in 2006

The Australian Earth Sciences Convention begins Sunday 2 July 2006 with the registration and exhibition area open from 3 pm onwards and the opening icebreaker at 5 pm. The meeting concludes 5 pm Thursday 6 July with a closing ceremony and drinks. Each day will begin with a Plenary 'Hot Topics' Lecture. Confirmed Plenary Speakers are:

- Dr Tim Flannery (SA Museum): Environmental change
- Prof Steve Self (Open University): Volcanic eruptions and impact on climate
- Dr Nick Sheard (Inco, Platinum Sponsor): The mining industry and the future
- Dr Tom Whiting (BHP-Billiton; provisional acceptance): Resources and innovation
- Dr Robin Batterham (Chief Technologist, RioTinto): Energy, uranium and geosequestration

The remainder of the program will be an interesting balance of symposia, workshops, fieldtrips and exhibitions on fundamental research and industry-related, environmental and innovation-related themes.

The Organising Committee is delighted with the interest being shown by a range of organisations in sponsorship and exhibition opportunities. See website (www.earth2006.org.au) for details. International explorer and miner Inco Resources (Australia) Pty Ltd has signed on as the Conference Platinum Sponsor, and the Victorian Department for Primary Industry has signed on as a Gold Sponsor.

The website is now open for submission of abstracts. The deadline for this is 15 December 2005. The Early Bird deadline is 31 March 2006.

Derecke Palmer features among the greats of geophysics

Derecke Palmer was featured twice in the Exploration Geophysics Timeline Chart published by the SEG in a supplement to October 2005 issue of The Leading Edge to celebrate its 75th anniversary. The chart contains such notable advancers of the profession as LaCoste, Vacquier and Dobrin. Derecke is included at 1980 for his monograph on the Generalised Reciprocal Method (GRM) and also for his Refraction Convolution Section (RCS) in 2001.

"Well done, Derecke!" from your fellow ASEG members in Sydney.

Derecke is also the only Australian so far, out of 50 recipients, to have received the SEG's Reginald Fessenden Award which is given for a specific technical contribution to exploration geophysics.

Roger Henderson

ASEG officers

Published for ASEG by:
PUBLISHER: Brian Wickins
RESolutions Resource & Energy Services Pty Ltd
Tel: (08) 9446 3039
Fax: (08) 9244 3714
Email: brian@resolutions-group.com.au

EDITOR: David Denham
7 Landsborough Street, Griffith ACT 2603
Tel: (02) 6295 3014
Email: denham@webone.com.au

ASSOCIATE EDITORS:

Petroleum: Mick Micenko
Email: micenko@bigpond.com

Petrophysics: Don Emerson
Email: systems@lisp.com.au

Minerals: Peter Fullagar
Email: p.fullagar@mailbox.uq.edu.au

Book Reviews: David Robinson
Email: david.robinson@ga.gov.au

Web Waves: Jill Slater
Email: jill.slater@santos.com

Geophysical History: Doug Morrison
Email: sth.lands@optusnet.com.au

ASEG HEAD OFFICE & SECRETARIAT:

Ron Adams
Centre for Association Management
PO Box 8463, Perth Business Centre
WA 6849
Tel: (08) 9427 0838
Fax: (08) 9427 0839
Email: secretary@aseg.org.au
Web site: http://www.aseg.org.au

FEDERAL EXECUTIVE 2005[1]

PRESIDENT: Terry Crabb
Tel: (08) 9385 9626
Email: tncrabb@westnet.com.au

PRESIDENT ELECT: James Reid
Tel: (03) 6226 2474
james.reid@utas.edu.au

1st VICE PRESIDENT: Jenny Bauer
Tel: (07) 3858 0601
Email: jenny.bauer@upstream.originenergy.com.au

TREASURER: John Watt
Tel: (08) 9222 3154
Email: john.watt@doir.wa.gov.au

SECRETARY: Lisa Vella
Tel: (08) 9479 8476
Email: lisa.vella@wmc.com

PAST PRESIDENT AND INTERNATIONAL AFFAIRS:
Howard Golden
Tel: (08) 9479 0576
Email: howard.golden@wmc.com

STATES' REPRESENTATIVE:
Don Sherlock
Tel: (08) 6436 8729
Email: don.sherlock@csiro.au

MEMBERSHIP COMMITTEE: Koya Suto
Tel: (07) 3876 3848
Email: koya@terra-au.com

ASEG Branches

ACT
PRESIDENT: Jacques Sayers
Tel: (02) 6249 9609
Email: jacques.sayers@ga.gov.au
SECRETARY: Adrian Hitchman
Tel: (02) 6249 9800
Email: adrian.hitchman@ga.gov.au

New South Wales
PRESIDENT: Michael Moore
Tel: (02) 9901 8398
Email: michael.moore@dipnr.nsw.gov.au
SECRETARY: Naomi Osman
Tel: (02) 9460 0165
Email: nosman@awexp.com.au

Northern Territory
PRESIDENT: Jon Sumner
Tel: 0407 089 261
Email: jon@thepod.com.au
SECRETARY: Roger Clifton
Tel: (08) 8999 3853
Email: roger.clifton@nt.gov.au

Queensland
PRESIDENT: Nigel Fisher
Tel: (07) 3378 0642
Email: kenmore_geophysical@bigpond.com
SECRETARY: Binzhong Zhou
Tel: (07) 3327 4189
Email: binzhong.zhou@csiro.au

South Australia
PRESIDENT: Selina Donnelley
Tel: (08) 8224 7560
Email: Selina.Donnelley@santos.com
SECRETARY: Tania Dhu
Tel: (08) 8303 5326
Email: tania.dhu@adelaide.edu.au

Tasmania
PRESIDENT: Michael Roach
Tel: (03) 6226 2474
Email: michael.roach@utas.edu.au
SECRETARY: James Reid
Tel: (03) 6226 2477
Email: james.reid@utas.edu.au.

Victoria
ACTING-PRESIDENT: Suzanne Haydon
Tel: (03) 9658 4515
Email: suzanne.haydon@dpi.vic.gov.au)
SECRETARY: Ashley Grant
Tel: (03) 8687 8179
Email: ashley_grant@ghd.com.au

Western Australia
PRESIDENT: Donald Sherlock
Tel: (08) 6436 8729
Email: don.sherlock@csiro.au
SECRETARY: Julianna Toms
Tel: (08) 9266 3521
Email: julianna.toms@geophy.curtin.edu.au

[1] Members and chairpeople of ASEG's Standing and ad hoc Committees can be found on the ASEG website.

New people for key roles

The end of 2005 provides three people with new challenges and important responsibilities in the Australian science sector. These are:

Kurt Lambeck, President-Elect Australian Academy of Science

Kurt Lambeck was elected President of the AAS for four years from May 2006, when Jim Peacock's term ends. Apart from Dorothy Hill, who was President for a few months in 1970, he will be the only geoscientist to have held this position.

He was elected to the AAS in 1984, served on its Council from 1996–2004; was Secretary (Physical Sciences) 1996–2000; Vice President 1998–2000; and Foreign Secretary 1999–2004.

Kurt's first degree was from the University of New South Wales; subsequently he was awarded doctorates from Oxford, Athens and UNSW.

He is currently professor of geophysics at ANU's, Research School of Earth Sciences, where he has been based since 1977. He was Director of this School from 1984-1994 and previously worked at universities in Athens, Delft, Havard and Paris.

Kurt's wide research interests include geophysics, geodesy, geology, climate and environmental science and space science.

During his distinguished career he has received many honours, including the Prix International Lemaitre from the Georges Lemaitre Foundation; the Alfred Wegener Medal from the European Union of Geosciences; the Jaeger Medal from the AAS; and the Charles A Whitten and Macelwane Medals from the American Geophysical Union.

He is a Fellow of the Royal Society and a Foreign Member of a number of Academies, including most recently the French Academy of Science.

He has also had experience with governments in his role as Chair of Antarctic Science Advisory Committee, 1999–2005 and as a member of the, Technical Advisory Group, Australian Agency for International Development.

He is therefore well qualified to lead the Academy in its role of promoting science through:

- recognition of outstanding contributions to science
- education and public awareness
- science policy and
- international relations.

We wish him well in this role.

James Johnson, Chief Minerals Division, Geoscience Australia

James Johnson has over 20 years of industry and research experience ranging from underground mine geology to near-mine exploration, regional exploration, management of operational geology, and advanced project evaluation.

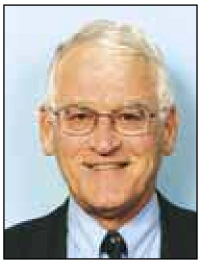
After graduating in 1985 from the University of Sydney he undertook production geology roles in the Kambalda nickel mines and at the Olympic Dam copper-uranium mine. In a PhD project on the Olympic Dam deposit, carried out at the Research School of Earth Sciences at the ANU, James was successful in constraining the timing of the deposit relative to regional geological events, thereby improving exploration models for this deposit type. He conducted further work on this deposit type during a Post-Doctoral Fellowship in Canada from 1993 to 1995.

His exploration roles include the search for iron oxide copper gold deposits in the Gascoyne Region of WA, gold exploration in Victoria and WA, and managing near mine exploration at two mining operations in the Norseman - Wiluna Belt of Western Australia. He spent two and a half years as the Manager of Exploration and Resource Development at the St Ives Gold mine during a major increase in exploration activity that resulted in the discovery of over 2 million reserve ounces, and sufficient resource inventory to justify the construction of the new St Ives processing plant. Through 2005 James has been involved in project evaluation and exploration planning in China and southeastern Australia.

The current aim of GA's Minerals Division is to provide the exploration and mining industry, government and research bodies, and the general public with:

- geoscience information products to support Australian mineral exploration, such as online databases, maps, and 3D models
- advice to government on mineral resources, mining and land use
- factsheets regarding mineral commodities and resources
- new research methods and standards to support mineral exploration in Australia.

James takes up his position to lead this important Division in January 2006.



Tom Spurling, President of FASTS

Tom Spurling became the President of the Federation of Scientific and Technological Societies at its AGM on 20 November, when he took over from Snow Barlow who has now completed a four-year term in the position. FASTS represents the interests of some 60,000 scientists and technologists in Australia. It works to influence the formulation of science and technology policy to the economic, environmental and social benefit of the nation.

The ASEG is a member of FASTS through the Australian Geoscience Council and has had representation on the Executive through Mike Smith who has been Treasurer and David Denham who was Vice-President.

Tom Spurling received his BSc and PhD degrees in Physical Chemistry from the University of WA in 1962 and 1966. He was a Post-Doctoral Fellow at the University of Maryland from 1965-1967 and a Lecturer in Chemistry at The University of Tasmania from 1967-1969. He joined CSIRO in 1969 where he became Chief of the Division of Chemicals and Polymers in 1989 and the Chief of the Division of Molecular Science in 1997. He led the World Bank funded Management and Systems Strengthening-Lembaga Ilmu Pengetuhan Indonesia Project in Jakarta from 1999-2001.

He was appointed Professor of Molecular Science and Director of the Industrial Research Institute Swinburne in 2002 and was Dean of the Faculty of Engineering and Industrial Sciences at Swinburne University of Technology 2004-2005. He is now the CEO of the CRC for Wood Innovations.

Tom is a Fellow of the Royal Australian Chemical Institute, a Fellow of the Australian Academy of Technological Science and Engineering and a Fellow of the Federation of Asian Chemical Societies. He was President of the RACI from 1987-1988 and of the FACS from 1989-1991. He will be the President of FASTS for two years.

It should be noted that both Kurt Lambeck and Tom Spurling have seats at the Prime Minister's Science Engineering and Innovation Council, which is Australian Government's principal source of independent advice on issues in science, engineering and innovation and relevant aspects of education and training. A very useful opening to influence government policy.

New Members

The ASEG welcomes the following new members to the Society. Their membership was approved at the Federal Executive meetings on 28 September and 26 October 2005.

Abdullah Ali Al Ramadhan
Curtin University WA

Brenton James Armitage
Surtron Technologies WA

Blair Berglin
Woodside Energy Ltd WA

John Caon
Zonge Engineering SA

David Neil Dewhurst
CSIRO Petroleum WA

Alexander Buchan Dunbar
Landmark Graphics WA

Kevin Gerlitz
Hampson-Russell Software Indonesia

Philip James Hawke
Rio Tinto Iron Ore WA

Ruiping Li
Curtin University WA

Benjamin Craig Mee
Woodside Energy Ltd WA

Robert John Musgrave
Geological Survey of NSW NSW

Angus Dale Ruddock
Chevron Texaco Australia WA

Steven Michael Sewell
Monash University Vic.

Roy White
Woodside Energy Ltd WA

Neil John Young
Chevron Texaco Australia WA

Australian Society of Exploration Geophysicists – Honours and Awards

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 18th ASEG conference, in Melbourne, July 2-6, 2006. 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 the 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.

Cont'd from page 8

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, and 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 by the State and Federal Executives.

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 published in *Preview*.

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

Chairman, ASEG Honours and Awards Committee
Email: bill@sgc.com.au
Tel: 08 9316 2814
Fax: 08 9316 1624

Applications will close on May 2nd 2006.

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)

Such nominations should be made directly using the following website: http://www.itsanhonour.gov.au/about/medal_descriptions/order_of_australia.html

Australian Capital Territory – by Adrian Hitchman

At our September meeting Trevor Dhu, manager of the Risk Assessment Methods Project at Geoscience Australia (GA), gave a topical presentation on *Modelling the impact and risk of natural hazards*. Recent catastrophic events such as the Indian Ocean tsunami, Hurricane Katrina, and the Pakistan earthquake have heightened the awareness of natural hazards in Australia and around the world. There is a growing recognition that a better understanding of the risk to Australian communities posed by natural hazards makes it possible to plan mitigation and response strategies well in advance of an actual event happening. Trevor's presentation focussed on GA's research into earthquake and tsunami.

In the case of earthquake, GA currently has a probabilistic risk assessment framework that is being combined with advances in modelling earthquake occurrence and propagation to provide realistic estimates of earthquake risk across the country. A new feature of this research is the development of earthquake occurrence models from neotectonic studies and national-scale regolith models that account for local variations in the intensity of earthquake ground shaking.

Tsunami impact and risk modelling within GA is accompanying the development of the new Australian Tsunami Warning System (ATWS). One essential component of this system is the ability to model onshore inundation from tsunami. GA and the Australian National University have collaborated to produce a sophisticated inundation model that will form the basis of tsunami impact modelling for the ATWS. This tool provides the ability to model rapidly the onshore flow of a tsunami and estimate its impact on structures and the population in general.

The October meeting enjoyed a presentation by Hugh Tassell on *Seismic characterisation of an ocean cavity beneath thick floating ice: Results from the Amery Ice Shelf, Eastern Antarctica*. Hugh is a graduate geophysicist with Geoscience Australia, and has been involved in a variety of projects including crustal-scale modelling of wide-angle seismic refraction data in the Bremer Sub-basin, and a national showcasing and implementation of interoperability of geospatial data delivery for the Australian minerals industry.

The Amery Ice Shelf is the third largest embayed ice shelf in Antarctica, with a surface area of 69 000 km^2. Hugh described his work using regional vertical incidence reflection and coincident refraction seismic soundings to delineate the ice thickness and ocean cavity beneath a region of the shelf.

The Amery Ice Shelf presents unique challenges to conventional seismic processing methods. The ice shelf velocity structure is complex and multi-layered with a high-velocity gradient firn layer constituting the upper 50 to 80 m. This layer influences the reflection characteristics of seismic data by preferential amplification and frequency modulation of incoming wave packages. High amplitude dispersive pseudo surface waves and their successive multiples generated by this waveguide can truncate or completely obscure the basal ice reflection.

Hugh's research has proven valuable for modelling the distribution of basal melting and re-freezing processes that influence oceanic circulation under the shelf. This modelling is a key factor in calculating the mass budget of the Amery Ice Shelf; and in turn contributes to understanding the response of Antarctica's ice shelves to climate variations.

At the November meeting, our final for the year, Ray Tracey spoke on *An absolutely fundamental gravity network*. Ray is a member of the Geophysical Acquisition and Databases project in the Minerals Division of Geoscience

Australia and is responsible for the upkeep of the Fundamental Gravity Network; which defines the scale and datum for gravity surveys conducted in Australia and the surrounding oceans. The network consists of about 900 monumented gravity stations at about 250 locations throughout the country. It was first established in 1950 when measurements were made at 59 sites using pendulum apparatus from the University of Cambridge, and was expanded to about 200 sites during the period 1964 to 1967, with further stations subsequently added on an as-required basis. All of these stations have been established by relative gravity meters measuring differences between the stations.

The datum for the original network was defined by relative ties to overseas sites. In 1980 a survey was conducted to tie the network to six absolute gravity sites that were established in 1979 using a Soviet absolute gravimeter. This survey defined a new datum for the network based on absolute gravity measurements and was called the Isogal84 datum.

Recent absolute gravity measurements show that the Isogal84 datum is 75 microgals higher than an absolute datum defined by current absolute gravity instruments. These measurements will form the basis for a new gravity datum for Australian gravity data.

The ACT Branch has a regular program of talks from invited guest speakers, together with other activities of professional interest to its members. New members and visitors who may wish to participate in branch activities are welcome. Please contact the Secretary, Adrian Hitchman (02-6249 9800, adrian.hitchman@ga.gov.au), or President, Jacques Sayers (02 6249 9609, jacques.sayers@ga.gov.au), with enquiries.

New South Wales – by Naomi Osman

Over the past few months our Branch has had the opportunity to hear speakers who were voted by the WA Branch as giving the best technical presentations in their monthly meetings in 2004. These guest speakers were sponsored by the ASEG Federal Executive. In August, Matt Lamont (DownUnder GeoSolutions Pty Ltd) spoke on *Spectral Decomposition: An evolving technology for interpretation*. His talk provided a good insight in using spectral decomposition for mapping and visualization, stratigraphic imaging, bed thickness estimation and direct hydrocarbon indication. In September, Andrew Duncan (Electromagnetic Imaging Technology) gave a talk on the *ATLANTIS Borehole Magnetometer System for EM*. Andrew discussed the advantages for the detection, discrimination and interpretation of highly-conductive massive-sulphide mineral deposits and showed some recent nickel exploration work that used the ATLANTIS system. Both these talks were a great opportunity for the Branch to hear two very good speakers.

On October 21st the Branch held its annual student night. Six students from Macquarie University and Sydney University presented short talks about their honours projects. These presentations were timed to allow the students to reveal their findings to a wider audience, before their projects undergo examination. The six presentations were:

- Martyn Allen (Macquarie) - *An Investigation of the Subsurface Structure of the Mole Granite Using Geophysical Techniques.*
- Glenn Gooch (Macquarie) - *An Investigation of the Gravity Signature of the Hunter Thrust, Singleton, NSW.*
- Margarita Pavlova (Sydney) - *The influence of anisotropy and inhomogeneity on the formation of geophysical images.*
- Takeshi Sato, (Sydney) - *VSP and Stress*.
- Heather Skeen (Macquarie) - *Applying geophysical techniques in grave detection.*
- Natalie Staib, (Macquarie) - *The Geophysical Expression of Tertiary Igneous Activity in South-Central Qld.*

When it came down to choosing the best talk… we couldn't, so the Branch gave each student a prize.

The abstracts for these and other talks that have been held this year can be found on the Branch website: http://www.aseg.org.au/nsw. Branch meetings will begin again in February 2006 and are usually held on the third Wednesday of the month at the Rugby Club.

NSW Branch student night, from left to right: Heather Skeen (Macquarie), Martyn Allen (Macquarie), Glenn Gooch (Macquarie), Takeshi Sato (Sydney), Margarita Pavlova (Sydney) and Natalie Staib (Macquarie).

South Australia – by Selina Donnelley

On the 22 September, we were again lucky to have an interstate speaker visit us from Perth. Andrew Duncan from ElectroMagnetic Imaging Technology, who was voted best Minerals speaker in the Western Australia Branch of the ASEG presented *ATLANTIS Borehole Magnetometer System for EM – Discussion and Examples*. A small but enthusiastic group of professionals enjoyed Andrew's talk, which described the differences in B and dB/dt, and how this can be applied for advantage in downhole magnetics.

The evening of the 19 October was the Annual ASEG Industry Night. Four speakers from a range of companies presented to a large group of industry professionals and tertiary students. Chris Anderson from Euro Exploration gave an interesting talk about his small and thriving company, and how they are dealing with life in the tough world of mineral contracting, trying to balance the boom/bust cycles with a good business model. Andrew Thompson from Minotaur Resources explained how he actually works for 3 companies – Minatour – working on the Prominent Hill development, Mithril – a small Nickel explorer, and Petratherm – hot rocks exploration in northern South Australia. John Hughes, Chief Operations Geophysicist at Santos, told us about what's been happening in the Santos acquisition and processing world, but specifically about the acoustic monitoring project on the southern margins – fish singing, whale noises, and ice moving in Antarctica – all recorded on the continental shelf of southern Australia! Tom Kivior from Schlumberger gave us a quick introduction to who Schlumberger are, and what that means for young people interested in the petroleum industry, and also gave an excellent demonstration of the new Ant-Mapping in Petrel, a fault interpretation product. Overall, the Industry Night was a great success, with lots of students present, and good interactions between the students and professionals.

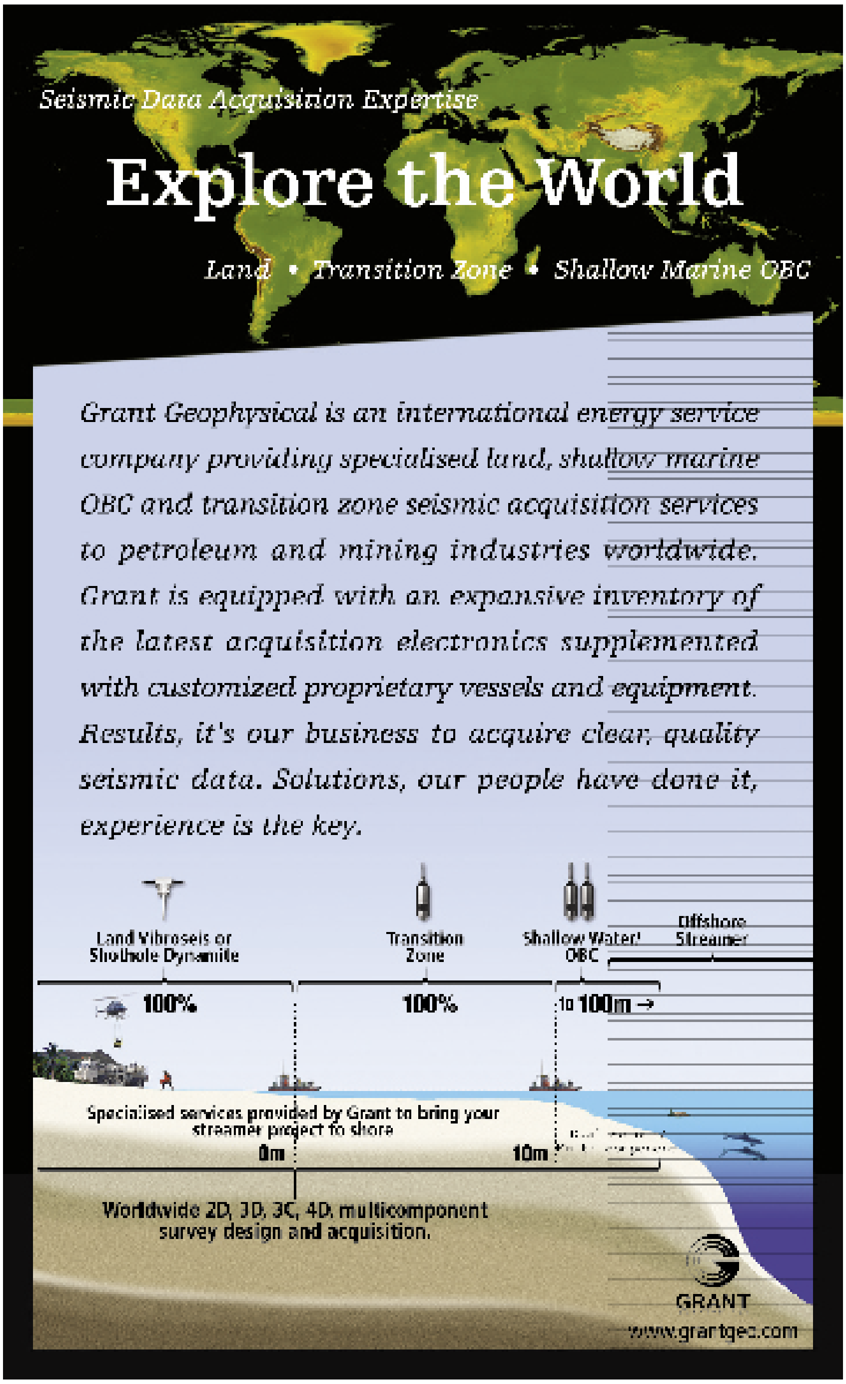
The first ever ASEG Schools Day was held on the 24th October. The ASEG Committee was approached by a high school science teacher from the northern suburbs of Adelaide, who wished to show her students the University of Adelaide, South Australian Museum and the Australian School of Petroleum's excellent visualisation suite. We decided to sponsor the 17 students and two teachers to come into the city and tour the museum, have a BBQ with professionals and university students, and see a demonstration of the visualisation suite. The day was a huge success, with the students (who come from Smithfield Plains High School, which is a disadvantaged school) thoroughly enjoying the whole day. The BBQ with professionals from Beach Petroleum, PIRSA, The University of Adelaide and Santos, was a chance for the students to ask questions and to chat with Geoscientists in a relaxed environment. The visualisation suite, with its impressive 3D facilities and excellent demonstration, had the students totally absorbed. The ASEG committee was very pleased with the day, and next year we plan to continue this event and probably expand it to multiple disadvantaged schools with students who are interested in learning more about the Geosciences.

