Preview

Australian Society of Exploration Geophysicists

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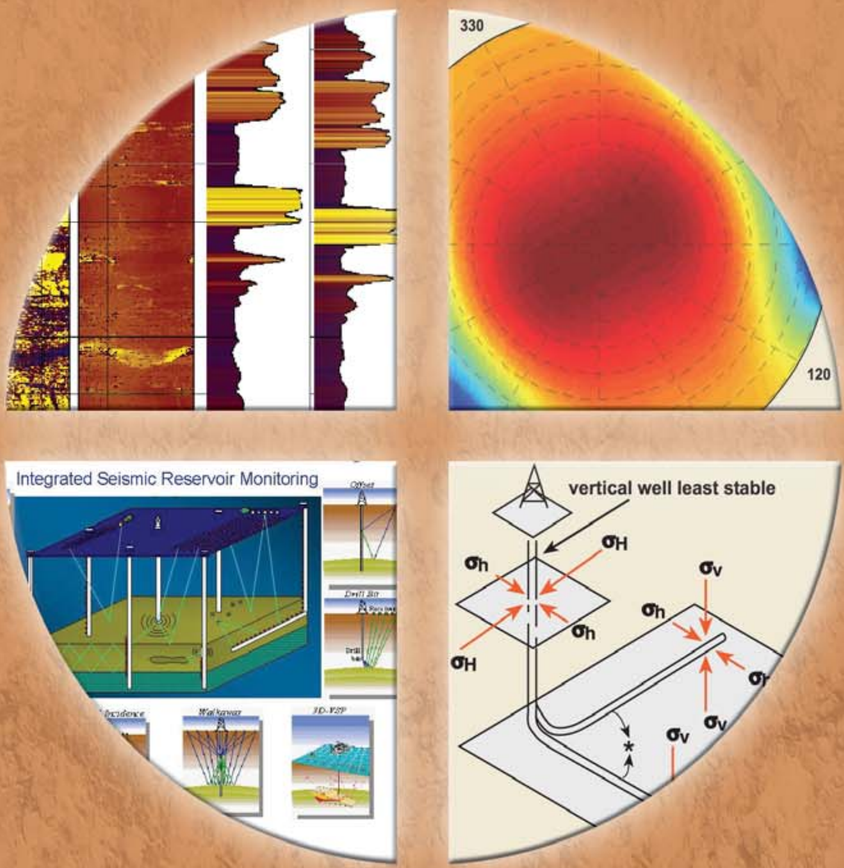
December 2000 Issue No.89

Borehole Geophysics



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In this Issue

This edition of Preview is the first of two issues focussing on borehole geophysics. In the past few years there have been significant advances in the technologies available to extract information from boreholes. We plan to review these in the minerals, petroleum and geotechnical sectors of our industry and hope that these reviews will form a useful reference for members who may be involved in borehole geophysics.

In the February issue we hope to have a case study of geotechnical applications by Burkhard Unterstell, a paper on rock strength determinations by Peter Hatherly, a discussion of some advanced applications of geophysics in boreholes by Kevin Dodds and an insight into borehole geophysics at Schlumberger by Henry Cao.

There is also a review by Brian Minty on the spectral smoothing of γ-ray data. The research results of the past five years or so into the processing of γ-ray data are now being applied in the geophysical service industry and it is timely to review the main methods available.

Science Meets Parliament

I had the privilege to attend the second *Science Meets Parliament* day in early November. This was organised by The Federation of Australian Science and Technology Societies (FASTS). Scientists and technologists from across Australia descended on Parliament House in Canberra for this event on 1st November 2000.

SMP Day aims to give both scientists and parliamentarians the chance to discuss science issues of importance to the nation. On this occasion some 160 scientists met with Members and Senators from across the political spectrum during more than 150 individual meetings.

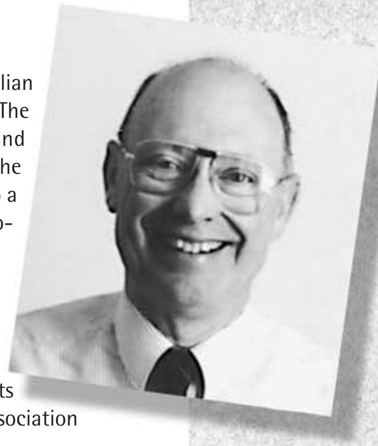
The focus of this year's event was the government response to the Batterham Report 'The Chance to Change', and the report from the Innovation Summit, 'Innovation – Unlocking the future'.

Both reports argued for a substantial increase in government investment for the Science, Engineering and Technology sectors. The Minister for Industry, Science and Resources, Senator Nick Minchin, told the gathering that innovation is the key to achieving global competitiveness in the future. He also stated that the Government was committed to science issues and welcomed the opportunity to engage in a policy dialogue with the science community.

The Prime Minister has given the job of dealing with the reports to Ministers Alston, Kemp and Minchin, who are expected to report early in the new year. We will have to wait to see if the additional funding will come close to the $1 billion/year argued by FASTS. However, it is clear that the government is looking for targeted funding to achieve higher business investment in R&D and an increased rate of commercialisation of research, for job creation. The Geosciences were well represented with:

Mike Smith and Ray Shaw from ASEG, Peter Stoker and Colin Simpson from AusIMM, Phil Lock and Andrew Barrett from PESA, Evan Leitch and Sarah Bellfield from the GSA, Matthew Huggan and Sam Lees from the AIG, and Peter Cook from the CRCs.