The ASEG Melbourne Cup Lunch was sponsored by Beach Petroleum. The Calcutta style bidding for horses was dominated by Beach, and the winning horse (Makybe Diva) was held in the end by Beach Petroleum and Andy McGee's table. As usual, the Melbourne Cup Lunch, held at the Duke of York Hotel, was a great event, with lots of ladies (and the odd gent) dressing up for the day, and a great atmosphere all around. The Duke of York provided enjoyable food, and after the race many people moved outside to the balcony in the sun.

Coming up soon is the ASEG Students' night, where we hope to have four representatives from the South Australian Universities to present their geophysical honours projects.

We again thank our sponsors for technical meetings in 2005: PIRSA, Schlumberger, Santos, Cooper Energy, Australian School of Petroleum, Minotaur Resources, Petrosys, Zonge Engineering, Beach Petroleum, Stuart Petroleum and PGS Reservoir.

We welcome new members and interested persons to come along to our technical meetings, usually held on a Wednesday night at the Duke of York Hotel at 5:30 pm. Please contact Selina Donnelley (Selina.donnelley@santos.com) for details.



SEG 75th Anniversary

The SEG 75th Anniversary was celebrated in Australia by holding a ball in Perth on the 17 September, 2005.The major sponsors of the event were Chevron, Singapore Airlines and Linneys Jewellers. The event was attended by over 230 people who enjoyed a night of history, entertainment, dancing and many prize give-aways. The event was hosted by Kim Hughes and Ken Judge from the “Captain and the Coach”, who told a variety of amusing stories and jokes throughout the night.

Norm Uren giving a speech about the brief history of the SEG

Patrick Andre presenting CGG AFL Grand Final tickets to Gail Tressider

Burswood restaurant voucher – Richard Tressider

Halo Restaurant voucher and Student Prize (Coles/Myer voucher) – Matthew Dielesen

Cape Lavendar gift pack – Nola Burns

A brief history of the SEG and some interesting corresponding events was given by Norm Uren, who then led the guests in a toast the 75 years of the SEG.

The speeches continued with many of the sponsors adding their congratulations to the SEG and presenting prizes.

The night continued well into the early hours with people dancing up a storm on the dance floor, then onto the casino!

The night included many prize give-aways including:

Mike Mclerie from Chevron

Dawn Davis from Singapore Airlines

Pauline Emiliani from Linneys Jewellers

Pauline Emiliani presenting Linney's champagne diamond to GiGi Ewing

- Two return economy class airline tickets to anywhere in the world on Singapore Airlines Network thanks to Singapore Airlines.
- A Champagne Diamond thanks to Linneys Jewellers
- Two tickets and 4 nights accommodation in Melbourne to attend the AFL grand final thanks to CGG.

The champagne diamond donated by Linneys was raffled off on the night which generated over $3000 towards the Indigenous Australian Engineering Summer School. This is a fantastic effort and thanks must go to everyone who entered the draw.

Many thanks to the organising committee for all their hard work associated with this event.

Congratulations to the SEG on it’s accomplishments during the last 75 years, we all look forward to many more achievements in the future.

The Organising Committee: from left to right: Megan Evans (Chairperson), Susannah Elvey, Norm Uren, Justin Keating, Paul Wellington, Damian Leslie, Jenni Powell, Louise Middleton.

Dawn Davies presenting Singapore Airlines tickets to Susan Stickland

A tribute to Sister Act tickets – Sean Murray

Business Investment in R&D highest ever

Business Expenditure on R&D (BERD) increased in 2003/4 by 10% over the previous year to $7.22 billion according to the Australian Bureau of Statistics, which released its analysis in September this year (ABS 8104.0 - BERD). This is the highest level recorded and is the fourth successive year of increase since the declines from 1995/6 to 1999/0.

There was also a modest increase as a share of GDP from 0.87% in 2002/3 to 0.89% in 2003/4 (see Figure 1).

The Executive Director of FASTS, Bradley Smith, said the increase in BERD was good news, although Australia remains in the bottom half of OECD countries in terms of the ratio of BERD to GDP (see Table 1).

“R&D is an essential contribution to long term productivity and economic growth as it underpins a significant proportion of innovation. It is estimated that technological innovation is responsible for at least 50% of productivity gains.”

“It is essential then that further measures are adopted to boost R&D innovation levels, rather than over-reliance on labour market participation and deregulation to drive productivity growth”.

	2000/1	2001/2	2002/3	2003/4
Sweden	na	3.31	na	2.95
Finland	2.41	2.42	2.41	2.46
Japan	2.12	2.26	2.32	2.36
Korea	1.96	2.23	2.18	2.01
United States of America	2.04	2.00	1.87	1.79
Denmark	na*	1.65	1.75	na
Germany	1.75	1.75	1.75	1.73
Belgium	1.48	1.60	1.64	1.71
Iceland	1.55	1.80	1.77	1.67
France	1.41	1.36	1.37	1.36
United Kingdom	1.21	1.24	1.26	1.24
Canada	1.21	1.15	1.05	1.03
Norway	na	0.96	0.96	1.00
Netherlands	1.10	1.11	1.03	0.99
Australia	**0.74**	**0.81**	**0.79**	**0.89**
Ireland	0.82	0.78	0.77	0.80
Czech Republic	0.78	0.80	0.79	0.77
Spain	0.50	0.50	0.56	0.60
Italy	0.53	0.55	0.54	0.55
New Zealand	na	0.42	na	0.47
Slovak Republic	0.43	0.43	0.37	0.32

na* not available

Table 1: BERD/GDP for OECD countries

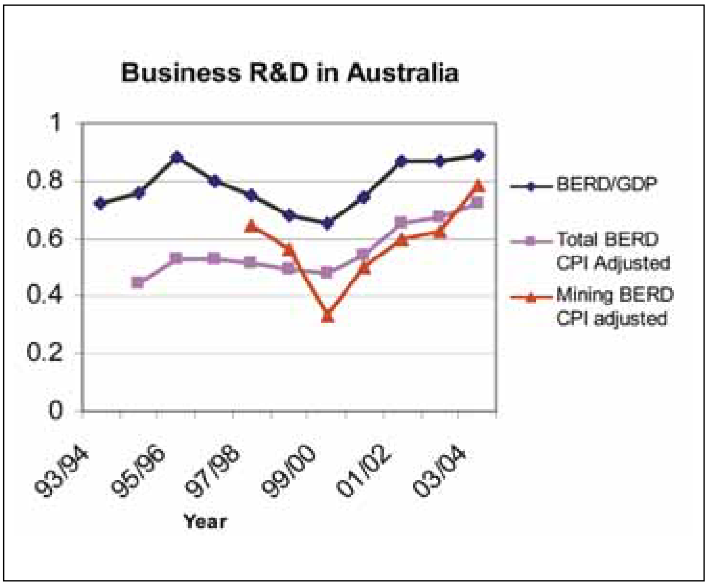


Fig. 1. Business R&D expenditure in Australia (BERD); BERD/GDP in %; total BERD in $billion; Mining (including petroleum) BERD in $billion (both adjusted for CPI movements to 2003/4 dollars). Figures for the mining industry before 1997/98 are not available.

“The Commonwealth has an important role in encouraging R&D but there are emerging problems with current policy settings”.

“Administrative requirements in the Government’s new *Commercial Ready* grants program are making it harder for companies to access support for early stage and ‘proof of concept’ R&D compared to later stage R&D”.

“A greater focus on reducing compliance and administrative burdens will help further improvements in BERD,” concluded Mr Smith.

Notice the decline in R&D investment in the US and Canada over the four year period. In the US this amounts to a reduction of 12% over a three year period – not a good sign for the world’s largest economy.

There was a significant increase of R&D in the ‘Mining Sector’, which is very encouraging. The numbers jumped from $612 million in 2002/3 to $783 million in 2003/4. The number of businesses reporting in this Sector increased from 142 to 168 and the people/year number went from 653 to 983. Let’s hope the trend continues.

CSIRO cuts staff to balance budget

CSIRO’s 2004/05 annual report contains some worrying trends relating to the financial health of the organisation. In a nutshell the external earnings targets in the budget estimates have been overly optimistic and as a result – according to Chief Finance Officer, Mike Whelan – 780 support positions are being reviewed to make savings of $5 million per year.

After posting a $47 million profit in 2001/02 CSIRO has had deficits of $21.7 million, $5.3 million and $9.2 million in the three subsequent years. This may not seem too significant for an organisation with a total annual turnover of just under a $1 billion and a staff of ~6000, but the failure to meet external earnings targets projected in forward estimates has been very serious.

For example in the 2003/04 budget papers the planned income from goods and services in 2006/07 was estimated at $435 million. In the 2005/06 papers this number has fallen to $325 million. In other words, in the context of strategic planning, the organisaton is likely

Estimates of [government revenues]/[goods & services income] in $m from budget papers for CSIRO

Budget	*2003/04*	*2004/05*	*2005/06*	*2006/07*	*2007/08*	*2008/09*
2003/04	568/314	561/348	572/385	582/435		
2004/05	569/314	577/320	590/356	604/403	622/430	
2005/06		577/285	594/303	608/325	627/346	633/346

to have a shortfall of over a $100 million in external earnings for 2006/07 over the 2003/04 forward estimates. The previous table shows the numbers from the budget papers.

Notice how the government appropriation always seems to increase with time whereas the external earnings decrease.

Clearly, CSIRO has been pushed from a research-based agency relying on government appropriations and focusing on long-term public good projects, to an enterprise-based institution with an emphasis on making money for its research through short term contracts with industry.

It is somewhat ironic that during tough times the remuneration of the CSIRO Board Members has increased from $268k (in 2004) to $405k in 2005 and for the same years, the number of senior executives earning more than $301k per annum has doubled from 5 to 10.

Anyway to address the funding issue a draft paper has been prepared for the Executive Management Council. The drafters had a tough job because there are so many areas that CSIRO could make important national research contributions.

In the wash-up the main recommendation commits the agency to grow the National Flagships Programs[1] to 30-40% of its appropriation funding, and build its collaborative linkages through the Flagship Collaboration Fund. In 2006/07 an extra $30.1 million will be allocated to the Flagships. This is a 24% increase over the 2005/06 allocation and brings their core funding up to $158.1 million. The areas to be cut to find the extra Flagship money are: intelligent transport systems; renewable energy, restricting health to preventable health; and agricultural research supporting small changes in productivity.

Further work on the business model and industry engagement for the Minerals Down Under Flagship proposal (see October 2005 *Preview*) is required before any change to investment levels in the minerals and metals area. There is also a commitment to maintain investment levels in research into upstream exploration, extraction and processing of coal, gas and oil.

Consequently the geoscience based work is likely to continue at current levels of investment.

[1] There are six Flagship Programs/Themes: Energy Transformed, Food Futures, Light Metals, Preventative Health, Water for a Healthy Country, and Wealth from Oceans.

News on Research Funds

For those of us who need funding to undertake research projects I would like to mention two opportunities that members may not be aware of.

Flagship Collaboration Fund

Of the $305 million provided by the Government to the Flagship initiative over seven years, $97 million has been allocated to enhance and reinforce the development of collaborative partnerships which reflect the National Research Priorities.

The Flagships offer many opportunities for collaborative work or study.

Elements of the Flagship Collaboration Fund include a contestable collaborative research program, visiting fellowships and postgraduate scholarships. To find out more visit: http://www.csiro.au/index.asp?type=blank&id=Flagships_Collaboration

$500m fund to generate low-emission future

In October the Government's $500 million Low Emissions Technology Demonstration Fund was open for business. Ian Macfarlane, the Minister for Industry, called for applications to develop the next generation of large-scale greenhouse gas abatement technologies.

The Low Emissions Technology Demonstration Fund, a flagship initiative of the Energy White Paper, will provide competitive grants in the order of $20 million and upwards to individual Australian projects demonstrating the commercial viability of their low-emissions technology.

Mr Macfarlane said the fund was expected to leverage an additional $1 billion in private sector investment in large-scale, long-term emission reduction technologies.

"The demonstration fund will support low-emission technologies across the full spectrum of energy sources – ranging from renewable energy initiatives to fossil fuel and energy efficiency technologies," he said.

Some of the technologies that could be eligible under the fund include hot dry rocks, new renewable energy technologies like large-scale solar concentrators, coal-fired generation with carbon capture and storage, and energy efficiency technologies in stationary and transport energy sectors.

"The key criterion will be the ability of the technology to reduce Australia's energy sector emissions by at least two per cent per annum over the longer term, and the potential to be available commercially by 2020 to 2030," Mr Macfarlane said.

For more information about the fund visit: www.ausindustry.gov.au.

Alexey Goncharov alexey.goncharov@ga.gov.au

Basement and crustal results from the Bremer Sub-basin, SW Australia and its Antarctic counterpart drive Australia-Russia cooperation

By Alexey Goncharov[1], Peter Petkovic[1], German Leitchenkov[2] and Hugh Tassell[1]

Introduction

As part of the Australian Government's ***New Oil*** initiative, Geoscience Australia undertook a geophysical survey (the Southwest Frontiers Survey 280) of the south-western Australian continental margin in late 2004. The survey acquired 2700 km of industry-standard, 106 nominal fold seismic reflection data recorded to 12 s two-way time using a 6–8 km digital streamer and 4900 cui gun array. Marine reflection seismic acquisition was supplemented by the recording of refraction seismic data by sonobuoys and land stations in the onshore/offshore observation scheme depicted in Figures 1 and 2. The main scientific objectives of refraction work were to:

1. provide accurate seismic velocity information to improve depth conversion of reflection seismic data,
2. assist with definition of type of basement and crust below the sedimentary basins, and
3. provide estimates of crustal thickness underneath major sediment deposition centres in the area to better constrain interpretation of tectonic evolution of the region.

The new refraction seismic data have substantially supplemented velocity measurement coverage of the area from old sonobuoy work and from sparse onshore stations. This has uncovered new evidence about the nature of basement and structure of the crust in the area of the study. 'Basement' in terminology adopted for this paper is acoustic basement, which we have interpreted to correspond to crystalline Precambrian basement.

Geological setting

Exposed to the north of the Bremer Sub-basin are rocks of the Mesoproterozoic Albany-Fraser Orogen (Fig. 1), which extends along the southern margin of the Archaean Yilgarn Craton. The Albany-Fraser rocks are mainly granitoid intrusions, orthogneisses, metagabbros, mafic dykes and metasediments. These rocks are basement to the onshore Eocene sediments of the Bremer Sub-basin, which have been extensively eroded, and fill the low-relief basement topography in discontinuous pockets close to the coast. The

[1] Geoscience Australia
[2] VNIIOKeangeologia, St-Petersburg

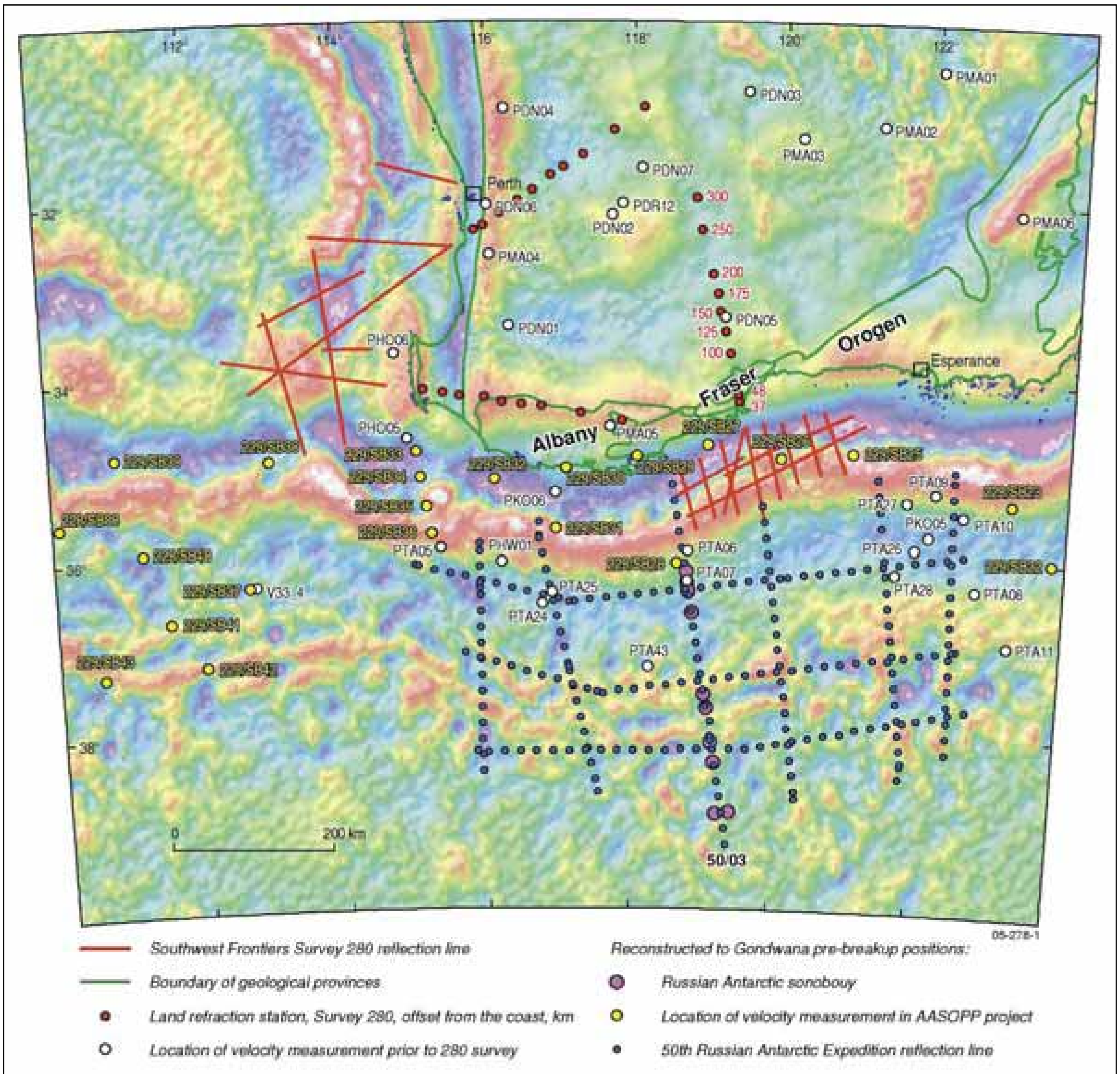


Fig. 1. Locations of seismic observations in southwest Australia and Antarctic observations in reconstructed Gondwana positions. Background image is a high-pass filtered Bouguer gravity anomaly (both onshore and offshore), in which wave lengths greater than 200 km have been attenuated and upper crustal density variations are amplified.

area has been subject to prolonged erosion and the subdued topography is extensively covered by a Cainozoic regolith (Abeysinghe, *et al.*, 2002; Myers, 1990).

According to Fitzsimons (2003), the Albany Fraser Orogen is thrust up against the Yilgarn Craton to the northwest and extends eastwards under the Eucla Basin to the Coompana Block and Gawler Craton. It is thought to be a collision zone between these two cratons and was previously contiguous with outcrops on the Wilkes Land coast in Antarctica. The Recherche Granite dominates the eastern region of Albany Fraser Orogen. Early stage deformation of the granite was followed by the deposition of the Mount Ragged metasedimentry rocks (quartzite with minor pelite) which are assumed to unconformably overly the Recherche Granite. Low grade metasedimentary rocks of Stirling Range and Mount Barren units outcrop in the western part of the Albany Fraser Orogen next to its northern border. Judging from relatively minor representation of metasedimentary rocks in outcrops onshore, prior to survey 280 it was anticipated that basement underlying the Bremer Sub-basin was most likely a correlate of Recherche granite. Interpretation of new data presented in this paper suggests that in fact this is not the case.

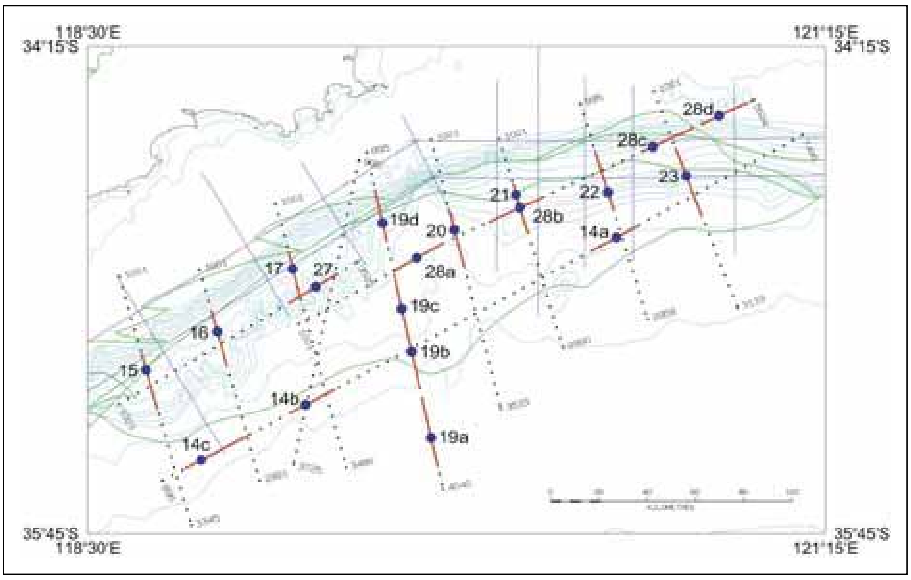


Fig. 2. Locations of sonobuoy recordings (red lines) in the Bremer Sub-basin deployed during the Southwest Frontiers Survey 280. Green line – outline of the Bremer Sub-basin, light blue lines – isobaths, dark blue lines – earlier reflection lines, blue dots – locations of 1D velocity solutions.

Earlier refraction work

The earliest refraction study in the area (primarily over the Yilgarn Craton) was carried out by the Bureau of Mineral Resources (now GA) in 1971 and reported in Mathur (1974) with interpretation constrained by gravity and seismic reflection data. The travel-time data were interpreted using constant velocity layers with planar boundaries. One of the profiles, extending southeast from Perth, is of interest. Near Albany, this profile consists of a three layer crust with velocities of 6.1, 6.6 and 7.3 km/s respectively, and a sub-crustal velocity of 8.1 km/s (see PMA05 graph in Fig. 3). The model profile is approximately 34 km thick near Albany, although Mathur (1974) points out this may not be accurate if the Moho dip in this region is higher than inland regions. The reliability of the travel-time data is also adversely affected by the uneven spacing of recording stations.

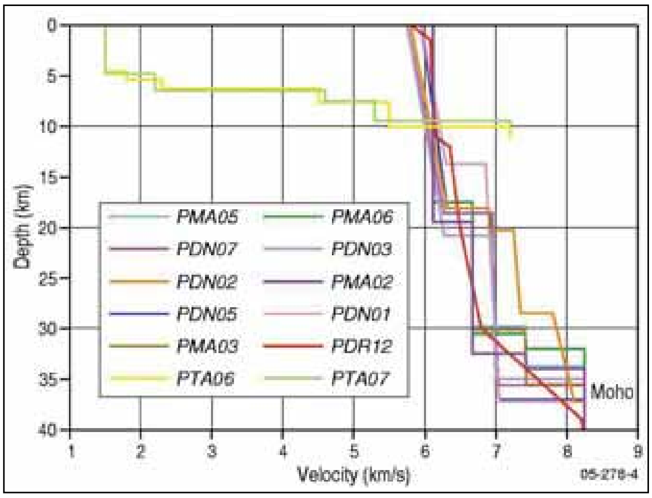


Fig. 3. Compilation of velocity-depth functions from earlier work. Onshore: (PDN – from Dentith et al., 2000; PMA – from Mathur, 1974) and offshore: (PTA – from Talwani et al., 1979). Note that velocities from 5.9-6.2 km/s dominate in the upper crust and extend as deep as 15 km in onshore measurements. The two offshore PTA measurements vary significantly from onshore measurements and are representative of the whole family of earlier offshore measurements presented in Fig. 4 which are dominated by 5.0-5.7 km/s basement velocities.

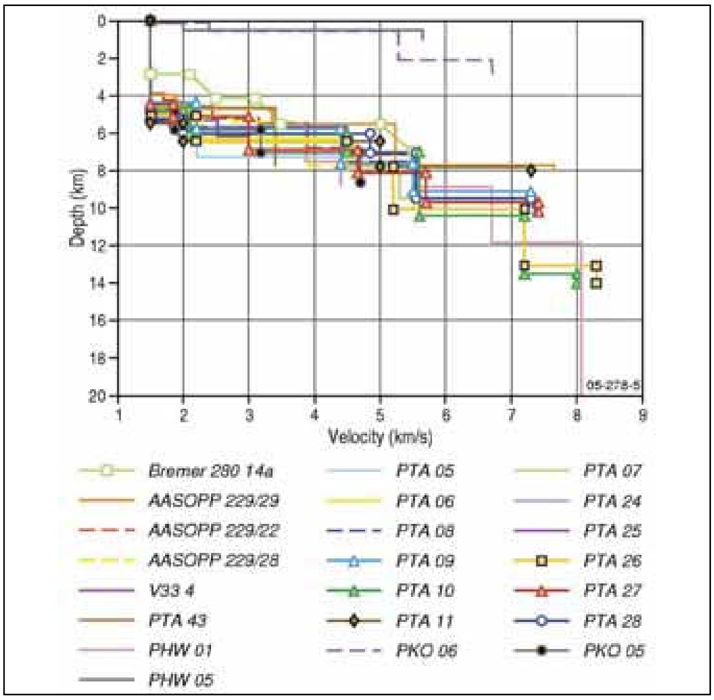


Fig. 4. Compilation of velocity-depth functions from earlier offshore work (PTA – from Talwani et al., 1979; PKO - Konig and Talwani 1977; PHW – Hawkins et al., 1965). Representative examples from one of the survey 280 sonobuoys and several Antarctic sonobuoys deployed in Geoscience Australia's AASOPP experiment are also shown. Note that velocities 5.0-5.7 km/s dominate in the basement on both conjugate margins.

Subsequent work on the Yilgarn Craton carried out by the Australian Geological Survey Organisation (now GA) in 1983 was reported in Dentith *et al.* (2000), who proposed a two layer model with horizontal and vertical gradients (see PDN graphs in Fig. 3). The south-eastern end of one of the Dentith *et al.* (2000) profiles, which stopped short of the Albany-Fraser province, had velocity gradients of 5.95-6.31 km/s in the upper crust, 6.90-7.05 km/s in the lower crust, and a mid-crustal boundary at a depth of 18 km (PDN05 graph in Fig. 3). The sub-crustal velocity was 8.25 km/s with a Moho depth of 36 km.

Drummond (1988) reported greater crustal thickness beneath the Albany-Fraser zone than Dentith *et al.* (2000). This is based on continuing weak reflections arriving later than the expected Moho travel-time as recorded over the Yilgarn Craton. This possibility was also raised by Wellman (1978) who, based on gravity considerations, predicted that the crust beneath mobile belts is thicker (and denser) than in the adjacent older cratonic areas.

All earlier land refraction results are consistent with the prevailing granitic and gneissic composition of rocks outcropping onshore in the study area; in both the southern part of the Yilgarn Craton and the Albany Fraser Orogen, velocities in the range 5.9-6.2 km/s dominate the upper crust and extend as deep as 15 km in onshore measurements (Fig. 3). However, it should be noted that there is no single velocity measurement in metasedimentary rocks of the Albany Fraser Orogen, and that velocities well below 6.0 km/s clearly dominate in the basement imaged by earlier refraction work offshore (Fig. 4).

Sonobuoy results and basement imagery

Nineteen sonobuoys were deployed successfully over the Bremer Sub-basin (Fig. 2). The maximum offset for identified refraction events was 23 km observed on two sonobuoys. Up to three refracted phases were identified in sonobuoy record sections on the analogue displays after a 6-30 Hz band-pass filter was applied to the data. The travel-times of phases were digitised, corrected for sonobuoy drift and formatted for input to the modelling software.

Two-dimensional velocity models for individual sonobuoys were derived by forward modelling using the SIGMA ray-tracing software based on the algorithm of Zelt and Smith (1992). A starting model for each line was the measured water depth and an estimate of basement depth from interpretation of reflection data converted to depth using stacking velocities. Modelling was an iterative process involving revised identification of refracted and reflected phases and aiming to minimise the difference between computed and observed travel-times of these phases.

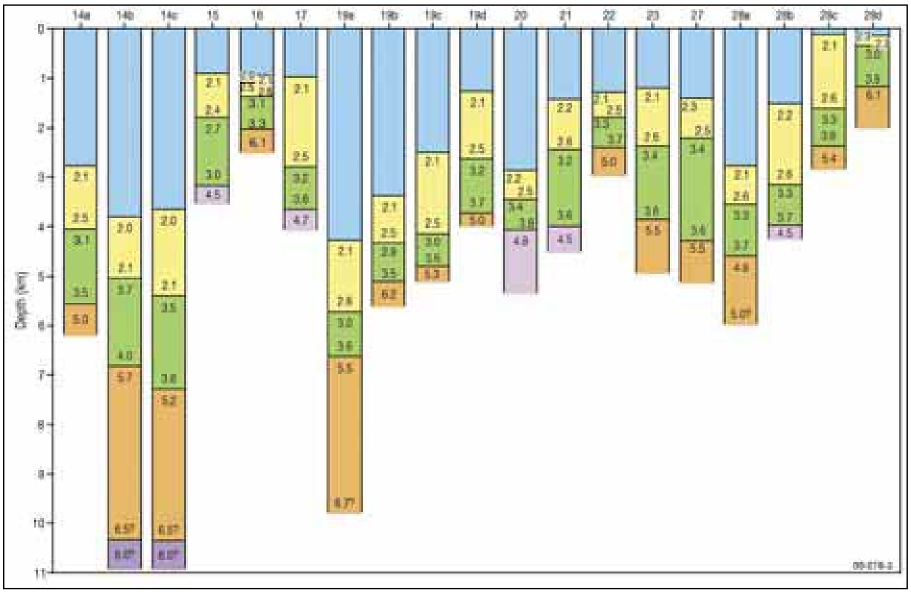


Fig. 5. Velocity solutions from all 19 sonobuoys deployed in the Bremer Sub-basin during the Southwest Frontiers Survey 280. Note that velocities 5.0-5.7 km/s (orange layer) dominate in the basement and in some cases (28c, possibly 27, 19d, 19c?, 14a) were interpreted to correspond to the lower part of the sedimentary pile as well.

The final 2D models were interpolated near to the location of maximum ray penetration and coverage to give the 1D velocity solutions shown in Figure 5. Estimates of basement velocity were made at these points where the velocity profile is considered most reliable.

Out of 19 sonobuoys deployed during the survey, eight recorded useful signal at offsets sufficiently large to characterise basement. Of these, five resulted in basement velocity measurements in the range 5.0-5.7 km/s and three (including two located on or next to basement highs imaged by reflection data) gave basement velocities of 6.1-6.2 km/s, i.e. in the expected range for granites (Fig. 5). For one sonobuoy (28c) a velocity of 5.4 km/s was interpreted to occur above basement. For sonobuoys 14a, 19c, 19d and 27, velocities of 5.0-5.5 km/s were also interpreted to occur above the basement identified in reflection data. However, confidence of basement interpretation in the reflection data at these locations is low, and it is plausible that the basement could be located at a shallower depth. In this situation, these velocity measurements could also be interpreted as low velocity basement. Thus, we conclude that prevailing velocities in the basement are considerably lower than old land refraction data suggested (Fig. 3), but they are consistent with results of earlier refraction work offshore (Fig. 4).

Basement identification in reflection data for input to the starting model was assisted greatly by combined reflection/refraction imagery (Fig. 6) produced for each of 19 sonobuoys. Basement (labelled 'b' in Fig. 6) identification on the basis of reflection data alone would have been ambiguous in many cases; usually there are several competing events that can be interpreted as basement. Clear refraction arrivals highlighted in the right-side panels of Fig. 6 eliminate ambiguity where they can be tracked back via tangential reflections to the reflection record in the left-side panel. Of course, reduction of ambiguity in basement identification applies only in the vicinity of sonobuoys that recorded refractions from the basement. Unfortunately, sonobuoy coverage in this experiment was not sufficient to eliminate ambiguity at all locations where events competing to become basement were identified in reflection data.

Depth conversion

A comparison of stacking velocities and velocities derived from modelling of sonobuoy data suggests that stacking velocities from survey 280 can be used as a reliable substitute for acoustic velocities down to 2 s two-way time into the sediments below sea floor, for the purpose of calculating sediment thickness. This is probably due to the effects of the longer streamer used for multi channel data acquisition, pre-stack time migration in the processing sequence, and lack of sharp velocity stratification of sediments in the Bremer Sub-basin. When applied to a basement travel-time pick interpreted in the multi-channel reflection data set, the new velocity data compiled from combined processing and interpretation of reflection and sonobuoy data indicate a maximum sediment thickness in major depocentres of the Bremer Sub-basin in excess of 9 km.

Velocity model from land refraction data

The density of observations in the onshore component of our experiment was significantly better than in earlier work. Land stations were deployed not more than 25-50 km apart and shots fired every 37.5 m while Dentith *et al.* (2000) had only three shots for each of two ~400 km long orthogonal transects with 27 stations recording half of each transect simultaneously. Our observation scheme was limited in that data were recorded in one direction, and there was no recording at near offsets (for the most remote inland station the nearest shot was fired at 295 km offset (see Fig. 1)). As a result, our velocity model of the upper crust for inland stations is not well constrained. However, there is good agreement between the main phases recorded by the station at minimum offset from the coast and those from the further inland stations, giving us confidence that we have not missed significant inland lateral variation in the upper crust due to the limitations mentioned above.

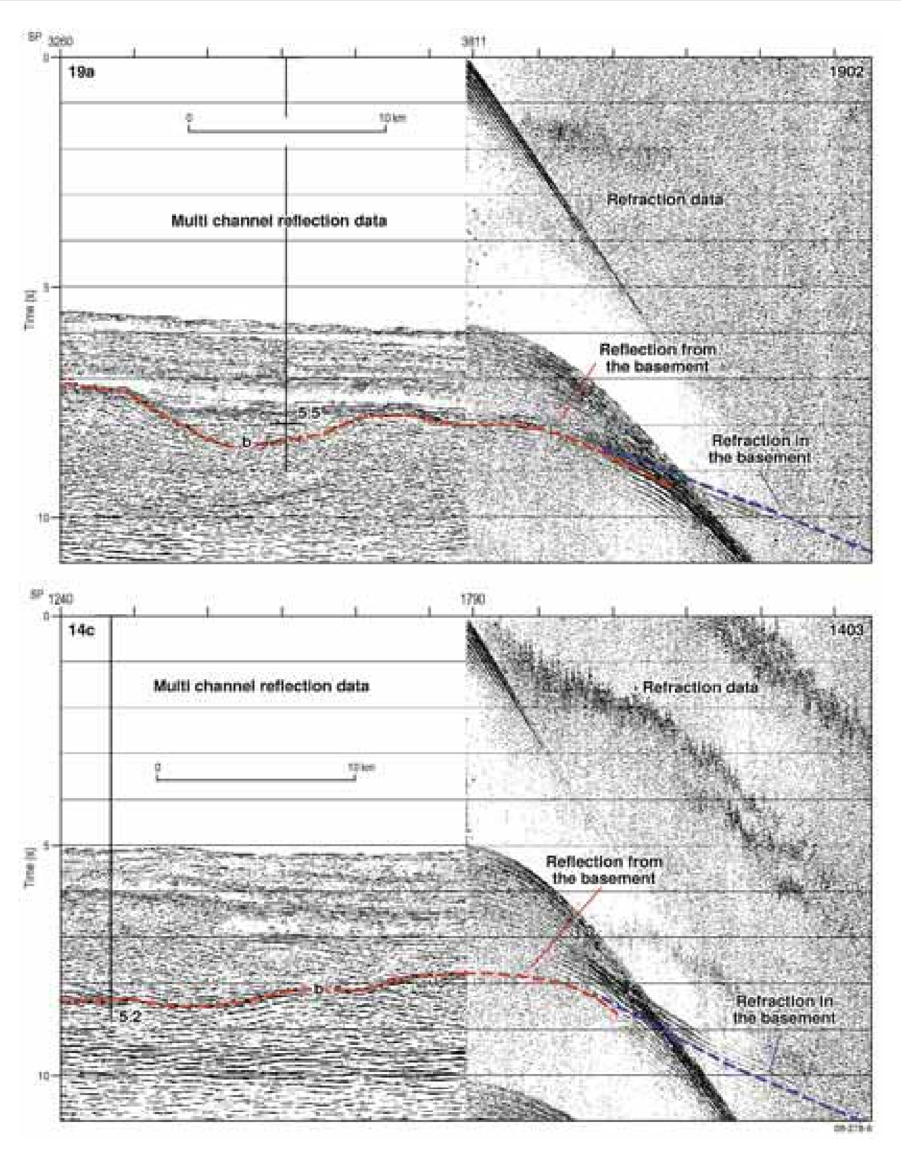


Fig. 6. Two classical examples of combined reflection/refraction imagery of basement in the Bremer Sub-basin (for sonobuoy locations see Fig. 2). Note that basement (labelled 'b') identification on the basis of reflection data only would be ambiguous: there are several competing events that can be interpreted as basement both below and above 'b'. Clear refraction arrivals highlighted in right panels essentially eliminate ambiguity: they can be tracked back to associated reflections recorded by sonobuoys and in the multi channel reflection data. Vertical black lines show locations of 1D velocity solutions taken at points of maximum ray coverage in the original 2D velocity models.

The quality of the data in terms of continuity of arrivals, clarity of phase changes in the first arrivals, and signal-to-noise ratio was very high (Fig. 7). Useful signal was recorded at a maximum offset of 400 km for the station located 300 km inland from the coast. Upper mantle refractions propagating at ~8 km/s are quite distinct in this record section. We have identified three major phases in the first arrivals: refractions in the basement and upper crust, refractions in the lower crust, and upper mantle refractions (Fig. 7). This pattern remains remarkably stable from one station to another. In addition, at some stations deep reflections were identified and were originally interpreted as PMP reflections from the Moho. However, subsequent modelling showed that they most likely originate beneath the Moho (Fig. 7).

Velocity models derived from the interpretation of the sonobuoy data set were fully integrated into the starting model, and were not modified in any form in subsequent iterative ray tracing. The same SIGMA code (Zelt and Smith, 1992) was used to model both sonobuoy and land refraction data. Travel-times of main phases were modelled for all nine land refraction stations. In the process of iterative modelling for the best travel-time fit, 364 models were generated and tested by ray tracing. The general pattern of seismic phases identified in the experimental data is well reproduced by the final model. Travel time mismatches for individual phases in the final model presented in Fig. 8 generally are within $\pm$ 0.2 s and do not exceed 0.5 s at some 'anomalous' locations. Given the complexity of the final model, we believe that this match is very good.

Our interpretation of land refraction data requires a thick crustal root centred around 200 km in Fig. 8, in order to match observed and calculated phase arrivals. Modelled mantle refractions (light green line in Fig. 9) and the PMP reflection from the Moho, where it is shallower than 40 km depth (light blue line in Fig. 9), arrive ~1 s earlier than recorded first arrivals, but sub-Moho reflections marked AB in Fig. 9 originate near the bottom of the root and match recorded first arrivals well. From this we conclude that the Moho has to be significantly deeper than 40 km to explain these observations. Similar events (Fig. 7, also marked AB) are very prominent on stations 48 km and 125 km. They arrive 1-2 s later than modelled PMP reflections and require significant dip on the sub-Moho reflector to explain their high apparent velocities. Thus, the presence of the crustal root in our model is supported by first arrivals and some subsequent phases recorded at several stations.

A limitation of the model presented in Fig. 8 in effectively imaging the crustal root is that it produces mantle refractions at station 150 km preceding observed first arrivals. We could not explain both AB and CD phases (Fig. 9) without creating these preceding mantle refractions. However, the neighbouring station (175 km) imaging the same feature does not produce mantle arrivals from the model although they are recorded in the experimental data. We speculate that amplitude effects due to the complex shadow zones forming from the crustal root may explain these mismatches. We intend to further explore this problem by means of computing synthetic seismograms.

Even if the problem of preceding mantle refractions is resolved using this technique, the need to somehow link AB and CD phases will remain. This in itself is another indication of crustal thickening in this area. The AB phases, as discussed above, originate from depths significantly greater than 40 km, but the origin of CD phases appears to be at a depth of ~40 km. Combining both together in the same model does not seem to be achievable without crustal thickening of some form.

There is also evidence of a crustal root expression in the gravity field along the survey transect. Old land refraction interpretations of crustal thickness (Dentith *et al.*, 2000; Mathur, 1974), when merged, also suggest crustal thickening in this area, but not to the extent that our data suggest. The total crustal thickness on the northern side of the crustal root in our model corresponds very well with the model presented by Dentith *et al.* (2000). In both cases it is ~37 km at PDN05 location in Fig. 1.

The land refraction velocity model presented in Fig. 8 stands up reasonably well in validation against gravity modelling, with a computed/

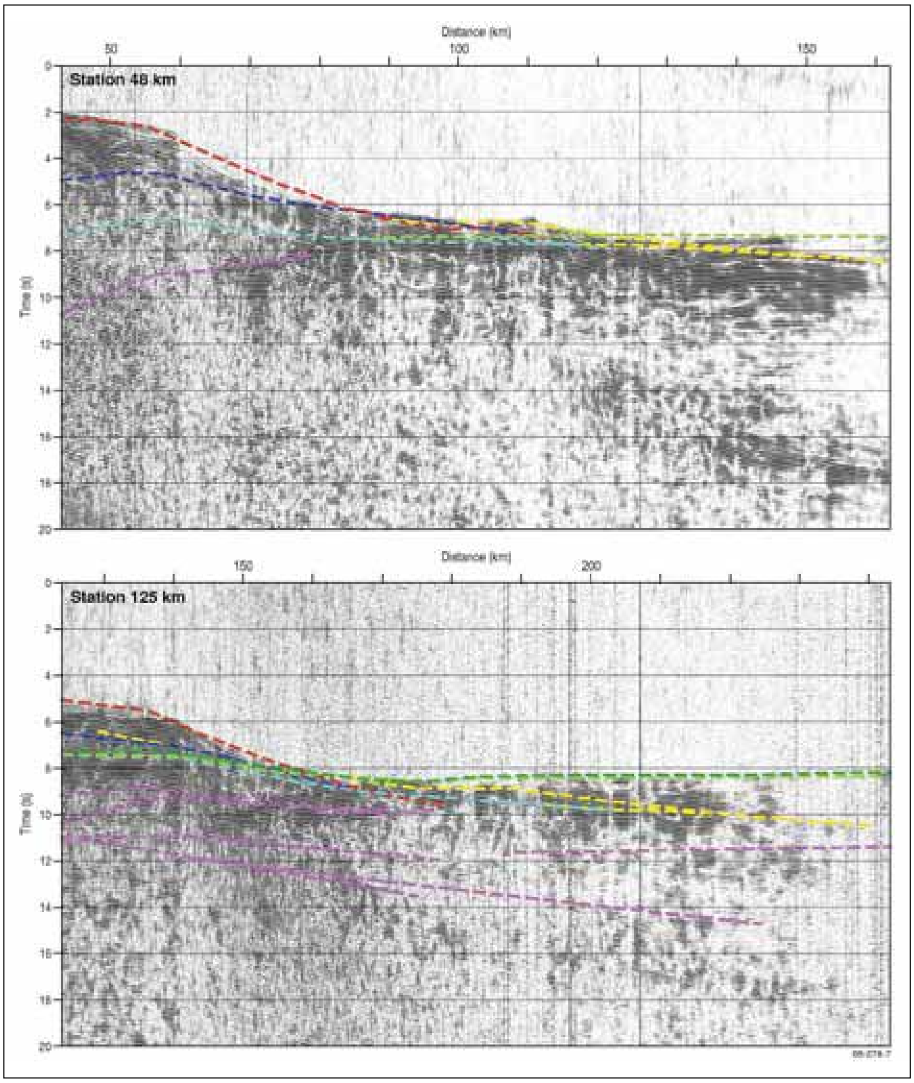


Fig. 7. Examples of data and interpretation for refraction stations deployed on the land extension of line 280/19: at (a) 48 km and (b) 125 km locations shown in Fig. 1. A 1:2:1 weighted running average mix, digital coherency enhancement and an 8 km/s time scale reduction have been applied to refraction data. Calculated travel times from the model in Fig. 8 are superimposed on top of record sections as colour coded lines: red – refraction in the basement and upper crust, dark blue – reflection from the top of lower crust, yellow - refraction in the lower crust, light blue - Moho reflection, green - mantle refractions, magenta - sub-Moho reflections. AB phases discussed in the text.

observed RMS error of ~8 mGal. To achieve this match, the density of the crustal root in the depth range 30-60 km was set to 3.25t/m^3, while the seismic velocity within this feature is in the range 7.0-7.1 km/s. Mafic garnet granulite appears to be the only petrology likely to explain the relatively low velocity and relatively high density within the crustal root identified in our model. According to Christensen and Mooney (1995), mafic garnet granulite at a depth of 50 km will have a density of 3.17$\pm$0.11 t/m^3 and a velocity of 7.13$\pm$0.19 or 6.97$\pm$0.19 km/s under low or average heat flow conditions respectively. Typical mantle rocks in this depth range would have substantially higher velocities – close to 8.0 km/s.

Results from the conjugate Antarctic margin

Results of the 50th Russian Antarctic Expedition (December 2004 – April 2005) provide invaluable support to understanding the nature of basement and crust in the area of our study on the Australian Southern Margin. This expedition collected high-quality multi-channel reflection seismic data recorded to 12 s two-way time along 9 lines of ~4000 km total length and sonobuoy data of highest quality in a fully reversed observation scheme.

As the existing plate tectonic reconstructions suggest (Müller, 2005, pers. comm.), had the Russian survey been conducted ~90 Ma ago while Gondwana still was an integral continent, they would have imaged crust in the very near vicinity of the Bremer Sub-basin (see Fig. 1 where Russian lines are reconstructed to positions that they would have occupied in Gondwana prior to break-up).

Using these data a very accurate velocity model was developed along line 50/03 (Fig. 10). Interestingly, interpretation of the Russian sonobuoy data from line 50/03 shows low velocities (5.1-5.4 km/s) in the basement on the inner side of Antarctic continent-ocean boundary (interpreted volcanic or low grade metamorphic rocks in Fig. 9), and therefore it is consistent with our results from the Australian margin. Furthermore, low grade metasediments have also been identified at Mounts Amundsen and Sandow on the Antarctic continent, which are within the conjugate counterpart of Albany Fraser Orogen on the Antarctic side.

Discussion

One of the key findings of the refraction seismic study is that velocities in the basement underlying Mesozoic sediments of Bremer Sub-basin are generally in the 5.0-5.7 km/s range. This indicates that, contrary to prior expectations, basement in the area appears to be primarily non-granitic in composition. If all available results are compiled, including results from Antarctic Margin and the earlier onshore and offshore seismic refraction results presented above, it appears that prior to break-up a ~400 km wide zone in Gondwana had basement velocities significantly lower than normal continental values of 5.9 - 6.2 km/s typical for granites and gneisses.

The presence of low grade metasediments of the Albany-Fraser Province and its Antarctic equivalent is our preferred interpretation of this observation. Indeed, structural and age considerations (Fitzsimons, Reddy, 2005, pers. comm.) indicate that low grade metasediments within the Albany Fraser Orogen (Mount Barren and other locations, see above) have been tectonically transported north to their present locations. In particular, age relationships between low grade metasediment (~1700 Ma) and high grade metamorphic rocks surrounding them (~1200-1300 Ma) are such that low grade metasidements could not have been deposited where they are today, as they would have been overprinted by younger high grade metamorphism. Thus, if northwards tectonic transport did occur, it seems logical that the 'birth place' of Mount Barren and similar low grade metasedimentary rocks is located beneath the Mesozoic sediments of the Bremer Sub-basin. This would be consistent with low seismic velocities in the basement of the Bremer discussed above.

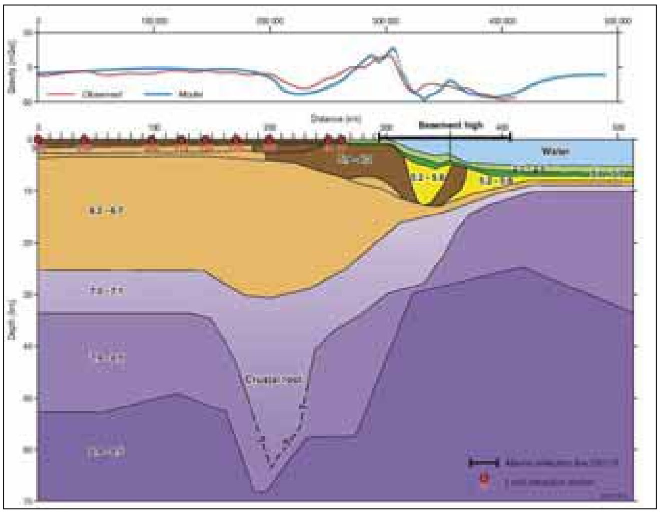


Fig. 8. Velocity model for line 280/19 from combined interpretation of sonobuoy and land refraction data. Velocity values in km/s. Note the presence of a thick crustal root centred around 200 km location and low (5.2-5.6 km/s) velocities in the Bremer basement, except for the basement high where basement velocities are above 6.0 km/s. Moho depth within crustal root may require some re-adjustment as a result of future research.

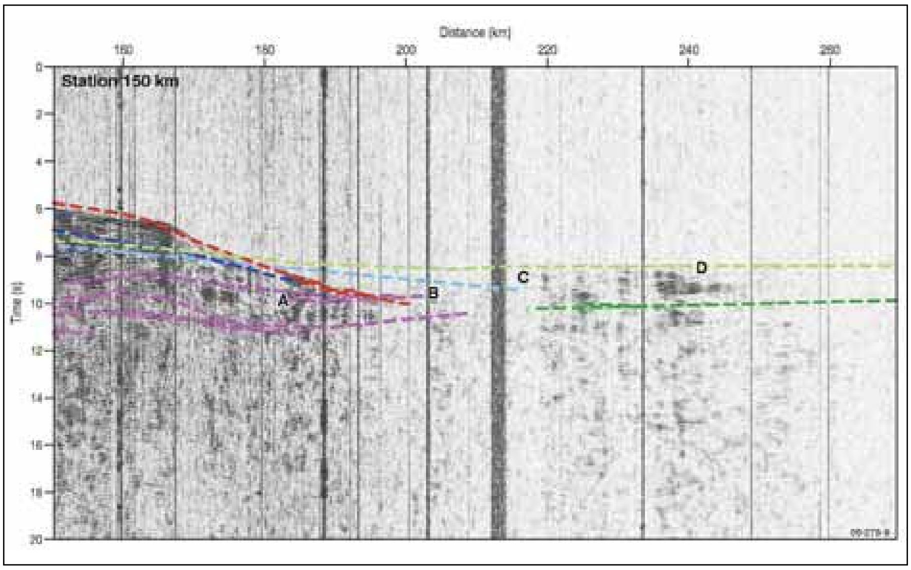


Fig. 9. Example of data and interpretation for land refraction station at 150 km location shown in Fig. 1. Same processing parameters and colour coding of phases as in Fig. 7. AB and CD phases are discussed in the text.

On a crustal scale, apart from low velocity basement considerations, our results do not support a three layer crust with velocities 6.1, 6.6 and 7.3 km/s suggested by Mathur (1974). We do not have evidence for a 6.6 km/s refractor in the middle crust in our land refraction data set. Mathur's (1974) crustal thickness of 34 km near Albany at PMA05 location (see Fig. 1) is consistent with our results as well as is a sub-crustal velocity of 8.1 km/s. The two layer model of Dentith *et al.* (2000) with upper crustal velocity gradient from 5.95-6.31 km/s and a lower crustal from 6.90-7.05 km/s is consistent with our model in terms of crustal velocity stratification, but our mid-crustal boundary is up to 12 km deeper than the 18 km in the Dentith *et al.* (2000) model (PDN05 graph in Fig. 3). This mismatch suggests that there may be a sharp SW-NE deepening of mid-crustal refractor between PDN02-PDN05 line and our land refraction line.

In addition to the unexpected low velocity basement, the presence of a thick crustal root in our velocity model (Fig. 8) between PDN05 and the coast (Fig. 1) was also unanticipated. As discussed above, this crustal root appears to be made of mafic garnet granulite, but fine tuning of the seismic model and further research into its geological origin are required. We cannot rule out that the depth to Moho, which forms the bottom of this feature, will require some re-adjustment as a result of future research.

On consideration of petroleum prospectivity for the Bremer Sub-basin, metasediments, which are our preferred interpretation for basement composition, have a substantially lower heat production than granitic rocks. This leads to a different scenario for hydrocarbon maturation in the basin, which is one of the targets of Geoscience Australia's Big New Oil program. Concentration of U, Th and K_2O in rock samples from onshore outcrops of Yilgarn Craton and Albany-Fraser Province, as well as in rock samples dredged from the seafloor in the Bremer Sub-basin were used to quantify the possible heat production in the Bremer basement and in the crust below it.

Advanced burial and thermal geo-history modelling in this area is currently being carried out for the first time in Australia, without relying on default values (such as heat flow or geothermal gradient) in modelling packages. Newly developed Fobos Pro modelling software is being used to model several pseudo wells. To constrain these models, estimates of total crustal thickness and composition before rifting were derived from the far inland refraction stations deployed during the survey. Crustal thickness and composition underneath major depocentres of the Bremer Sub-basin were constrained by data from land refraction stations deployed near the coast. Sensitivities of models to whole lithosphere parameters (mainly initial thickness) are also being explored. These results will be presented at the APPEA Conference in May 2006.

Finally, clear similarities in seismic properties of the crust between the Bremer area on the SW Australian continental margin and its conjugate on the Antarctic margin, have generated a big interest among Russian scientists. As a result, planning of the Russian Antarctic Expedition 51 (to start in December 2005) will take into consideration the need to record data at specific locations to answer questions of interest to both Australian and Russian geoscientific programs.

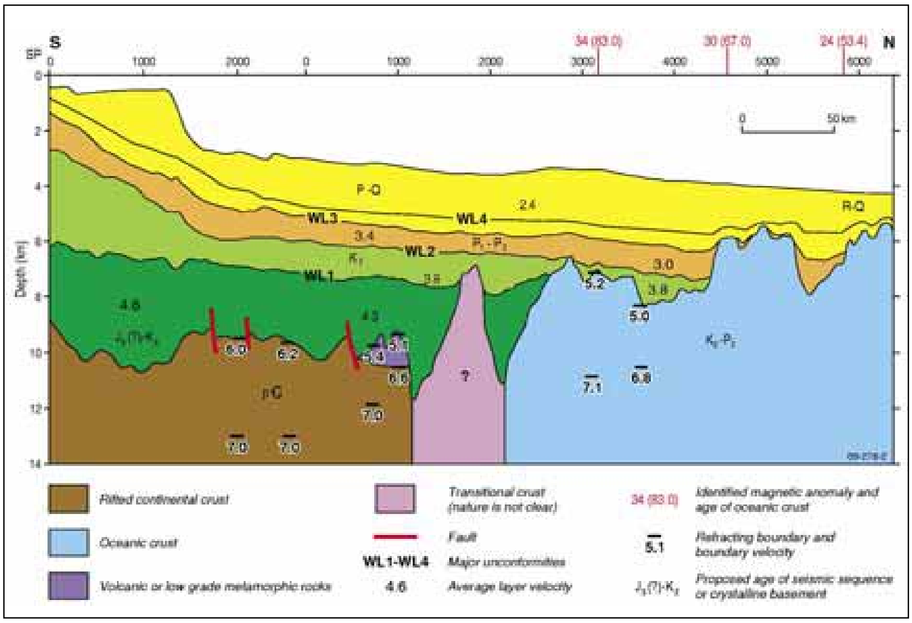


Fig. 10. Interpretation of seismic section along Russian Antarctic Expedition line 50/03. The location of the line reconstructed to a pre-breakup Gondwana position is shown in Fig. 1. Note velocities of 5.1-5.4 km/s in the basement on the inner side of transitional crust have been interpreted by Russian colleagues as corresponding to volcanic or low-grade meta-sedimentary rocks.

Conclusions

1. Combined reflection/refraction imagery has significantly reduced ambiguity of basement identification on the basis of reflection based interpretation alone. The density of sonobuoy data coverage and range of offsets, from which useful signal was recorded, have to be increased in future experiments to reduce this ambiguity even further.
2. Calibration of stacking velocities against sonobuoy-derived velocities resulted in more accurate depth conversion of reflection interpretation, which suggests that the maximum sediment thickness in the Bremer Sub-basin is in excess of 9 km.
3. Velocities in the basement underlying Mesozoic sediments of Bremer Sub-basin are generally in the 5.0-5.7 km/s range, indicating that, contrary to prior expectations, basement in the area is unlikely to be granitic in composition. The presence of low-grade metasediments of the Albany-Fraser Province is our preferred interpretation of this observation. Such interpretation is consistent with results from the Antarctic Margin.
4. Interpretation of a thick crustal root underneath Albany Fraser Orogen and southern part of Yilgarn Craton is an unexpected result of our work. This crustal root appears to be made of mafic garnet granulite, but fine tuning of its seismic model and understanding of its geological origin require further research.
5. Basement and crustal controls on hydrocarbon maturation resulting from this work are being implemented in advanced burial and thermal geo-history modelling and these results will be reported at APPEA Conference in May 2006.

Acknowledgements

This highly dynamic and logistically complex work is a collective effort by many people. Fred Kroh, Damien Ryan and the onboard geophysical party of M/V "Pacific Sword" contributed to various aspects of sonobuoy and land refraction work. Tanya Fomin, Chris Heath, Alan Crawford and Jack Pittar participated in the land refraction fieldwork.

Equipment and support was provided by the Australian National Seismic Imaging Resource thanks to Brian Kennett, Tim Barton and Armando Arcidiaco. Yulia Guseva, Victor Ganduykhin and Sergei Ivanov of the Polar Marine Geophysical Expedition in St-Petersburg contributed to the processing and interpretation of Antarctic data. An Australian IGCP travel grant, supported by Cec Murray, Doug Finlayson and Steven Reddy, allowed Alexey Goncharov to travel to St-Petersburg to work with Russian colleagues on interpretation of the Antarctic data. This work benefited from discussions with Howard Stagg, Barry Bradshaw, Phil Symonds, Dietmar Müller and Ian Fitzimons. Fred Kroh, Bruce Goleby, Clive Collins and Howard Stagg reviewed earlier versions of the manuscript and provided useful remarks. AG, PP, HT publish with the permission of the Chief Executive Officer, Geoscience Australia. The Geoscience Australia Catalogue reference number for this paper is 63911.

References

Abeysinghe, P. B., Flint, D. J., Luckett, J., McGuinness, S. A., Pagel, J., Townsend, D.B., and F. Vanderhor, 2002, Geology and mineral resources of the Southern Cross-Esperance region of Western Australia: Western Australia Geological Survey, Record 2002/3.

Christensen, N. I., and W. D. Mooney, 1995, Seismic velocity structure and composition of the continental crust: a global review: J. Geophys. Res., **100**, 9,761–9,788.

Dentith, M. C., Dent, V. F., and B. J., Drummond, 2000, Deep crustal structure in the southwestern Yilgarn Craton, Western Australia: Tectonophysics, **325**, 227-255.

Drummond, B. J., 1988, A review of crust/upper mantle structure in the Precambrian areas of Australia and implications for Precambrian crustal evolution: Precambrian Research, **40/41**, 101-116.

Fitzsimons, I. C. W., 2003, Proterozoic basement provinces of southern and south-western Australia, and their correlation with Antarctica, in, M. Yoshida, B. F. Windley, and S. Dasgupta, eds., Proterozoic East Gondwana: Supercontinent Assembly and Breakup: Geological Society, London, Special Publication 206, 93-130.

Hawkins, L. V., Hennion, J. F., Nafe, J. E., and H. A Doyle, 1965, Marine seismic refraction studies on the continental margin to the south of Australia: Deep Sea Res., **12**, 479-495.

Konig, M., and M. Talwani, 1977, A geophysical study of the southern continental margin of Australia: Great Australian Bight and western sections: Geol. Soc. Am. Bull., **88**, 1000-1014.

Mathur, S. P. 1974, Crustal structure in southwestern Australia from seismic and gravity data: Tectonophysics, **24**, 151-182.

Myers, J. S., 1990, Albany-Fraser Orogen, in, Geology and mineral resources of Western Australia, Western Australia Geol. Surv. Memoir **3**, 255-265.

Talwani, M., Mutter, J. C., Houtz, R., and M. Konig, 1979, The crustal structure and evolution of the area underlying the magnetic quiet zone on the margin south of Australia, in, J. S. Watkins, L. Montadert, and P. W. Dickerson, eds., Geological and Geophysical Investigations of Continental Margins: Am. Assoc. Petrol. Geol., Memoir **29**, 151-176.

Wellman, P., 1978, Gravity evidence for abrupt changes in mean crustal density at the junction of Australian crustal blocks, BMR Journal. Austral. Geol. and Geophys., **3**, 153-162.

Zelt, C. A., and R. B. Smith, 1992, Seismic travel time inversion for 2-D crustal velocity structure. Geophys. J. Intl., **108**, 16–34.

Wishing all our clients and friends a Merry Christmas and a prosperous 2006

Tenix

Rhys Barker
Account Service Manager

Tenix LADS Corporation Pty Ltd
Second Avenue
Technology Park
Mawson Lakes SA 5095
Australia

Telephone +61 8 8300 4447
Facsimile +61 8 8300 7528
Mobile +61 (0) 417 885 084
Email rhys.barker@tenix.com

Richard Bennett
Director/Geophysicist

QUADRANT GEOPHYSICS PTY LTD

545 Terranora Road
Terranora NSW 2486
PO Box 360
Banora Point NSW 2486

Ph: 07 - 5590 5580
Mob: 0408 983 756
Fax: 07 - 5590 5581
E-mail: quad.geo@pobox.com

---

encom

David Pratt MSc, PhD
Managing Director

Encom Technology Pty Limited www.encom.com.au
Level 1, 123 Walker Street, North Sydney NSW 2060, Australia
tel +61 2 9957 4117 **dir** +61 2 9923 5817 **fax** +61 2 9922 6141
mob +61 414 614 117 **email** david.pratt@encom.com.au

ER Mapper
Helping people manage the earth

Andrew Skiers
Business Development Manager - Mining

ER Mapper Asia Pacific
2 Abbotsford Street
West Leederville WA 6007
AUSTRALIA

Telephone: +61 (0) 8 9388 2900
Facsimile: +61 (0) 8 9388 2901
Mobile: +61 (0) 433 460 030
andrew.skiers@ermapper.com
www.ermapper.com
www.EarthEtc.com

GeoSolve Pty Ltd

Henk van Paridon
Consultant Geophysicist

Seismic Interpretation Services
Petroleum, Coal and GIS Mapping

Tel: 07 3367 3031 Fax: 07 3371 0114
Mob: 0438 337 102 Home: 07 3371 0244
email: henk@geosolve.com.au

2 Park Rd
Milton
Qld Australia 4064

SEISMIC ASIA PACIFIC PTY. LTD.

MITCHAM INDUSTRIES, INC.

GARY BUTLER
MANAGER - GEOPHYSICAL SYSTEMS

Phone: +61 (0) 7 3719 3400
Mobile: +61 (0) 402 140 428
Direct: +61 (0) 7 3719 3406
Fax: +61 (0) 7 3216 7665

556 Tarragindi Roa
Salisbury, QLD 4107
AUSTRALIA

gary.b@seismic.com.au

www.mitchamindustries.com
www.seismic.com.au

SEISMIC ASIA PACIFIC PTY. LTD.

MITCHAM INDUSTRIES, INC.

PAUL DUNCAN
EXECUTIVE DIRECTOR

Phone: +61 (0) 7 3719 4300
Mobile: +61 (0) 414 332 824
Direct: +61 (0) 7 3719 3408
Fax: +61 (0) 7 3216 7665

556 Tarragindi Roa
Salisbury, QLD 4107
AUSTRALIA

paul.d@seismic.com.au

www.mitchamindustries.com
www.seismic.com.au

by Peter Milligan, Geoscience Australia peter.milligan@ga.gov.au

New Products from MAGDA (the Geoscience Australia Magnetic Anomaly Grid Database of Australia)

MAGDA Database

Geoscience Australia released the 4th Edition of the Magnetic Anomaly Map of Australia in November 2004. This edition is underpinned by a database of nearly 700 matched total magnetic intensity (TMI) grids, from which other products are readily generated.

Program *GRIDMERGE*[1], originally developed by Geoscience Australia, performs the task of matching the initial grids by minimising their overlap differences in one inverse operation. As each grid is stored at its optimal resolution (according to the original survey line spacing), *GRIDMERGE* also enables any area of selected data to be seamlessly merged to a user-specified final resolution.

For continental-scale merges of Australia, we are currently using a cell-size of 0.0025 seconds of arc (~250 m), but much smaller cell sizes are possible, producing files many gigabytes in size.

With the database in place, almost an infinite variety of further products can be generated, such as various derivative grids, reduction-to-the-pole grids, etc. These can be produced from individual survey project grids, from selected merged grids, or from continental-scale composites.

Products for Release December 2005

1. Vertical derivative grid and image
Geoscience Australia is releasing a 0.0025 seconds of arc (250 m) grid cell size vertical derivative grid and digital image of Australia, to complement the grid of TMI released in November 2004. This grid has been generated by using a standard filtering process in the Fourier domain. As the vertical derivative operator is essentially a high-pass filter, longer wavelengths are suppressed, and shorter wavelengths emphasised. Figure 1a shows the greyscale vertical derivative image of Australia, with a more detailed subset in Figure 1b.

2. Thumbnail tiff images
A suite of enhanced colour tiff images has been generated for each grid in the MAGDA database. These images are georeferenced, and will provide clients with a quick overview of the magnetic field variations of each project. They may also be useful as backdrops in GIS and publications. The enhancement includes histogram equalisation, and the application of a rainbow colour look-up table. Each image also has an accompanying colour z-scale of TMI values. We are providing only one possible enhancement, to give clients a flavour of the data. If other enhancements are required, the higher-resolution dataset of Australia, or individual project grids, should be downloaded from GADDS for geophysical and image processing. Figure 2 shows examples of the tiff images available. The filename of each grid incorporates the Geoscience Australia project number, and also the names of the 1:250 000 map sheets across which the original data were acquired.

Fig.1a. First vertical derivative of total magnetic intensity of Australia.

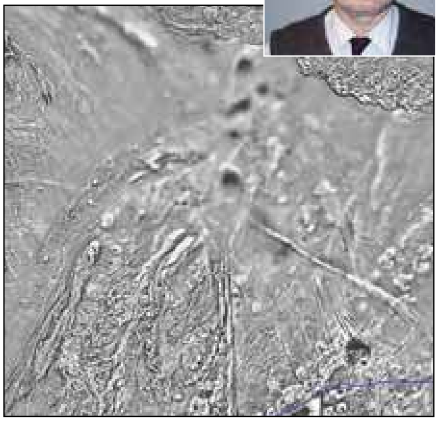


Fig. 1b. First vertical derivative of total magnetic intensity of Australia, for the region in red outlined in Figure 1a.

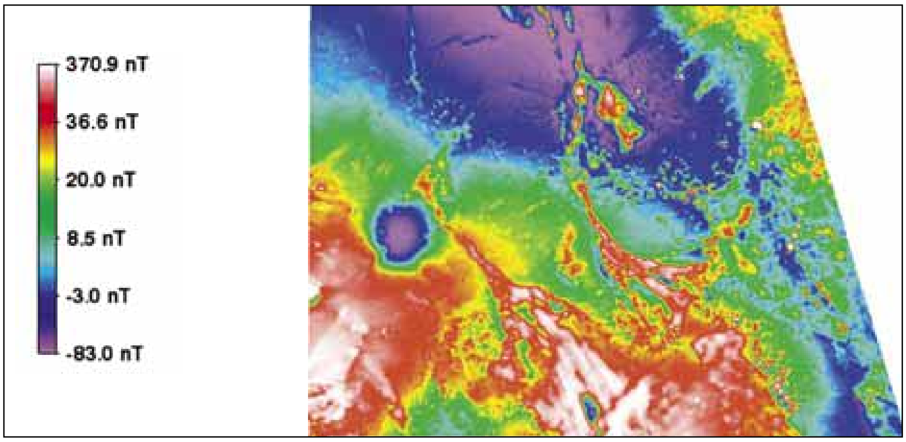


Fig. 2a. Total magnetic intensity histogram-equalised colour image of Geoscience Australia project 583, covering part of the Wagga Wagga 1:250 000 map sheet area in New South Wales.

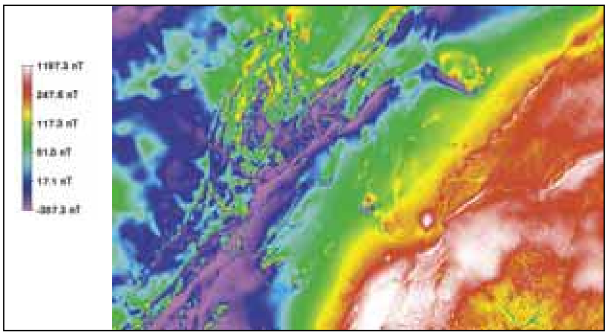


Fig. 2b. Total magnetic intensity histogram-equalised colour image of Geoscience Australia project 607, covering the Lissadell 1:250 000 map sheet area in Western Australia.

Data Access

Total magnetic intensity data for Australia are available for free download via the internet using the Geophysical Archive Data Delivery System (GADDS) – http://www.geoscience.gov.au/gadds

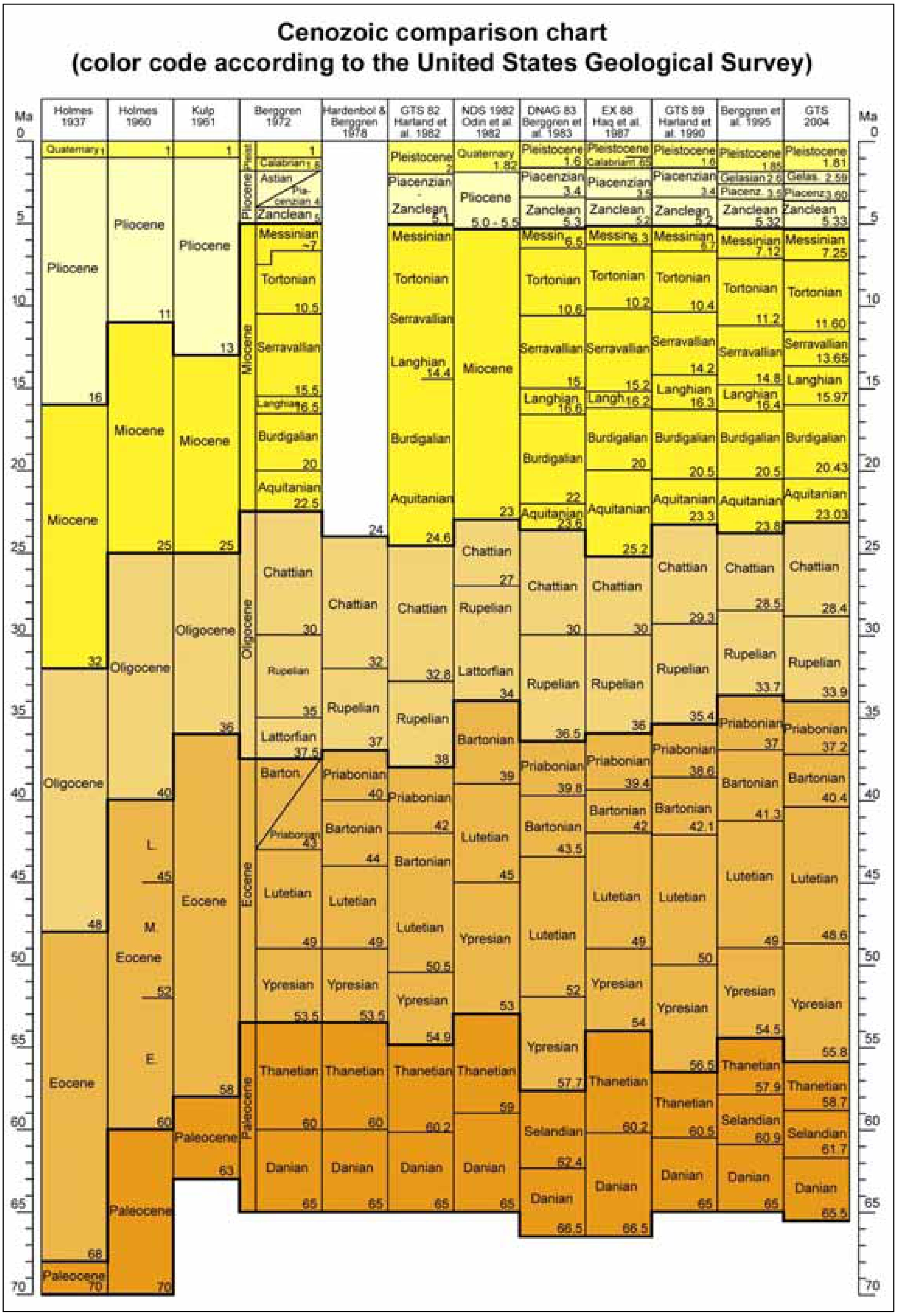
[1] now part of the Intrepid data processing system

New Geological Timescales

ICS's new charts

Reliable and accurate geological timescales are essential for resource exploration and understanding the history of the Earth – particularly for geophysicists.

In 2005 Cambridge University Press published a 589 page volume, based on the monumental work of the International Commission of Stratigraphy {A Geologic Time Scale 2004, Edited by Felix Gradstein, Jim Ogg and Alan Smith, Cambridge University Press, £80 (£40 - paperback)}. Over 40 geoscientists contributed to this major study, which was last reviewed in 1989. They used a variety of techniques including, radiometric dating, orbital cycles tuning (Milankovitch-type climate oscillations reflected in sediments), biostratigraphy, sequence stratigraphy, geomagnetic reversals and other events to complete the work.



The ICS produced several new charts, which can be downloaded from their website (http://www.stratigraphy.org) or acquired in hard copy from the Commission. Two of these charts are reproduced here. The first is the International Stratigraphic Chart, which is the current world standard and the second details the progress made with the Cenozoic timescale during the last ~70 years.

Interactive Geological Time Scale charts (I-GTS) planned

The next task for the Commission is to produce an interactive version of the international, standard Cenozoic-Mesozoic-Paleozoic bio-magneto-sequence time scale charts.

At present there are nearly 10 000 bio-stratigraphic, sea-level, magnetic and geochemical events available for presentation in appropriate columns, with documentation of zonal definitions and other

This Cenozoic Comparison Chart is reproduced here by kind permission of the International Commission on Stratigraphy. Note the changes in the ages of the boundaries and the sub-divisions during the last ~70 years.

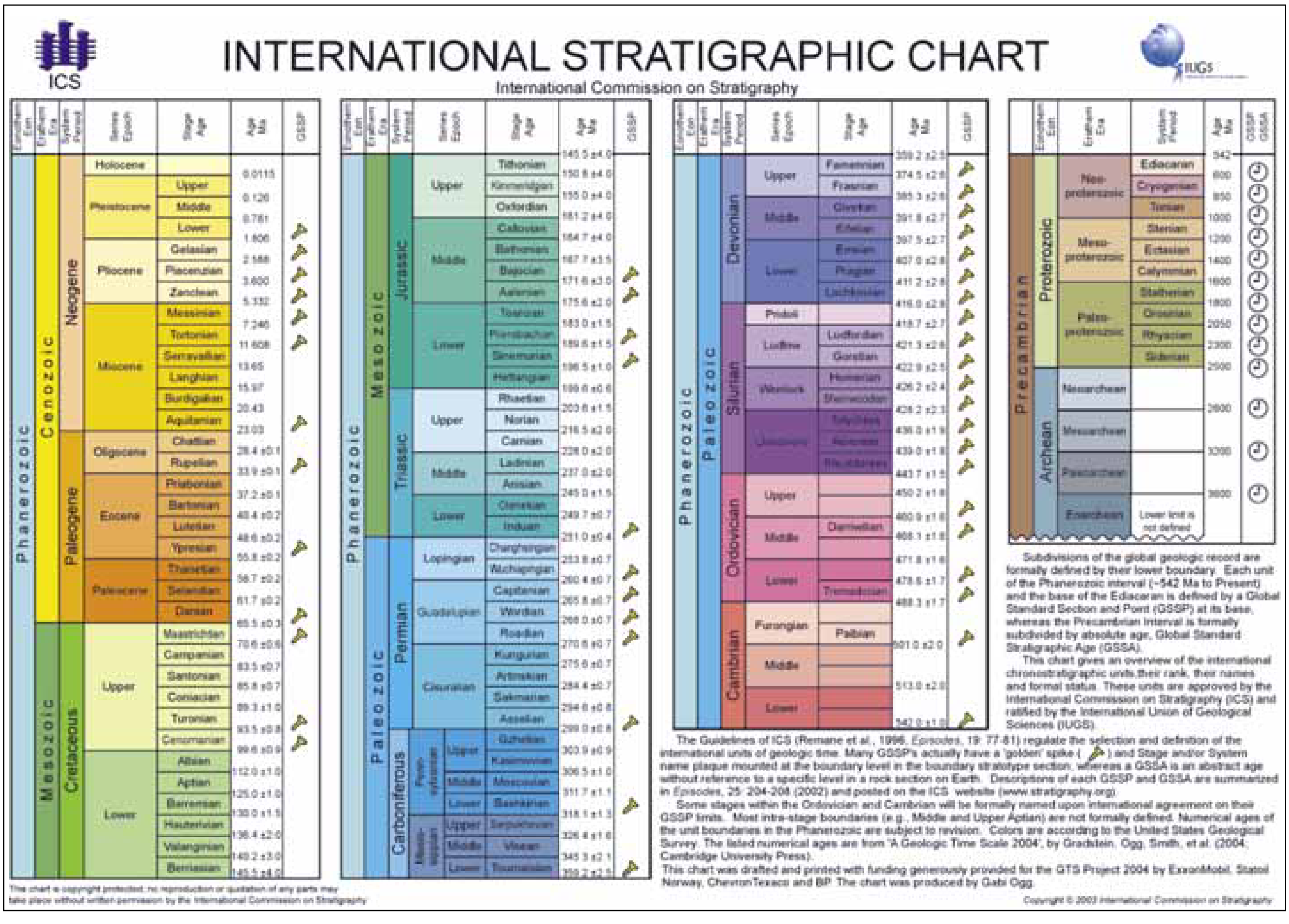
details. The plan is to improve this data set and make it available interactively on the web. Some of the main goals are listed below:

1. The recalibrated ages of Paleozoic-Mesozoic-Cenozoic events will be compiled as an XML database for digital input to other databases and look-up tables. This database will also allow conversion, for access by other web-based applications, such as graphic correlation, or age-depth plots.
2. An application (JAVA) will be designed to automatically take the XML database, get instructions from the user and generate scalable-vector graphic (SVG) renditions that directly input into Adobe Illustrator.
3. Query-capable on-line charts will be available to users by clicking on a value, zone or boundary, to open a window with an explanation of the calibration, definition and interpolated age.
4. Regional correlation charts will be compiled for major basins for each geological period.

The aim is to have an initial suite of the interactive time-scale charts and the associated software prepared by August 2006; and the regional correlation charts on-line by August 2007.

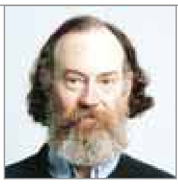
Acknowledgments

I would like to acknowledge the International Commission on Stratigraphy for permission to reproduce the two charts and particularly the Chairman of the Bureau, Professor Felix Gradstein for providing information on the future plans of the ICS.



This International Stratigraphic Chart is reproduced here by kind permission of the International Commission on Stratigraphy. Note the Golden Spikes obtained from radiometric isotopic ages.

B. R. Goleby



R. J. Korsch

The 2003/2004 Curnamona Deep Seismic Reflection Traverse, South Australia

By R. J. Korsch[1], B. R. Goleby[1], T. Fomin[1], W. V. Preiss[2], C. Conor[2], S. Robertson[2] and A. Burtt[2]
Email: russell.korsch@ga.gov.au

The Curnamona Deep Seismic Reflection Traverse (CDSRT) was completed in 2004, after the survey was postponed due to heavy rain in mid-2003. Approximately 200 line-km of seismic data were collected along a single east-west traverse extending westwards from the 1996 Broken Hill seismic traverse, 96AGS-BH1A, towards the Flinders Ranges (see Fig.1).

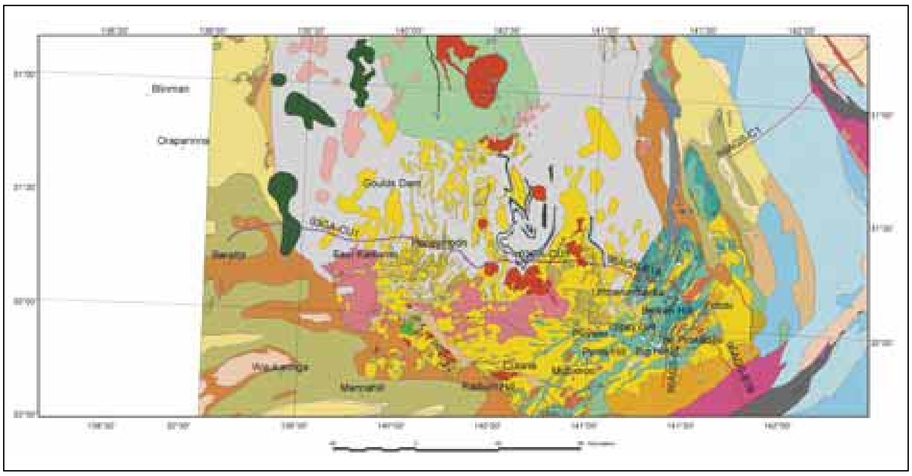


Fig. 1. Location of the 2003/2004 Curnamona Deep Seismic Traverse 03GA-CU1 on a solid geology of the Curnamona Province (from PIRSA).

Fig. 2. Members of the Curnamona Province seismic interpretation team, working through details of the Curnamona seismic data in PIRSA's offices, Adelaide (Photograph – Wolfgang Preiss).

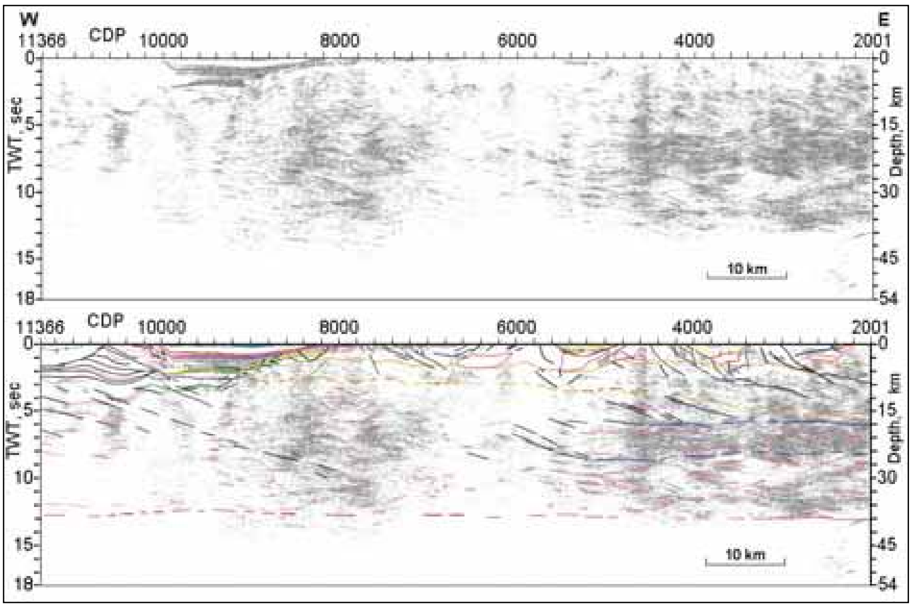


Fig. 3. Final migrated 18 s seismic section for Curnamona Province Traverse 03GA-CU1 (top); interpreted Curnamona Province seismic section. TWT = two-way travel-time (bottom).

The CDSRT was a collaborative Research Project involving PIRSA Minerals and Energy Resources, South Australia, the Predictive Mineral Discovery Cooperative Research Centre (*pmd**CRC), and Geoscience Australia (GA). ANSIR, the National Research Facility for Earth Sounding, arranged and oversaw the acquisition of the seismic reflection data. The objectives of the survey were to map the crustal structure of the Curnamona Province and identify the location of deep penetrating shear zones that could control the location of mineral deposits in the Province.

The seismic data were processed at GA, with the main focus of the processing being the production of a high-quality image of the whole of the Curnamona crust, as well as a detailed seismic section of the uppermost crust.

Interpretation was carried out in two work-sessions held at PIRSA's head office, where geoscientists from GA teamed with PIRSA's Curnamona Province geologists to work through the results and develop a geologically consistent model of the Curnamona Province at depth (see Fig. 2).

Results from this survey were presented to interested parties from State and Federal Government, Industry, and Academia during the ***2003/2004 Curnamona Province Deep Crustal Seismic Survey: Presentation to Industry – Workshop*** held on the 30 November in Adelaide. Workshop attendees

[1] *pmd**CRC @ Geoscience Australia, GPO Box 378, Canberra, ACT, 2601, Australia.

[2] Office of Minerals and Energy Resources, South Australia (PIRSA), GPO Box 1671, Adelaide, South Australia, 5001, Australia.

were shown the Curnamona seismic sections, and interpretations of detailed images of the seismic section were discussed. Implications discussed included highlights of the basement structure of the Curnamona Province and cratonic nucleus, and possible implications for hydrothermal fluid flow and Pb-Zn and IOCG mineralisation.

Key results from the Curnamona Deep Seismic Reflection Traverse are as follows:
The crust along the Curnamona Province traverse is divided into four sections:

1. Far-western Section with a fairly bland reflectivity pattern,
2. Central-western Section with reasonable strong reflections,
3. Central Section with a pronounced low reflectivity seismic pattern, and
4. Eastern Section with a highly layered and partitioned crust.

This well defined subdivision of the Curnamona Crust suggests that, in the west, we could be imaging a basement similar to that imaged beneath the north-eastern Gawler Craton and in the east, a "Willyama" basement, with some intermediate material in between.

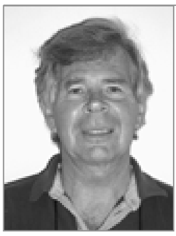
The Eastern Section of the seismic traverse shows the crust to be divided into a series of horizontal "bands" of differing reflectivity. The upper "band" shows predominantly east-dipping structures that are interpreted as thrusts. These thrusts sole onto a lower band of strong, sub-horizontal reflections. This pattern is similar to that imaged on the 1996 Broken Hill seismic traverses, 96AGS-B1A and 96AGS-B1B, beneath the Broken Hill Domain, where the late D_3 folds (upright folds refolding recumbent D_2 isoclinal folds) verge to the west and have the same southeast dip to the faults.

The Moho beneath the Eastern Section is well defined and lies at approximately 13 s TWT (~ 40 km). The Moho separates a reflective lower crust and a non-reflective upper mantle. The Moho continues westward for 60-80 km before the lower crust loses its reflectivity and the Moho is not as clearly defined.

Within the central-western part of the traverse, there is a thick Neoproterozoic-Cambrian succession. Clearly imaged stratigraphic packages down to at least 3 s TWT (~9 km) and possibly deeper can be seen in the seismic image. Individual Neoproterozoic sequences are well defined by unconformity surfaces with good truncations below the surface.

The far-western end of the seismic traverse is within the Adelaidian at the surface and shows that the crust is weakly to moderately reflective beneath a near-surface triangle zone consisting of a west-directed thrust duplex. The reflections beneath the triangle zone generally have apparent dips that are gently east dipping in the depth range 4-6 s TWT. In this area, the Moho is at ~12.5 s TWT (~ 37 km).

The seismic results from the Curnamona Province provide important information on basement architecture and have enhanced investment and targeting strategies for mineral explorers in the province. For example, the observation that the Kalkaroo Prospect appears to be related to second-order faults associated with hanging wall anticlines above a major bounding east-dipping fault at depth, opens up the possibility for further mineral deposits associated with other hanging wall anticlines above east-dipping faults.



Some old books

Late 19th Century exploration geophysical publications

In my ongoing search for the first documented geophysical surveys I have occasionally stumbled across texts that can be considered benchmarks for our industry – and as most will never get to see such items I thought I should make a brief mention of some of these old publications and their contents – or at least show a few illustrations.

In the second half of the 19th Century there was a small band of Russian, German, Swedish and eastern European astronomers and physicists who were leading the way in applying the infant sciences of geophysics and geodesy to finding, identifying or mapping regional and subsurface geology. Nearly all of the experimenting was with magnetic, gravity (pendulum) and torsion balance methods.

Little mention of this early European exploration work has ever made it into the English language, although some has been referenced over the years. Most geophysical texts in the late 1800s I have found were published in German.

The first text book

It was some years ago that I purchased a copy of Robert Thalén's 1879 publication *Untersuchung von Eisenerzfeldern durch Magnetische Messungen* (Investigations of Iron Ore Fields by means of Magnetic Measurements), which appears to be the first publication specifically dedicated to geophysical exploration. Despite its historical significance with a general description of methods, magnetometers, measurements, geometric conversions, some pioneering modelling and one illustration (Figure 1) it was somewhat disappointing to me as it contains no 'real' survey data, my primary interest.

Thalén's work is however very important in the historic context and reasonably priced copies occasionally appear for sale on internet booklists. It has never been translated into English.

The first interpretation map? – gravity and magnetics

In 1898 the German Professor Max Eschenhagen (who, by the way, introduced the word *gamma* into the geomagnetism vocabulary) reported, in a short item titled *Magnetische Untersuchungen im Harz*[1], on magnetometer measurements he obtained a number of years earlier (1888 to 1890). Eschenhagen made regional measurements (42 of them) in the Harz Mountains in an attempt to discover the causes of pendulum inconsistencies that had been observed there for many years. Geodetic pendulum surveys in the region had inferred large masses at depth.

Eschenhagen described in his paper the magnetic instruments and methods he used and he went to some lengths to emphasise the accuracy of his positioning of the observation sites (accurately fixed sun and lunar sightings). He recorded that the sensitivities of his instruments were within one minute for both declination and inclination and ".00010 C.G.S. units" for horizontal intensity – all of which was pretty good.

In his report Eschenhagen indicated that his magnetic data were diurnally corrected by comparing simultaneous observations at the Potsdam and Wilhelmshaven Observatories and that his data were, over three field seasons, allocated a mean epoch at 1888.5 for corrections. He really knew what he was doing and it begs the question as to whether earlier surveys by him or others exist, buried in some place or another.

Eschenhagen 'modelled' the regional magnetic anomalies he had mapped and estimated their depths at 20-35 km – a figure he seriously questioned at the time. He also noted that the granites he was mapping had high magnetic susceptibility. Eschenhagen made no real geological conclusions for his survey although he did produce a regional map that portrayed magnetic and gravity lineaments, contours and vectors (Figure 2).

[1] Published in "Forschungen zur deutschen Landes und Volksunde", Elfter Band , Heft I. 1898.

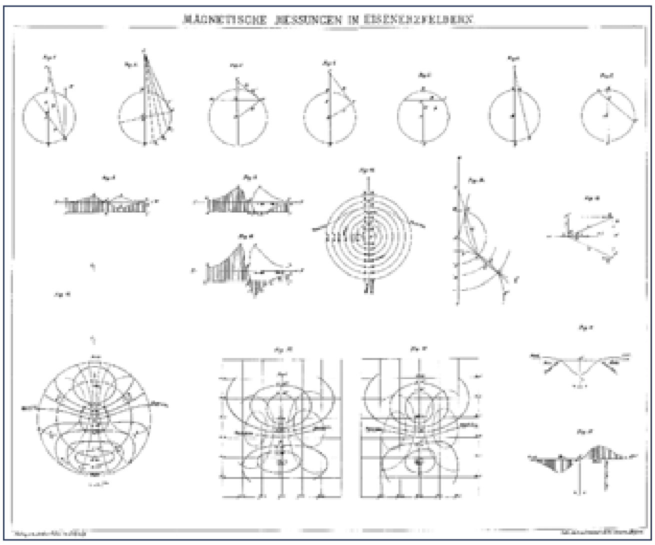


Fig. 1. The one and only illustration (figures) from Robert Thalén's 1879 textbook.

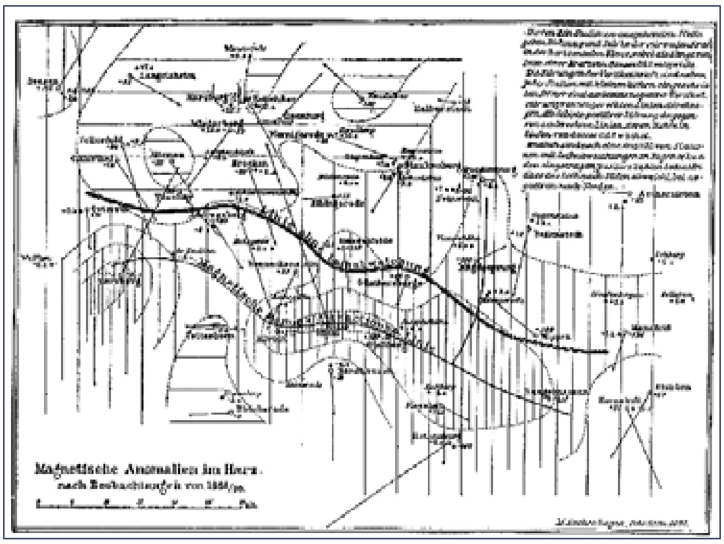


Fig. 2. Max Eschenhagen's 1888-1890 magnetic survey in the Harz Mountains. Note in addition to his magnetic contours and vectors his portrayal of the WNW-ESE magnetic and pendulum alignment.

Some Russian combined gravity and magnetics

Three years after Eschenhagen had performed his survey in the Harz Mountains and five years before he had published his results, the Russian physicist Hermann Fritsche in 1893 independently made a somewhat similar survey near Moscow. His results were published in a small item titled *Die magnetischen Lokalabweichungen bei Moskau und ihre Beziehungen zur dortigen Lokalattraction*[2] a paper unsighted by me but briefly reviewed (in the English language) in *Terrestrial Magnetism*, Vol I, Jan-Oct 1896.

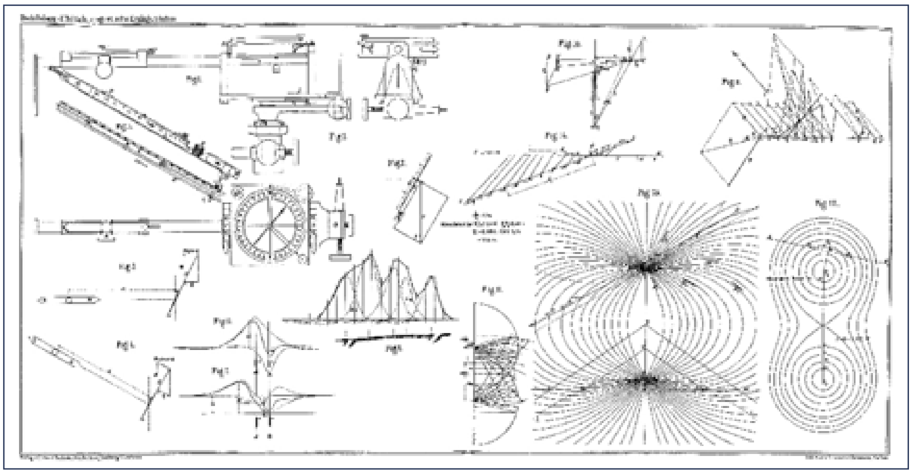


Fig. 3. Dahlblom and Uhlich's only illustration from their 1898 publication on magnetic ore deposits.

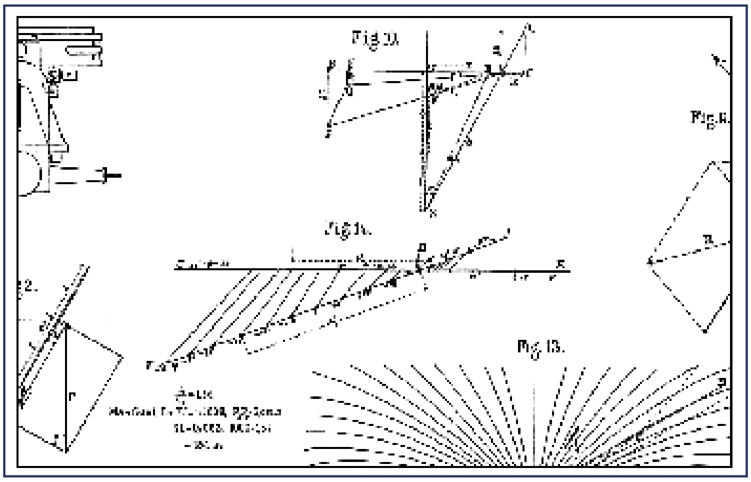


Fig. 4. Some detail from Dahlblom and Uhlich's 1898 publication. The first depth to source graphic?

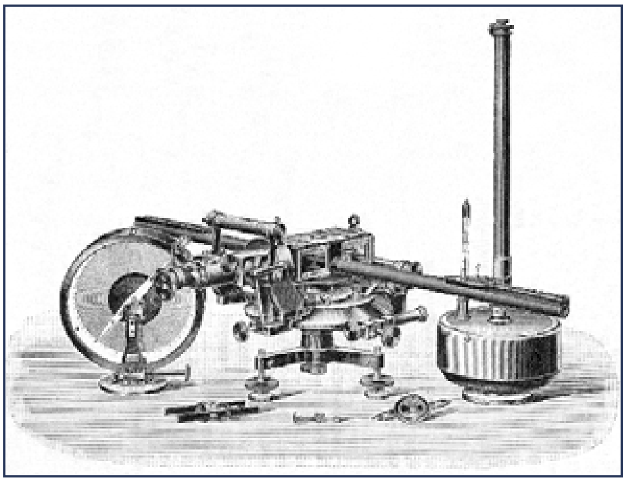


Fig.5. A dip circle, declinometer/magnetometer and torsion compass; G. von Neumayer and J. Edler circa 1903.

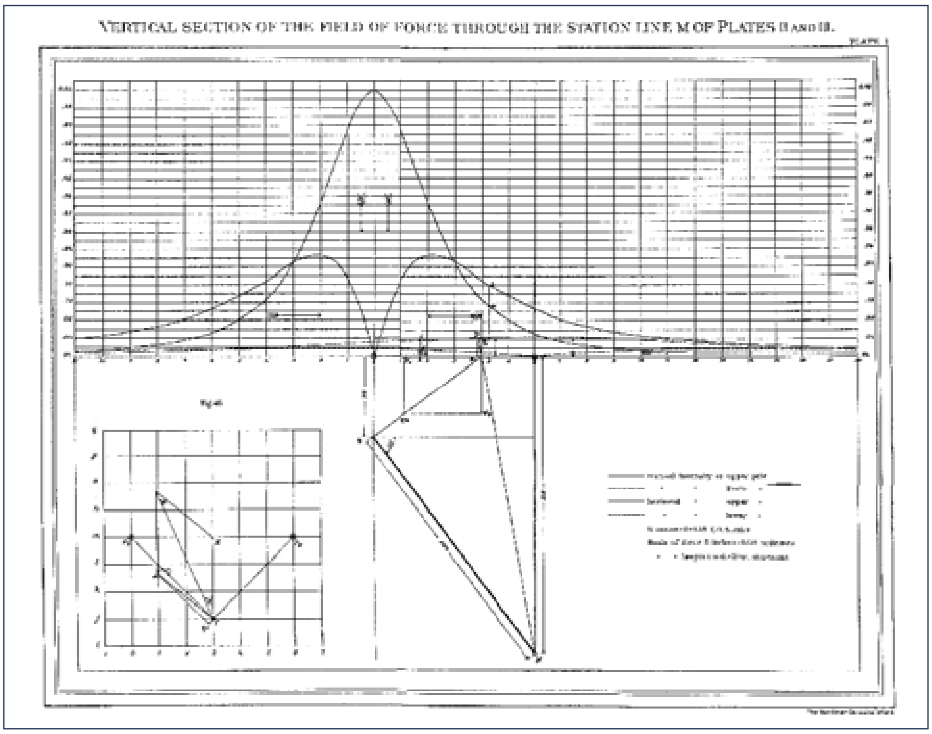


Fig. 6. One of Eugene Haanel's classic geophysical models; Circa 1904.

Fritsche wrote on gravity (pendulum) disturbances near Moscow – for many years it had been observed that numerous geographic locations in the region had significant deviations in "plumb lines" in flat terrain. In the summer of 1893 Fritsche made regional magnetic intensity, plus horizontal and vertical component measurements at 31 stations around Moscow – extending up to 80 km north and south of the city. He diurnally corrected these data and tied them to earlier regional mag observations, some of which had been made as early as the mid 1850s. He reported the depth to the "central disturbing mass" at being 10,700 m. The strike of the regional magnetics was found to coincide with the general direction of the gravity disturbances and except for noting this alignment he did not (or could not) make a connection between the two properties.

---

[2] Published in "Bulletin de la Société Impériale des Naturalistes de Moscau", No.4, Année, 1893, p.381.

Seismic imaging of complex geological structures[1]

By

Stewart Greenhalgh
and

Bing Zhou

Department of Physics
University of Adelaide
SA 5005

stewart.greenhalgh@adelaide.edu.au
bing.zou@adelaide.edu.au

[1] Condensed version of an invited talk given to the 16th Congress of the Australian Institute of Physics, Canberra, February 2005. It is an excellent introduction to seismic inversion techniques for explorers (Ed.).

Introduction

Geophysicists use sound waves to "see" inside the Earth. Such seismic imaging can be either passive, utilising earthquakes, or active, utilising controlled sources like explosions and weight drops. It is convenient to distinguish between

(i) solid earth seismology, where the interest is in the structure and constitution of the Earth's interior (crust mantle and core) to depths of tens, hundreds and even thousands of kilometres, and
(ii) exploration seismology, where the targets are of economic importance and located in the outer portion of the Earth's crust. The principal application is to petroleum exploration and development, where the target depth is typically from 1 to 4 km. The seismic probing can also be at other depth scales, such as from near-surface to 100 m (includes environmental, groundwater and engineering investigations), and from 100 m to 500 m (such as in coal mining). In each application, the objective is to map the 3D subsurface geology (object space) from the observed seismic data volume (image space).

Physical basis of seismic imaging

Seismic methods, like all geophysical methods, depend on some contrast in the physical properties of the subsurface. Here it is changes in the elasticity and density of various rock units. Apart from a contrast in the mechanical properties across each interface separating different materials, there must also be some continuity (areal extent) and smoothness to the interface such that it can act like a mirror and reflect the sound. In addition to reflection, the incident energy from a seismic source can be returned to the surface (where it is recorded) by the processes of refraction and diffraction. The former depends only on a change in sound wavespeed (see later), whereas reflection and diffraction depend on a density change as well. Or more strictly, they depend on a change in the product of density and sound wavespeed, a quantity referred to as acoustic impedance.

There are two types of elastic wave that can propagate inside the Earth: longitudinal (compressional) or P waves, and transverse (shear) or S waves. Each can be generated by the seismic source, and at every interface in the medium there is not only the partitioning of energy into reflected and refracted (transmitted) waves, but also mode conversion from P to S and S to P. So the basic goal of seismic prospecting is to infer the mechanical constitution of the subsurface from observations of the reflected, refracted and scattered (diffracted) seismic waves. This mapping or inversion process tries to invert for the **rock physics** (elastic constants, density) directly. A lesser goal may be to determine the **structure** or geometry of the rocks (formation boundaries, anticlines, faults). The **stratigraphy** (*e.g.* lithology**,** pinchouts**,** reefs) can often be inferred from the patterns and texture of the seismic data. Delineating important features like a petroleum reservoir depends on both the structural and stratigraphic information being extracted from the seismic measurements. This leads us to the important question of what are the important properties.

Cont'd from page 30

Dahlblom and Uhlich

In 1898 Theodor Dahlblom wrote (in Swedish) an interesting and important text in the mould of Thalén's earlier 1879 writing, it was edited and translated into German in the following year by the German geodesist Professor P. Uhlich and published as *Ueber Magnetische Erzlagerstätten und deren Untersuchung durch magnetische Messungen* (Regarding magnetic ore deposits and then analysis by means of magnetic measurements) both Dahlblom and Uhlich wrote forewords and both of them credited Thalén for his early work and in the text described the Thalén magnetometer and other instruments. Dahlblom included some interpretation advice including the first visual evidence I have seen for determining depth to source. He brushes on permeability of rocks, and he describes mapping and presentation methods where he interestingly references earlier work by Georg Neumayer. The one and only illustration, a series of figures, is worth reproducing with some of the detail deserving enlargement (Figures 3 and 4). Like the Thalén publication, copies of this work occasionally appear on internet booklists at a reasonable price.

Instrument pictures from the era are few and far between but Georg Neumayer in one of his numerous educational texts[3] included a nice engraving (Figure 5).

The first English language textbook

Thalén and Dahlblom's texts did eventually gain recognition in North America for in 1904 the Polish immigrant Dr. Eugene Haanel, then Superintendent of Mines for Canada and under the auspices of the Canadian Department of the Interior, produced the benchmark *On the Location and Examination of Magnetic Ore Deposits by Magnetometric Measurements*. Haanel's publication was, in my opinion, the first useable textbook for exploration geophysics in the English language but I may be corrected on that. He even constructed an ingenious laboratory test bed for modelling, which he describes in some detail. Except for showing a nice model cross-section (Figure 6) I will leave Haanel's work to another time.

[3] Published in "Anleitung zu magnetischen Beobachtungen an Land" by Dr. G. von Neumayer and Dr. J. Edler, circa 1903.

Key Parameters

There are three key parameters which we seek to find from seismic measurements. The first one is a kinematic property (*i.e.* relating to travel-time); the other two are dynamic properties (*i.e.* relating to amplitudes):

- *Wavespeed.* In an isotropic medium, the longitudinal (P) and transverse (S) waves travel at characteristic speeds (sometimes referred to as velocities) given by:

$$V_P = \sqrt{\frac{k + 4\mu/3}{\rho}} \qquad V_S = \sqrt{\frac{\mu}{\rho}}$$

where k and μ are the bulk modulus and the rigidity modulus, and ρ is the density. For most sedimentary rocks density lies is the range 1.5 to 3.0 t/m^3, and the compressional wavespeed lies is in the range 2.0 to 4.5 km/s. The P waves travel about twice as fast as the S waves. The travel-times of the observed seismic waves depend on the wavespeed distribution.

- *Attenuation.* This refers to the absorption or loss of energy as a seismic wave travels through a rock. It depends on the frequency (almost linearly) and the fluid content. It is often measured in dB per wavelength, with values typically in the range 0.05 to 1.0.
- *Reflection Coefficient.* For a wave incident at 90 degrees on a boundary separating medium 1 of wavespeed V_1 and density ρ_1 from a medium 2 of wavespeed V_1 and density ρ_2 the reflection coefficient, which measures the amplitude ratio of the reflected wave to the incident wave, is given by:

$$R = \frac{V_2\rho_2 - V_1\rho_1}{V_2\rho_2 + V_1\rho_1}$$

The formula for a wave arriving at an arbitrary angle of incidence is much more complicated, and takes into account the differences in both P- and S-wavespeeds. Nevertheless, if one can recover R at each interface from the amplitudes of reflected waves, it is possible to infer the impedance (or wavespeed) change across each interface. The observed variation of amplitude with angle, or offset (AVO), yields additional information on the nature of the materials, and is keenly exploited in seismic exploration.

These three key seismic parameters can be related to the geological properties through petrophysical control, but the relationship is often quite complex. Seismic parameters depend not only on the type of rock but also on the rock condition (porosity, cementation, texture, type of pore fluid, fracturing, weathering etc) and physical factors like pressure and temperature.

Recording geometries

Seismic surveying can be conducted using three broad recording geometries, shown schematically in Figure 1.

Surface profiling, with the sources and receivers (detectors or geophones) placed in a co-linear array, is the traditional field layout. This is referred to as 2D seismic, in that one hopes to obtain a 2D profile of the subsurface from such an experiment. The sources and receivers can also be distributed in the form of an areal array on the Earth's surface, giving rise to 3D seismic. A data cube is obtained for which the horizontal co-ordinates are the source and receiver positions, or some variant thereof, such as the mid-point. The vertical co-ordinate is travel-time It is related to depth through the unknown velocity distribution.

VSP involves placing the receivers downhole and firing the source on the surface. Alternatively, the arrangement can be inverted with the geophones on the surface and the shots downhole. The VSP provides an important link between surface seismic data discussed above, and sonic logs recorded in a borehole, enabling the individual reflections to be traced downwards and tied to known formation boundaries.

The other layout is ***crosshole*** seismic, where receivers are placed in one borehole and sources in the other. The aim is to image the inter-well medium from measurements of the travel-times and amplitudes of the transmitted (and reflected) arrivals.

Regardless of the recording geometry, we can recognise two survey types:

- **Reflection** (or back-scatter experiments) where attention is focussed on the reflected and diffracted arrivals.
- **Transmission** (or tomography experiments) in which attention is focussed on the transmitted direct and refracted arrivals. *i.e.* the forward scattered arrivals.

The number of recording channels can vary enormously, from 50 to several thousand. Most modern surface seismic systems use at least a couple of hundred channels. The maximum distance (offset) between source and receiver depends on the target depth and whether the survey is reflection or refraction. In marine reflection work for hydrocarbons the offsets can be several kilometres and the shots are fired every 10 seconds, 24 hours per day.

Seismic measurements

There are a wide variety of seismic ***sources*** available. They include explosives (dynamite), weight drops, air guns, water guns, sparkers and Vibroseis. The latter uses a swept frequency long duration waveform rather than an impulse. The ***receivers*** are the transducers which convert the mechanical motion of the ground into an electrical signal. Moving coil geophones (whose output is proportional to the particle velocity) are normally used on land and pressure-sensitive hydrophones (piezoelectric elements) are used in the marine environment. Accelerometers are occasionally used in mine seismic work. The ground motion, which is sensed, is usually scalar (*e.g.* vertical component of particle velocity, excess dynamic pressure), but vector measurements (*e.g.* displacement, velocity, acceleration) using triaxial sensors, or even tensor measurements (*e.g.* strain) can be made as a function of time.

The ground motion records from each detector are digitally recorded to high dynamic range on a seismograph which multiplexes between the various channels. The record length and sample rate depend on the application and target depth. Survey position and other important information (*e.g.* instrument gains) are also

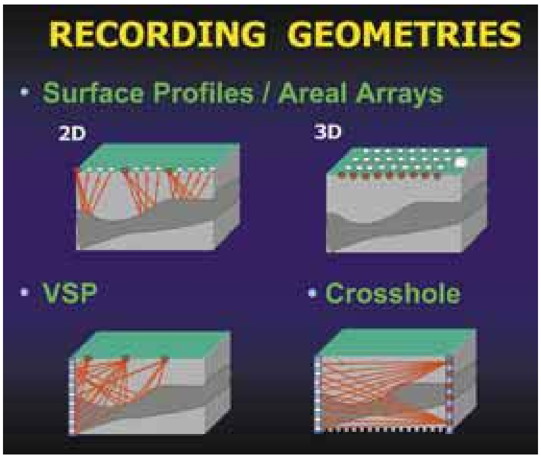


Fig. 1. Various recording geometries for seismic surveying- surface (2D or 3D), VSP and cross-hole. Source and receiver points are placed on the Earth's surface (linear or aerial arrays) and/or down boreholes.

recorded for use in subsequent processing. The ***seismic measurements*** extracted from the raw seismograms can be broken down into:

- Travel-times of various waves
- Amplitudes
- Frequencies
- Full waveforms
- Polarisation (if multi-component recording)
- Direction of arrival/apparent velocity (from array analysis)

Earth models

The one-dimensional (layer cake) earth model is implicit in much of traditional seismic processing. Of course most targets of interest (*e.g.* petroleum traps) involve departures from horizontal layering and seismic interpreters seek to ascertain the geometry of subsurface reflectors from the patterns seen on the seismic section. Strictly speaking one should use more involved models to characterise wave propagation in the Earth. It is a tribute to the remarkable robustness of the seismic method that the 1D model has been used so successfully for so long. The 2D model permits wavespeed variations in two spatial directions (*e.g.* X and Z) while the 3D model accommodates variation in all three directions. Figure 2 compares the three classes of model. In parameterising any of these models one must specify the elasticity in each sub-volume of the Earth. The simplest elastic model is to treat each layer or sub-volume as a fluid in which only P waves can propagate. This is the ***acoustic*** model in which the wavespeed $c=\sqrt{k/\rho}$. Next we have the ***elastic*** model in which both compressional and shear wavespeeds V_P and V_S must be specified. ***Viscoelastic*** models are those in which attenuation of P and S wave energy is considered (ignored in the elastic and acoustic models). The attenuation is generally specified in terms of Q_P and Q_S. The inverse of Q specifies the fractional amount of energy dissipation per cycle. We must also specify in a model whether the wavespeeds depend on the direction of measurement (***anisotropic model***) or not (***isotropic model***).

For the isotropic model there are just two independent elastic constants for each sub-volume element. The most general anisotropic solid requires 21 elastic constants to fully specify its behaviour, but in practice we rarely go beyond 5 (transversely isotropic solid) or 9 (orthorhombic solid). Wave propagation in anisotropic media is quite different to wave propagation in isotropic media. This is discussed in some detail later.

It is always useful as part of seismic data analysis and interpretation to be able to theoretically calculate the seismic response of our Earth model. We now enquire into the computer requirements. Taking a typical petroleum seismic example, for a 3D model having physical dimensions of 3 km x 3 km x 4.5 km, and assuming a source spectrum of 10 – 50 Hz (say average wavelength of 60 m) then the problem size (in wavelengths) is 50 x 50 x 75. Using 600 x 600 x 900 model grid points and 7200 time steps in a finite difference numerical simulation, involving 25 calculations/grid point/time step, leads to 1.5G words of core memory and 6×10^{13} flops per source. With modern supercomputers running at speeds of 1 terraflop and more, it is no longer out of the question to perform such computations for a modest number of source positions. But in the recent past it was not possible to even simulate a detailed 3D seismic experiment let alone invert the measurements to actually image the Earth. This involves iterative modelling and adjustment, as discussed below.

The seismic inverse problem

The seismologist's dream is to invert the equations of physics to obtain Earth properties directly from the observations. In other words, we wish find the subsurface model which best predicts the seismograms subject to certain constraints, and a certain assumed degree of model complexity. Taking our 3 km x 3 km x 4.5km model volume above for illustration, and digitising it every 10 m to specify two elastic constants and a density, yields $3 \times 300 \times 300 \times 450 \approx 10^8$ model parameters (isotropic, inhomogeneous model). Such a ***model space*** can be compared with the ***data space*** (*i.e.* the digitised seismic records) of $\approx 10^{10}$ numbers. So in principle at least, the problem is overdetermined and the model parameters can be recovered. In practice of course, there are serious ***problems of image reconstruction***, such as:

- Spatial undersampling (limited site access, finite aperture on source/receiver arrays)
- Angular undersampling (a limited range of directions from which the target can be viewed)
- Band-limited data
- Noise (both random and source-generated)

There are basically three approaches which can be used to move from the seismic data (image space) to the geology (model space).

- Seismic travel-time tomography
- Seismic time/depth migration
- Seismic waveform inversion

The first one is mainly applied to the first arrivals on the seismograms (direct and refracted waves) and constitutes a kinematic inversion which is successful at recovering the long spatial wavelength features of the wavespeed distribution. A similar approach can be used with amplitudes of specified seismic arrivals to recover the attenuation (Q) distribution. The migration approach stops short of a full inversion but essentially recovers the correct geometry of reflectors and diffractors in the subsurface. It involves summing energy on the observed seismograms along specified search envelopes and looking for maximum correlation or semblance of arrivals. Such techniques recover the short wavelength features of the velocity field, where there are sudden changes, giving rise to the reflected signals. Full seismic waveform inversion involves using the entire seismograms, and trying to match the waveforms with those calculated theoretically. Various inversion algorithms can be used to adjust the model parameters. The dynamics of the wavefields are very sensitive to slight changes in the parameters and it is essential to remove all of the known amplitude factors

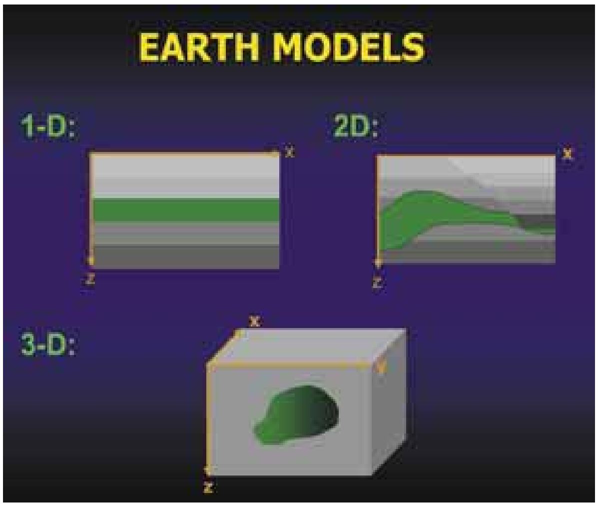


Fig. 2. Types of earth model in which the seismic wavespeed (elasticity) is permitted to vary in 1-, 2- or 3- dimensions.

like source size variations, shot and geophone coupling, polar radiation and reception patterns etc before assigning waveform variations to real geological effects.

The waveform inversion can be carried out in the time domain using the actual seismograms f(**x**, t) or in the frequency domain using the Fourier transforms of the seismic traces F(**x**, ω). The latter can be separated into amplitude A(**x,** ω) and phase φ(**x,** ω) data. Note that **x** denotes the vector position for each trace (source and receiver co-ordinates). Inversion is equivalent in the two domains in the least squares sense, but the frequency domain offers certain computational advantages. To illustrate the methodology, we will consider a particular form of 2.5D non-linear inversion using multi-frequency amplitude data. This refers to inversion for a 2D model involving point (as opposed to line) sources.

The ***observed data*** (surface, crosshole, or VSP) can be written as:

$$d_{ob}(r_s, r_g, \omega) = \left| S(\omega) G^{2.5D}(r_s, r_g, \omega, m^*) \right|$$

The ***synthetic data*** can be generated using the finite element method (FEM) or the finite difference method (we prefer the former) and is given by:

$$d_{th}^k(r_s, r_g, \omega) = \left| S_o(\omega) G^{2.5D}(r_s, r_g, \omega, m_k) \right|$$

Here $G^{2.5D}$ is the 2.5D Green's function obtained by the FEM for a particular model. Alternatively, it represents the physics of how the Earth responds to an impulsive source at a particular location r_s and recorded on a geophone at a specified location r_g. The quantity S(ω) is the actual source spectrum, while the quantity $S_o(\omega)$ is the assumed source spectrum for the synthetic source (often we don't know the true source). The quantity m^* is the true model of the Earth while m_k represents the model used in the synthetics after the k-th iteration. The quantity ω is the angular frequency.

We start with an initial first-guess model and try to improve it by reducing the differences between the observed and computed spectral amplitudes. We proceed in an iterative manner using a gradient procedure, which has to be stabilised. The non-linear inversion formulation can be summarised as follows:

$$m_{k+1}(r) = m_k(r) + D^{-g} W_m^T \left(\frac{\partial d}{\partial m_k}\right) W_d \left(d_k^{th} - d_{ob}\right)$$

$$D^{-g} = \left[W_m^{-1} \left(\frac{\partial d}{\partial m_k}\right)^T W_d \left(\frac{\partial d}{\partial m_k}\right) + \lambda I \right]^{-g}$$

It is understood that *m* and *d* are vector quantities representing all of the model parameters and data values, respectively. The quantities W_m, W_d are weighting matrices for the model and data. The Jacobian matrix $\frac{\partial d}{\partial m_k}$ is a measure of the sensitivity of the data to each model parameter, I is the unit matrix and λ is a regularisation parameter. The quantity D^{-g} is a general inverse matrix.

Figure 3 shows the theoretical seismograms obtained for a synthetic 8-shot experiment over a simple, shallow acoustic model. It involves a highly irregular interface separating rocks of P- wavespeed 2.0 km/s from rocks of P-wavespeed 4.5 km/s. This is a large contrast, typical of karstic topography. Such situations have presented extreme challenges to seismic exploration in the past. Four shots are fired from each direction into rolling 24 geophone spreads having a detector spacing of 2 m. The line length is 120 m and the maximum depth is 15 m. The displayed seismograms for each shot gather show direct, refracted, reflected and diffracted arrivals. Each seismogram was then Fourier transformed (over its entire length, involving all arrivals) and the magnitudes or spectral amplitudes computed at 5 Hz intervals in the range 25 – 110 Hz. The input data vector to the inversion comprised 3456 points. Figure 4 shows the results for this surface seismic numerical experiment. The reconstructed velocity distribution matches the true model very well. By contrast, standard migration procedures fail to properly recover the interface geometry. Moreover, they don't yield information on the velocity field. This could be obtained from tomographic analysis of the first arrival times, but it is far less accurate than that obtained from the full waveforms.

To further illustrate the benefits of waveform inversion over travel-time inversion, we present the comparison results from a synthetic VSP experiment in Figure 5. The model on the left shows a faulted low velocity bed (2.0 km/s) at a depth of 30 m sitting in host rock of velocity 2.9 km/s. The first arrival ray paths

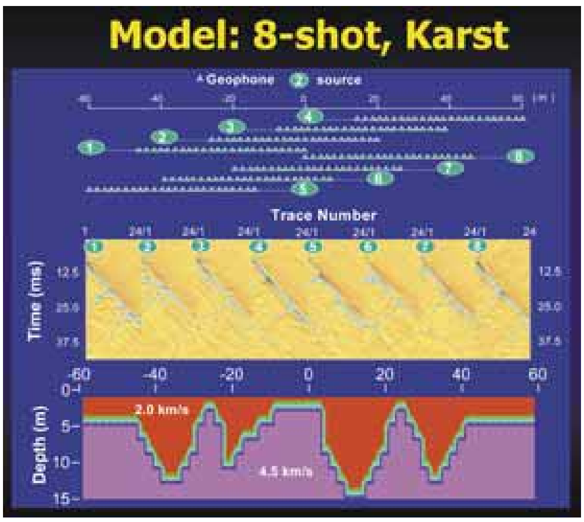


Fig. 3. Karstic model and theoretical seismograms for an 8-shot synthetic experiment. The velocity contrast is large and the boundary highly irregular. The recording geometry, shown along the top, involves 4 offset shots fired from each direction into a rolling 24 receiver array. The seismograms show direct, refracted, reflected and scattered P waves.

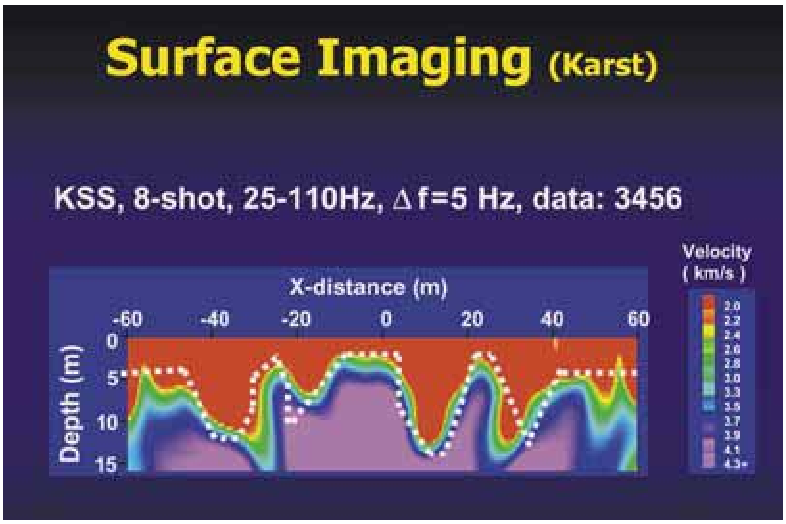


Fig. 4. Imaging result for data of Fig. 3 obtained by multi-frequency spectral amplitude inversion. The structure and velocity values are well recovered from the 3456 spectral data points.

are also shown. The middle panel gives the results of travel-time inversion. It fails to image the structure because of the poor ray angular coverage. The right panel is the result of waveform inversion. The recovered velocity model is close to the real model. It shows clearly the two flat lying parts of the bed, separated by a vertical displacement of 10 m.

Seismic anisotropy

In recent years there has been increasing interest in the effects of anisotropy on seismic wave propagation and seismic inversion. The most common class is referred to as VTI, which is transverse anisotropy with a vertical axis of symmetry. Horizontally layered rocks and cracked rocks frequently exhibit this behaviour (see Figure 6). The maximum P wavespeed occurs in the plane of the layering (and remains constant and independent of azimuth in this plane) and the minimum in the perpendicular direction. The velocity is in general a smooth function of the incidence angle. Similarly, S waves show a directional dependence of the wavespeed and also undergo birefringence or splitting into fast and slow modes. The fast S wave has its polarisation in the horizontal plane (SH) and the slow S wave is polarised in the vertical plane (SV), perpendicular to the ray direction. If the axis of symmetry is tilted, then there are two additional variables to specify, viz. the polar angles for this type of anisotropy (Figure 6).

Anisotropy Parameters

Figure 7 lists the elastic moduli for the different types of anisotropic solids in terms of the elements of the 6 x 6 modulus tensor (or matrix). The modulus tensor connects the stress and strain second rank tensors, which are both symmetric, reducing the elasticity fourth rank tensor to just 36 components. From thermodynamic and other arguments there are at most 21 independent constants. It reduces to 2 for an isotropic solid, to 5 for a VTI medium, 9 for an orthorhombic solid, etc. The Thomsen parameters α_o, β_o, ε, λ and γ are often used instead of the *a* terms for a VTI solid.

Wavespeeds and polarisation directions

The mathematical aspects of anisotropic wave propagation are beyond the scope of this article. However, the wavespeeds or phase velocities *c* can be determined as the solution of the Kelvin-Christoffel equation:

$$F(a,n,c) = Det\left|\Gamma_{ij}(a,n) - c^2\delta_{ij}\right|$$

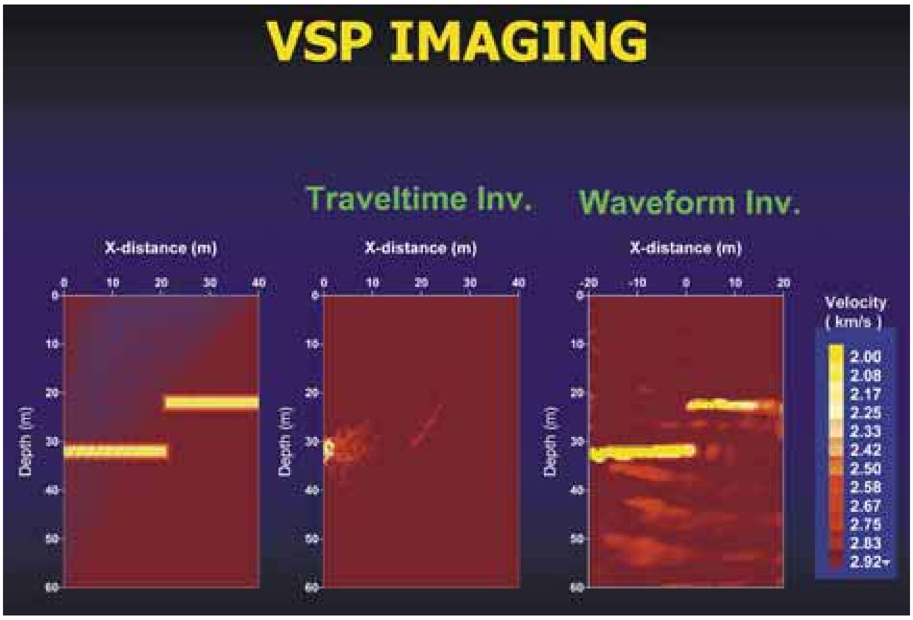


Fig. 5. VSP imaging experiment and results of travel-time inversion and waveform inversion. The former is inferior because the first arrivals shown do not properly sample the structure, whereas the waveforms incorporate the later diffracted signals.

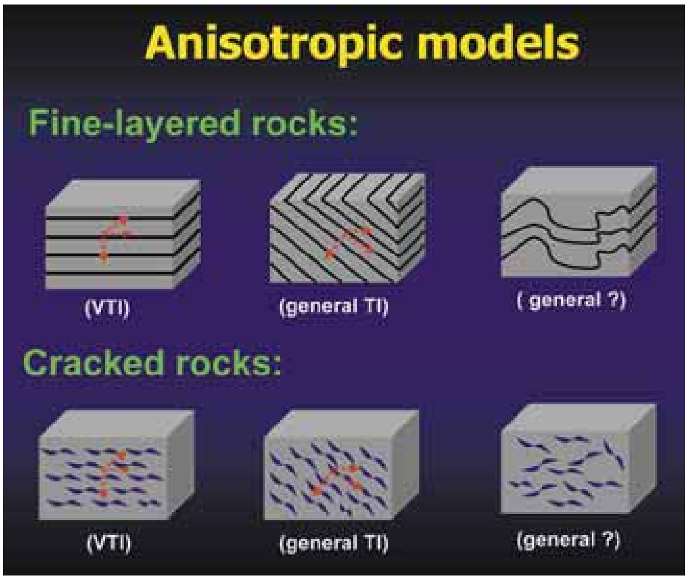


Fig. 6. Different types of anisotropic models. The simplest (VTI) involves layers or cracks having a vertical axis of symmetry. The general TI model has a dipping axis of symmetry. Higher classes of anisotropy also exist, in which the symmetry is less developed.

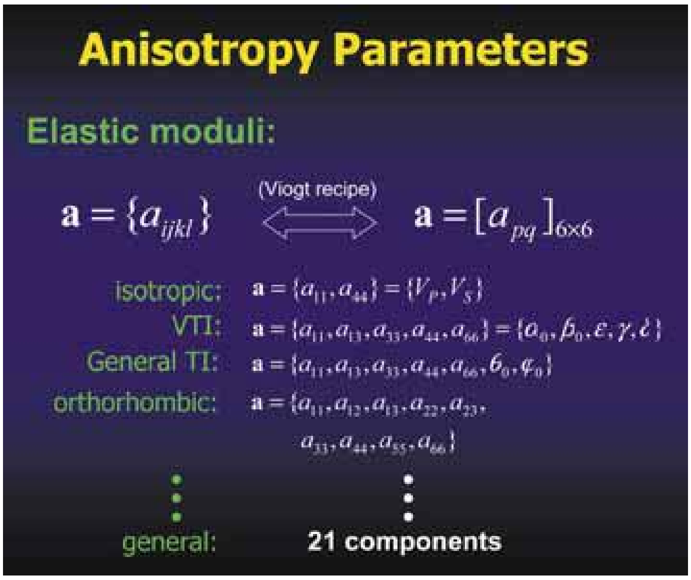


Fig. 7. Anisotropic parameters for various models: isotropic, VTI, TI, Orthorhombic

where the vector **n** specifies the wave direction and the matrix **a** constitutes the matrix of elastic constants. There are three solutions (eigenvalues) to the cubic equation corresponding to the three quasi wave modes qP, qS_1 and qS_2. In addition to the three phase velocities there are also three group velocities U to consider, one corresponding to each mode. They too are functions of the wave direction and the elastic constants. The group velocity corresponds to the ray direction or the direction of energy flux. It differs from the phase velocity, which corresponds to the wavefront normal direction or the slowness **s** direction. This is illustrated in Figure 8 which shows the vectors **s** and **U**, and the corresponding eigenvectors. The latter convey the amplitudes or polarisation directions for each mode.

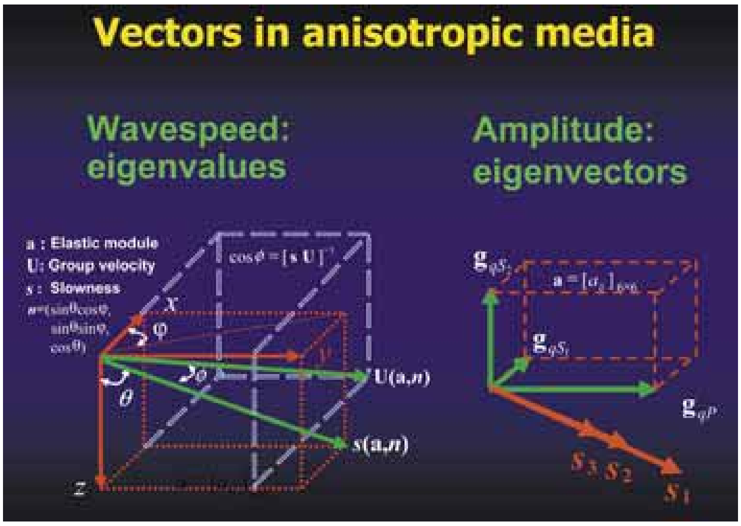


*Fig. 8. Group velocity **U** and phase slowness **s** vectors in an anisotropic medium, along with eigenvectors (polarisation directions) for the three wave modes. Note that the group velocity is in the direction of the raypath, which no longer coincides with the wavefront normal direction.*

Wavefronts and travel-times

Figure 9 shows graphically how the group velocity varies with ray direction for each of qP, qS_1 and qS_2. The two sets of diagrams correspond to two rocks having different TI elastic properties and differing dips for the axis of symmetry. Actual values are given on the diagram. Note the complex cuspidal pattern which obtains for qS_1. What this means is that there are multiple values for the group velocity (also the phase velocity) for certain ray directions *i.e.* there are up to three arrivals to consider.

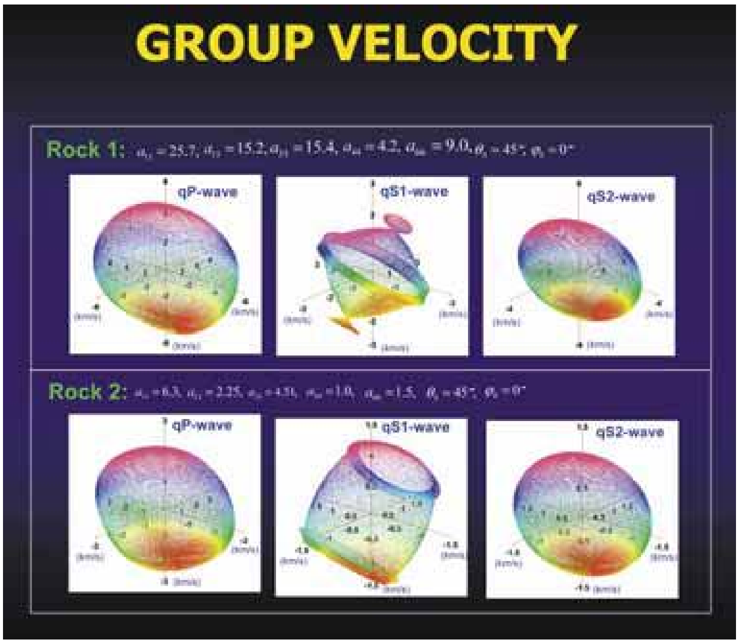


Fig. 9. Group velocity for the qP and qS waves as function of ray direction for two different TI solids, whose elastic moduli are given. The –qS_1 mode exhibits complex behaviour (triplications and cusps).

Figure 10 illustrates anisotropic 3D wave propagation in two separate uniform VTI solids characterised by the same moduli as for the dipping TI models given in Fig. 9. Note the distortion of the wavefronts and the triplications in the wavefront pattern for the $qSV(=qS_1)$ wave. Figure 11 shows the wavefront pattern for an inhomogeneous 3D model comprising two simple anisotropic solids separated by a vertical contact. Refraction at the boundary is evident.

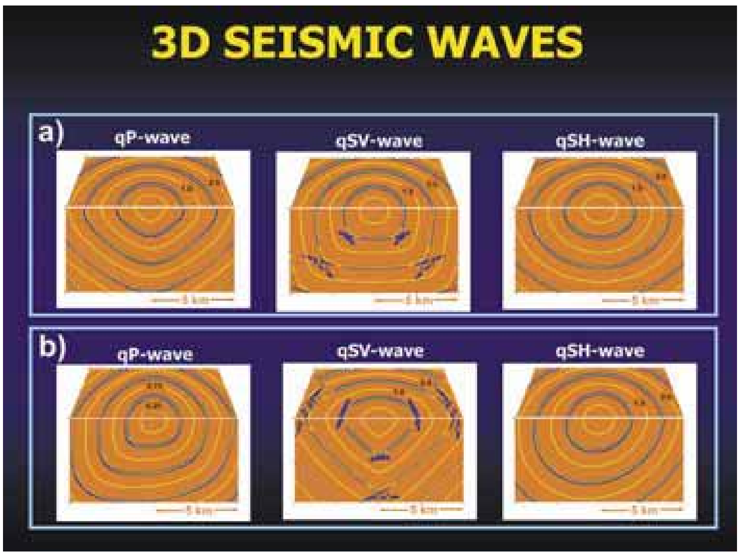


Fig. 10. 3D wavefronts for the three wave modes in the two homogeneous, anisotropic models given in Figure 9.

It is instructive to trace rays through a 4-layer 2D model which is made up of a water layer overlying three anisotropic layers (Figure 12). The interface separating layer 2 from layer 3 is steeply dipping. The only difference between the 3 sets of raypaths shown is that the axis of anisotropic symmetry for layer 3 is changed from 0° to 45°to 90° degrees. For all other layers it is held at 0°. The travel-time graph on the bottom right shows the

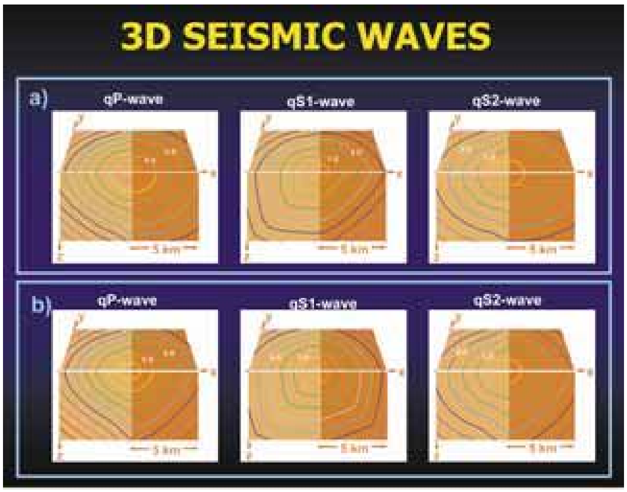


Fig. 11. Distortion of 3D wavefronts in a heterogeneous, anisotropic model.

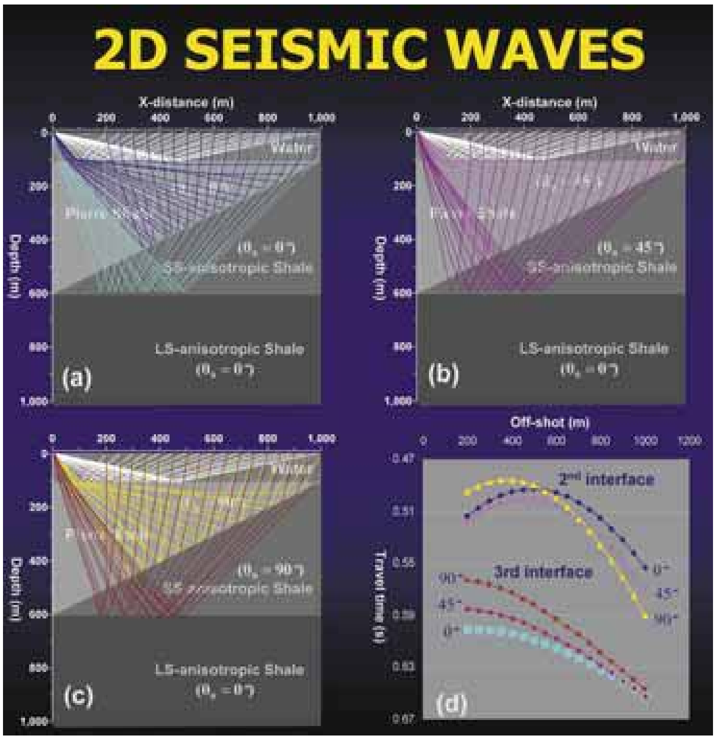


Fig. 12. Reflected raypaths and travel-time curves in a 2D model having variable dip on the axis of symmetry for the 3rd anisotropic layer.

different branches in each of the three separate cases for reflections from the bottom of layers 2 and 3. The patterns and times are quite different yet all that has changed has been the dip of the axis of symmetry in layer 3.

Group velocity sensitivity

It is useful to examine the group velocity sensitivity, or Frechet derivatives $\frac{\partial U}{\partial a_i}$. The derivatives indicate how the group velocity will change for a small change in each elastic modulus. The terms δd / δm were seen to be important in the inversion formula given above. Some parameters are far more sensitive than others and will strongly influence the measurements. As an illustration, we show in Figure 13 the sensitivity patterns for the qP- wave in a rock having orthorhombic anisotropy. The nine diagrams correspond to the influence of each of the nine independent elastic constants. The plot shows the group velocity derivatives as a function of the wave slowness direction, expressed in terms of the azimuth and inclination. There are strong peaks (dominant moduli) on some plots for certain directions, and complementary patterns for other moduli.

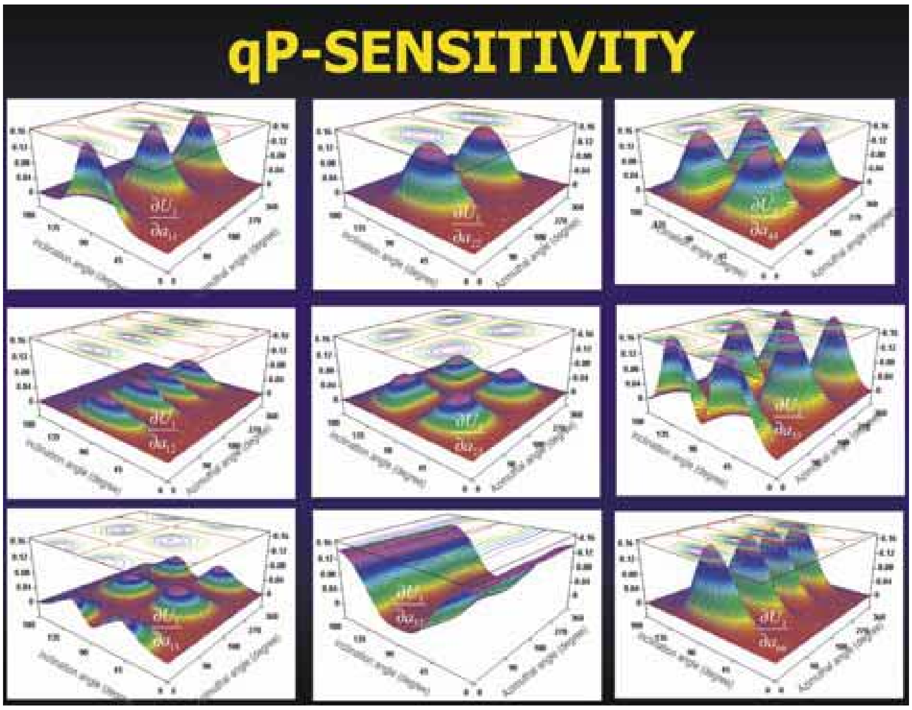


Fig. 13. Group velocity sensitivity for the qP wave in an orthorhombic solid as a function of the polar angles for the phase slowness vector. Each plot is for a different elastic modulus. The peaks indicate the dominant moduli over certain directions of propagation. The flat portions show which moduli have little influence (weak moduli) over certain angular ranges. The patterns are complementary.

Conclusions

Three-dimensional acoustic imaging of the subsurface to obtain structural information from reflected waves is now commonplace, especially in the petroleum industry. Inversion of the data to obtain rock physics is largely 1D, and involves matching the seismic data with well control. Vector processing of shear wave and converted wave data is done on a limited basis. Anisotropic media imaging, if carried out at all, is largely VTI. Two-and three-dimensional viscoelastic, anisotropic inversion is still in its infancy but offers great promise for the future.

Further reading

There is a very large book and journal literature on seismic exploration. A useful introductory account is given in the text by R. E. Sheriff & L. P. Geldart, 1995, Exploration Seismology, 2nd Edition, Cambridge University Press.

Western Australia, Northern Territory South Australia Queensland and Geoscience Australia

New Survey Data added to the Australian National Gravity Database

New gravity data from the recently completed survey over the western two thirds of the **Paterson Range** and **Rudall** 1: 250 000 sheet areas have now been incorporated into the Australian National Gravity Database (ANGD, see Figure 1).

These new data are from a survey project managed by Geoscience Australia on behalf of the Geological Survey of Western Australia. Data were acquired at a station spacing of 2.5 km x 2.5 km. Figure 2 is an image generated from the new gravity data.

Processing of the gravity data collected along the 2005 **Tanami seismic lines** has now been completed and the data added into the ANGD. The data were obtained by the Northern Territory Geological Survey at 1 km spacing; occasionally closing to 500 m in the vicinity of some key structures or high gradients. Figure 3 shows the location of the seismic lines. Contact Clarke Petrick (08 8951 8162; clarke.petrick@nt.gov.au) of the NT Geological Survey for further details.

Data supplied by the Northern Territory Geological Survey and collected along traverses on the Bauhinia Downs 1:250 000 sheet area in the **Central McArthur Basin** have also been added to the ANGD. The data were originally obtained by the Centre for Ore Deposit Research, University of Tasmania. See Figure 4 for location details. For further information on this survey, contact Mark Duffett (08 8951 8176; mark.duffett@nt.gov.au) of the NT Geological Survey for further details.

All data in the Australian National Gravity Database can be obtained free-of-charge using the download facility “GADDS”: http://www.ga.gov.au/gadds

For further information, please contact Mario Bacchin on +61 (0) 6249 9308, or email: mario.bacchin@ga.gov.au.

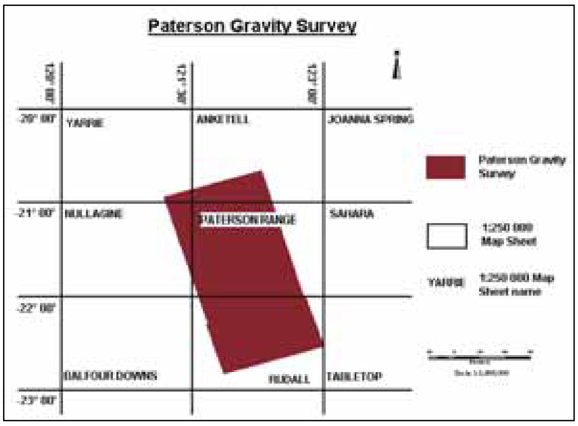


Fig. 1. Locality diagram for the 2005 Paterson Gravity Survey.

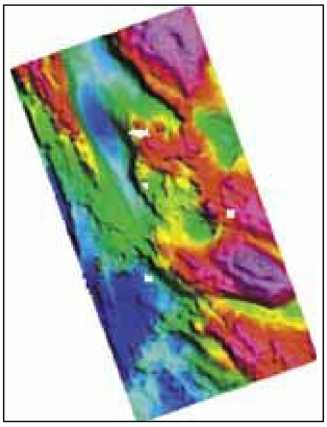


Fig. 2. Gravity image (Bouguer anomalies) of new data over the Paterson Survey area shown in Figure 1.

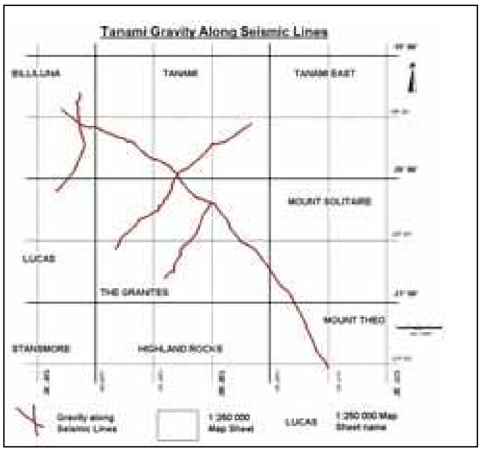


Fig. 3. Gravity along Tanami seismic lines.

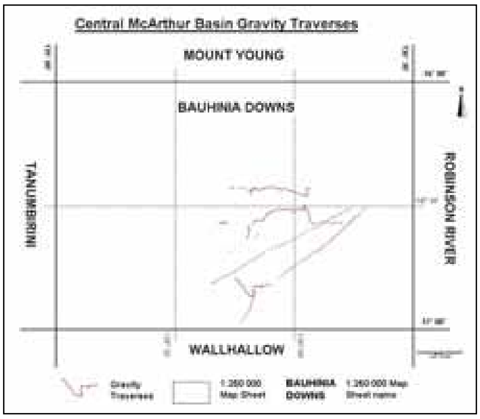


Fig. 4. Gravity traverses in the Central McArthur Basin.

Current Seismic Surveys

Processing for the **2005 Tanami Seismic Collaborative Research Project** is progressing efficiently. The first in a series of interpretation meetings were held in early November between the project’s collaborators, Geoscience Australia, the Geological Survey of Western Australia, the Northern Territory Geological Survey, Newmont Australia Pty Ltd and Tanami Gold NL. Scientists involved in these Tanami Seismic interpretation sessions report that the preliminary interpretation results from the seismic survey are very stimulating and promise to answer fundamental questions on the crustal architecture and mineral systems that operated in the Tanami region. The interpretation of the **2005 Tanami Seismic Collaborative Research Project** will be collectively presented at a **Seismic Workshop** in June 2006 in Alice Springs.

Processed data and results for the **2003/2004 Curnamona Province Seismic Survey** (a collaborative project involving the Office of Minerals and Energy Resources, South Australia, the Predictive Mineral Discovery Cooperative Research Centre and Geoscience Australia) were presented to interested State and Federal Government, Industry and Academic geoscientists during the recent **Curnamona Province Deep Crustal Seismic Survey: Presentation to Industry – Workshop** held at PIRSA’s Adelaide Office. Attendees were shown the Curnamona Seismic data and then walked through the data and their implications, including highlighting the basement structure of the Curnamona Province and cratonic nucleus and possible implications for hydrothermal fluid flow and Pb-Zn and IOCG mineralisation.

Forthcoming Surveys at GA

Geoscience Australia, GeoScience Victoria and ANSIR (National Research Facility for Earth Sounding) are actively preparing for a deep seismic reflection transect across the wester part of Victoria. This seismic traverse will be acquired as part of GeoScience Victoria’s

"Delivering Gold Undercover" program that aims to attract greater investment in gold exploration in Victoria through the provision of pre-competitive geoscience data. It is a collaborative project involving GeoScience Victoria, Geoscience Australia, the *pmd**CRC and mineral exploration companies. The traverse is orientated roughly east-west, and runs from north of Stawell to northeast of Bendigo over a distance of approximately 200 km in order to gain valuable information on the nature of the crust in the Stawell, Bendigo and Melbourne structural zones. It will be acquired in the second quarter of 2006.

Geoscience Australia, Geological Survey of Queensland Natural Resources & Mines and ANSIR (National Research Facility for Earth Sounding) are planning to acquire a series of deep seismic reflection transects across the Mt Isa Inlier. These seismic transects will be used to improve the understanding of the linkages between crustal architecture, fluid flow and regional scale mineral systems and to assist in the discovery of further mineral resources in the Mt Isa region. The east-west and complementary north-south traverses focus on different structures and each incorporates a different set of mineral deposits whose structural setting and regional context are still largely unknown in the third dimension.

ANSIR @ GA

ANSIR, the National Research Facility for Earth Sounding, has recently collected high resolution seismic data within the Sydney Basin as part of Sydney Gas's investigations of coal bed methane (CBM). ANSIR's MiniVibe was used as the energy source in a seismic reflection survey aimed at the detection of sweet spots in coal seams (potential CBM zones) through the direct imaging of secondary fracturing in coal seams using longitudinal and transverse reflected waves.

ANSIR, the National Research Facility for Earth Sounding, has also recently collected high resolution seismic data as part of a BHPBilliton Illawarra Coal investigation into the delineation of geological structures for coal mine planning using a variety of sources including explosives, the MiniVibe and a Hemi 60. With the high cost of longwall mining, the early detection/mapping of any geological structure that may disrupt a coal seam sequence reduces any unexpected downtime.

For further information please contact Bruce Goleby 02 6249 9404 or bruce.goleby@ga.gov.au.

New Airborne Geophysical Surveys

Smart Exploration Initiative Queensland - airborne geophysical & gravity surveys

Two contracts have been awarded to acquire gravity data as part of the Queensland Government's four-year $20 million Smart Exploration Initiative to stimulate exploration investment in Queensland.

- Daishsat Pty Ltd have been engaged to acquire 5263 new gravity stations (4 km intervals) over an area of approximately 85 000 km^2 in the Bowen-Surat region of southern Queensland. The survey started in November 2005.
- Daishsat Pty Ltd has been engaged to acquire 6719 new gravity stations (2 km intervals) over an area of approximately 26 000 km^2 in the Mount Isa region of western Queensland. The survey is proposed to start in March 2006.

Requests for bids for the first airborne geophysical survey projects, as part of the Queensland Government's Smart Exploration Initiative, have been released. These are for provision of magnetic and radiometric coverage in two areas:

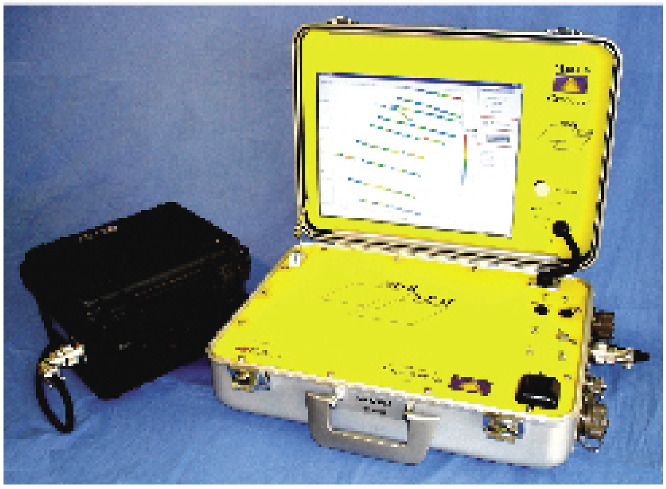
- 114 000 km^2 in the Bowen - Surat region;
- 22 000 km^2 in the Mount Isa region.

When completed, the projects will release a total of more than 381 000 line km of magnetic and radiometric data to the public domain.

The new data will be acquired on east - west flight lines spaced 400 m apart at a height of 80 m above ground level. Geoscience Australia will be managing the flying program.

See *Preview* 118 (October 2005 – Page 41) for locality diagram of the survey areas.

For further details, contact David Searle by telephone on 07 3362 9357 or by email at david.searle@nrm.qld.gov.au or Murray Richardson by telephone on 02 6249 9229 or by email at murray.richardson@ga.gov.au.



Update on Geophysical Survey Progress

Paterson Province WA – airborne magnetic and radiometric surveys

UTS Geophysics commenced data acquisition on the Paterson Central and Paterson South-East surveys on 24 June. Approximately 123 000 line-km of magnetic and radiometric data will be acquired over an area of approximately 42 000 square kilometres.

At the beginning of November UTS Geophysics had completed 35% of this survey.

Maryborough/Gympie Qld – airborne magnetic and radiometric survey

UTS Geophysics completed data acquisition on the survey on 1 August. The survey acquired approximately 51,700 line-km of new data. The data were released into the public domain on 4 October 2005.

East Yilgarn WA – Airborne Magnetic and Radiometric Survey

Fugro Airborne Surveys commenced data acquisition on the survey on 14 August. At the beginning of November Fugro had completed 79% of this survey. See *Preview* 117 (August 2005 – Page 34, Figure 3) for a locality diagram of this survey.

Gascoyne WA – airborne magnetic and radiometric survey

UTS Geophysics commenced data acquisition on the survey on 6 October. At the beginning of November UTS had completed 15% of this survey. See *Preview* 117 (August 2005 – Page 34, Figure 4) for a locality diagram of this survey.

Western Gawler – airborne magnetic and radiometric survey

Primary Industries and Resources SA (PIRSA) is conducting an extensive airborne magnetic and radiometric survey in the Western Gawler region of South Australia (see Figures 5a & b).

Fugro Airborne Surveys have been engaged to acquire 36 000 line-km of magnetic and radiometric data over an area of approximately 12 500 square kilometres.

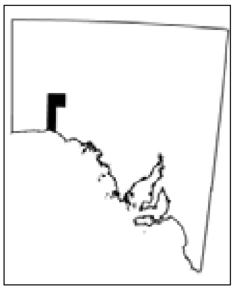


Fig. 5a. Western Gawler Airborne Geophysical Survey – survey locality.

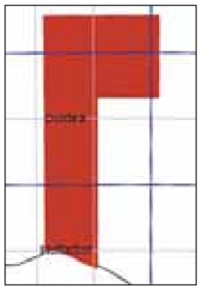


Fig. 5b. Detailed locality diagram for the Western Gawler Airborne Geophysical Survey.

Fugro started data acquisition on 30 October and at the beginning had completed 5% of the survey.

The new data will be acquired on east-west lines spaced 400 m apart with a ground clearance of 80 m above ground level. Geoscience Australia will be managing the flying program.

For further details, contact Domenic Calandro by telephone on 08 8463 3051 or by email at calandro.domenic@saugov.sa.gov.au or Murray Richardson by telephone on 02 6249 9229 or by email at murray.richardson@ga.gov.au.

$180 million boost to offshore petroleum exploration

The award of seven new offshore petroleum exploration permits in waters off Western Australia, Victoria and the Northern Territory will see an additional $180 million invested in offshore exploration over the next six years.

Federal Industry Minister Ian Macfarlane announced on 2 November 2005 the new permits as part of the government's ongoing program of releasing offshore acreage for petroleum exploration. This approval adds to the 22 exploration permits already granted by the Australian Government in the last 12 months, and brings total committed exploration expenditure to $675 million, according to the Minister.

The permits are in the Perth Basin (1) off Western Australia; the Otway Basin (1) off Victoria; the northern Bonaparte Basin (3) off the Northern Territory; and in the Browse Basin (2), also off the Northern Territory.

The table below summarises the results of the bids and the exploration programs being proposed. Notice that of the six permits allocated; only two attracted more than one bid.

Fig. 1. V04-2 gazettal block in Otway Basin showing bathymetry and well sites.

Permit Area Number of Bids	Operating Companies	Exploration Program
Otway Basin, Permit Vic/P62 (released as V04-2), see Fig. 1. One bid only.	Trident Energy Limited	Primary Work Program of 420 km new 2D seismic data acquisition at an estimated cost of $1.77 million. The secondary work program consists of data analysis and one exploration well at an estimated cost of $8.4 million.
Offshore Perth Basin, Permit WA-368-P (released as W04-17), see Fig. 2. Three bids.	Nexus Energy Australia N L.	A guaranteed work program of studies, acquisition of 300 km^2 of new seismic data and one exploration well with an estimated cost of $9.05 million. The secondary work program consists of studies and one exploration well estimated to cost $5.4 million.
Bonaparte Basin, Permit NT/P69 (released as NT04-2), see Fig. 3. Three bids.	ConocoPhillips Australia Exploration Pty Ltd and Santos Offshore Pty Ltd	A guaranteed work program of one exploration well, acquisition of 1 000 km^2 of new 3D seismic data, reprocessing of 5 000 km of 2D seismic data and studies, at an estimated cost of $37 million. The secondary work program consists of one exploration well and studies at an estimated cost of $23 million.
Northern Bonaparte Basin, Permit NT/P70 (released as NT04-3), see Fig. 3. One bid only.	Australian Oil and Gas Corporation Ltd	A guaranteed work program of 300 km^2 of 3D, and 700 km of 2D seismic data acquisition and studies at an estimated cost of $3.85 million. The secondary work program consists of one exploration well and studies with an estimated cost of $15.45 million.
Bonaparte Basin, Permit AC/P35 (released as AC/04-2), see Fig 4. One bid only.	Natural Gas Corporation Pty Ltd, Auralandia N L, and Gascorp Inc.	A guaranteed work program of studies, and acquisition of 250 km^2 of new seismic data estimated to cost $3.4 million. The secondary work program consists of studies, and one exploration well at an estimated cost of $15.6 million.
Northern Browse Basin**,** Permit AC/P36 (released as AC/04-3), see Fig. 4. One bid only.	Finder Exploration Pty Ltd	A guaranteed work program of licensing 4064 km^2 of 3D multi-client seismic data, and studies at an estimated cost of $13.95 million. The secondary work program consists of one exploration well and studies with an estimated cost of $10.2 million.
Northern Browse Basin, Permit AC/P37 (released as AC/04-4), see Fig. 4. One bid only.	Apache Northwest Pty Ltd	A guaranteed work program of purchasing 415 km^2 of 3D multiclient seismic data, one exploration well and studies with an estimated cost of $15 million. The secondary work program consists of acquiring 500 km^2 of new 3D seismic data, one exploration well and studies estimated to cost $18.8 million.

Fig. 2. Location of area W04-17, offshore Perth Basin, showing bathymetry and well sites.

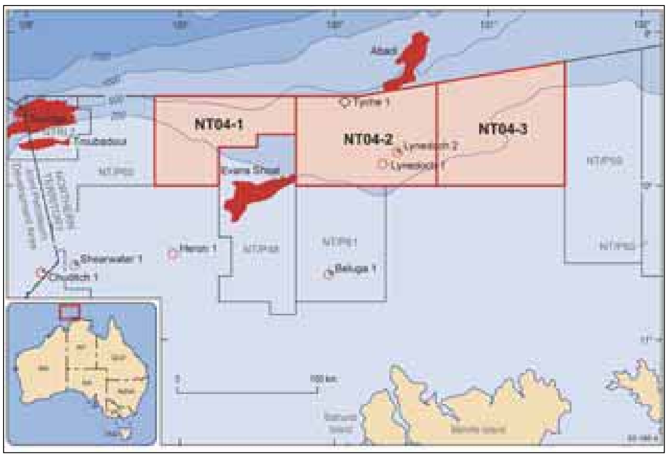


Fig. 3. Location of areas NT04-1 to 3, Northern Bonaparte Basin, showing bathymetry and well sites. Permit area NT04-1 was not allocated in this round of releases.

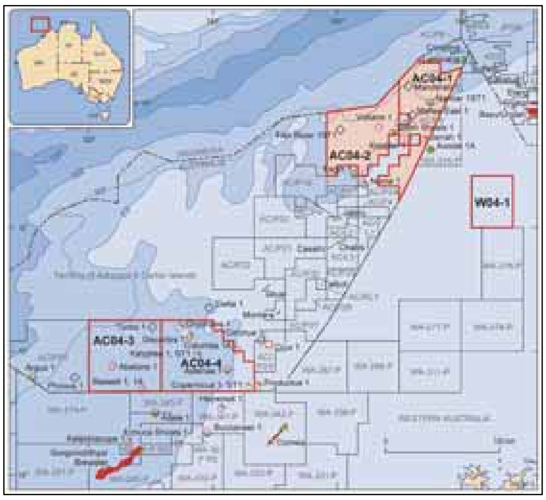


Fig. 4. Location of areas AC/04-2 to 4, in the Bonaparte and Browse Basins, AC/04-1 was not allocated in this round of releases.

One of the few advantages of knee surgery is that it facilitates a plethora of undisturbed reading time. I devoted my recuperation towards reviewing two recently released texts on inverse problem theory and parameter estimation:

(i) Parameter Estimation and Inverse Problems by Richard Aster, Brian Borchers and Clifford Thurber and

(ii) Inverse Problem Theory and Methods for Model Parameter Estimation by Albert Tarantola. Here are my reviews.

Parameter Estimation and Inverse Problems

Richard Aster, Brian Borchers and Clifford Thurber
Publisher: Elsevier Academic Press
pp. 301
Copies can be purchased direct from Elsevier Australia Customer Service,
Tel: 1800 263 951, Fax. (02) 9517 2249 or Email: service@elsevier.com
Price: $146.30 (GST Inc.)

The principle goal of Parameter Estimation and Inverse Problems "*is to promote fundamental understanding of parameter estimation and inverse problem philosophy and methodology*". The text achieves this by offering a concise review of parameter estimation that covers important theoretical developments, methods of inversion, detailed explanations of error analysis and a variety of examples, many of which are drawn from the geophysical field.

Chapter 1 introduces parameter estimation and inverse problems. Important issues such as existence, uniqueness and instability are all explained via easily followed examples. Linear regression is introduced in Chapter 2 and related to maximum likelihood techniques for normally distributed data. Detailed statistical analysis is used to cover the propagation of errors, confidence intervals, the covariance matrix and outliers. The discretisation of continuous inverse problems is discussed in Chapter 3. Quadrature, linear combinations of basis functions and the method of Backus and Gilbert are all introduced. This chapter on discretisation broadens the scope of the text to continuous inverse problems without requiring a detailed discussion of functional analysis.

The singular value decomposition (SVD) is introduced in Chapter 4 and used to describe the characteristics of rank-deficient and ill-conditioned linear problems. The tradeoff between bias caused by limited resolution and the mapping of data noise into model parameters is explained. Chapter 5 covers the stabilisation of inverse problems via Tikhonov regularisation. Zeroth- and Higher-order Tikhonov regularisation are described and the L-curve criterion and other techniques for estimating the regularisation parameter introduced. Chapter 6 covers iterative techniques for solving inverse problems that are two large for SVD or other direct methods. Most notably the conjugate gradient least squares method is introduced and described via example.

Chapter 7 expands on the Tikhonov regularization covered in Chapter 5 by describing the bounds constraint methods, maximum entropy regularization and total variation. Fourier techniques are introduced in Chapter 8 and related to linear time invariant systems by casting the forward problem as a convolution and the inverse problem as a deconvolution. Nonlinear regression is discussed in Chapter 9 through the introduction of Newton's method and some of its variants, such as the Gauss-Newton and Levenberg-Marquardt techniques. Statistical analysis is described via a linearization of the misfit function about the estimated model parameters. Chapter 10 describes the regularization of ill-conditioned non-linear inverse problems. Tikhonov regularization and Occam's inversion are both covered and examples in seismic tomography and electrical conductivity presented. An introduction to Bayesian methods is provided in Chapter 11. The Bayesian approach of seeking a solution as a probability density of model parameters (the posterior distribution) is contrasted against the classical approach of seeking a specific but unknown model. The text concludes with short summaries reviewing important facets of linear algebra, probability and statistics and vector calculus. The appendices provide readers with a useful refresher preparing them with the required mathematical tools to understand the main text.

Parameter Estimation and Inverse Problems is an excellent introduction to inversion and parameter estimation. It is suitable for advanced undergraduates, graduate students and researchers in geophysics or other related fields. Student exercises accompanying each chapter promote the book's suitability for classroom teaching. It is accompanied by a CD containing Matlab programs and data for homework exercises and examples. I have no hesitation in recommending this book to anyone who is interested in learning more about inversion and I encourage lecturers to consider its suitability for teaching.

Inverse Problem Theory and Methods for Model Parameter Estimation

Albert Tarantola
Publisher: Society for Industrial and Applied Mathematics (SIAM)
pp. 342
Copies can be purchased direct from SIAM via the web: www.siam.org/catalog/,
Tel: +1 215 382 9800
Fax: +1 215 386 7999

$59.50 US	Members of SIAM
$85.00 US	Non-Members
+ $22.99 US	postage to Australia

Inverse Problem Theory and Methods for Model Parameter Estimation is a rewrite of an earlier book by Tarantola. Like its 1987 predecessor, this text treats inverse problems in a probabilistic fashion whereby solutions are sought as probability distributions over the model space rather than a specific set of model parameters. This text underplays the role of optimisation techniques and places an increased emphasis on Monte Carlo methods.

In Chapter 1 Tarantola explains how the general inverse problem can be set as a problem of combining measured data; a priori on model parameters; and information on the physical relationship between observables parameters and model parameters. Tarantola introduces the notion of "combination of states of information" which is in principal free from some difficulties associated with the use of conditional probabilities and Bayes theorem. Chapter 2 describes how Monte Carlo techniques can be used to design random walks that efficiently sample the probability distribution. This is necessary because the majority of practical inverse problems have sufficiently many dimensions that analytical expression can not be derived for the probability distribution over the model space. Furthermore, the number of dimensions commonly prohibits systematic exploration of the probability distribution. In Chapter 3 the least squares criterion is introduced and used to analyse the inverse problem. It is shown that the posterior distribution is Gaussian when measurement uncertainties follow a Gaussian distribution and the forward problem is linear. Covariance operators, model resolution and the gradient techniques are all discussed. The use of least squares techniques is described for problems where a nonlinear forward problem can be linearised in some region of interest. Chapter 4 introduces the least-absolute value (or ℓ_1 -norm) criterion for use when outliers are present in the data and the ℓ_∞ –norm criterion for use when data rounding is significant. In Chapter 5 Tarantola describes how some inverse problems are best formulated as a functional inverse problem, even when discretisation is required for the actual computation. Random functions and functional analysis are discussed and geophysical examples presented.

The end of Chapter 5 occurs roughly half way into the book and it represents the conclusion of the main text. The remainder of the published work comprises a suite of 32 appendices (approximately 100 pages) and 23 worked problems (approximately 60 pages). The appendices cover a broad range of topics by way of brief summaries. For example; there are appendices covering the chi-squared probability density, the distance norm and elements of linear programming. Written in this manner the appendices represent a good source of reference material in their own right. The worked problems can be separated into two broad categories. The first category includes problems that cover specific geophysical applications such as earthquake location, elementary tomography and geodetic adjustment. The second category includes those problems that are more general in nature but could easily be applied to specific geophysical (or other disciplines) problems. For example, there are worked problems that explore least-squares regression, the conjunction of two probability distributions and using the simplex method.

At times Inverse Problem Theory and Methods for Model Parameter Estimation can be a little tough going. Despite this, I expect that it will become one of the classic texts on probabilistic inverse problems. I recommend this text to graduate students or researchers who are interested in learning how to approach inversion and parameter estimation from a probabilistic viewpoint.

Fifth Edition of the *Glossary of Geology* Published

The American Geological Institute (AGI) announces the publication of the fifth edition of the *Glossary of Geology*. This book has served as an important resource to geoscientists in all fields. The fifth edition, edited by Klaus K.E. Neuendorf, James P. Mehl, Jr. and Julia A. Jackson, reflects advances in scientific thought and changes in word usage.

Of the 40,000 entries, approximately 3,600 are new additions, and 13,000 entries have been updated, providing the most comprehensive set of geological terms in publication. Many definitions include a syllabification guide and background information, as well as helpful resources for a variety of problems, such as look-alike pairs; for example, the difference between sylvanite (a mineral) and sylvinite (a rock). The reference also indicates the origins of terms, the meaning of abbreviations and acronyms common in geoscience vocabulary, dates of first recorded usage of a term, prefix meanings, as well as the preferred term of two or more synonyms.

The authority of the fifth edition, like those before it, rests on the expertise of geoscientists from many specialties who have added new terms, reviewed definitions and cited references using those terms. Their contributions make the *Glossary of Geology* an essential reference work for everyone who works in or with geoscience information.

The fifth edition of the *Glossary of Geology* (ISBN#: 922152-76-4) is a 779-page hardcover text, available now. List price is $99.95, $79.95 for AGI Member Society Members. To determine overseas shipping costs, obtain additional information, or to order, contact the AGI Publications Department at: www.agiweb.org/pubs, or email to pubs@agiweb.org.