Australian Geoscience Council



We also had two meetings of the Australian Geoscience Council during the SMP days. The Council comprises seven societies and associations and represents most of the geoscientists in Australia. This amounts to a total of about 10 000 professional geoscientists.

The Societies represented on the Council are:

- Association of Exploration Geochemists
- Australian Geoscience Information Association
- Australian Institute of Geoscientists
- Australian Society of Exploration Geophysicists
- Geological Society of Australia
- Petroleum Exploration Society of Australia
- The Australasian Institute of Mining and Metallurgy

We outlined key issues for the AGC and developed a series of action plans to address the under-employment of geoscientists in Australia. The three main goals are to raise:

- Mineral and petroleum exploration levels in Australia,
- The perception/awareness of the geosciences throughout the Australian community, and
- The levels of geoscience research in the Federal and State governments, industry and the tertiary sector.

A big ask, but we have to try and make a difference. If any member would like more details please let me know.

Book Reviews

We try to include one or two book reviews in each issue of Preview and are looking for sharp critical geophysicists to review interesting books. On my desk at present I have copies of:

- Numerical Models of Oceans and Oceanic Processes by Kantha and Clayson
- Small Scale Processes in Geophysical Fluid Flows by Kantha and Clayson
- Earthquake Thermodynamics and Phase Transformations in the Earth's Interior by Teisseyre and Majewski, and
- Sea Level Rise - History and Consequences by Douglas et al.

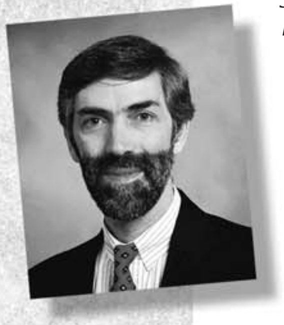
These are all quality hardback publications and will be sent to members on a first come first served basis.

Finally, I would like to thank our contributors, readers and publisher for their support during the year. I hope you all have a relaxing Christmas and that the New Year brings more exciting challenges for us all.

David Denham

David Denham

President's Piece



In this issue of Preview, I will hand over the President's Piece to a prominent member of our Society - Andrew Mutton, Chairman of the ASEG Publications Committee since 1998 - to share his vision for one of the Society's major functions - Publications. Early in the New Year, I will share with you the outcome of the Society's strategic planning meeting, and give an update on the membership survey.

Until then, I wish you and your family a joyous holiday season.

Brian Spies
President

Publications in the ASEG - is it time to abandon tradition?

The Society's publications - an enviable reputation.

One of the most important roles and expectations of a professional society such as the ASEG is the production of various publications to meet the members' needs as an outlet for presentation of their professional work, to keep abreast of technological developments and applications, and as a communication vehicle. Over the past 30 years, the ASEG has earned an enviable reputation with its flagship publications Exploration Geophysics and Preview, as well as Special Publications and the Membership Directory.

In particular Exploration Geophysics (EG) - the primary publication of the ASEG, and the Society's archival technical journal containing fully refereed papers - has gained a reputation of global importance as a geoscientific publication. But the cost of publishing EG - greater than $100 000 per year - represents the highest cost of any single activity of the ASEG. Although the cost is subsidised by income from advertising and conferences, the net cost is still unacceptably high. On the other hand, Preview - the ASEG's bimonthly newsletter - now imposes very little net cost to the ASEG because of the substantial advertising revenue it generates.

Time for a change?

In the last few years, two main factors - increasing production costs, and the advent of new digital publication technology - have led to the ASEG considering alternative options and making changes to the Publications portfolio. These options have ranged from combining EG and Preview into one publication, reducing the frequency and size of some publications, reviewing publishing arrangements and costs, and migrating to full digital or web-based publishing. As a result of this, several changes have been made:

- tendering and selection of a new publisher in 1999, with emphasis on reducing costs without compromising quality, as well as marketing and electronic publishing capabilities;
- appointment of a Managing Editor responsible for editorial content and financial management for Exploration Geophysics;
- improving the controls on income from advertising and author's charges; and,
- commencing with the 2001 Conference, discontinuation of one of the ASEG's major publications, the conference edition of EG, to be replaced by a "Best of Conference" EG published after the ASEG conference. Papers accepted for the conference will now be published separately as expanded abstracts on a CD-ROM.

The future vision - clear or somewhat fuzzy?

Whilst the recent changes are a step forward, they are only evolutionary in that they have still not addressed one of the most far-reaching technological developments that confronts mankind today - the Internet and the virtual information super-highway. The options that this medium opens up have enormous ramifications, especially with regard to publications.

As an alternative to expensive hard-copy printing and distribution of journals, web-based publishing, already offered by some professional societies, certainly has its attractions. However, the questions raised by jumping onto this fast-moving juggernaut are numerous - is there any cost saving unless you abandon hard-copy altogether; how do you reference papers published on the web; how do you secure the information to ensure that only financial members and subscribers have access; will it be possible to maintain quality refereeing of articles, and will advertisers still support the Society if only web-based advertising is available?

The ASEG is committed to continue to provide a quality technical journal and informative newsletter to its members while at the same time containing costs by more efficient and timely production, and improved marketing. However, in the interests of the financial well being of the Society, the Executive will only maintain the current publications if there is demonstrated support of these by members and advertisers. The current membership survey aims to elicit members' views on the content and relevance of the current ASEG publications and future options including web-based publishing. I encourage all members to respond to the survey and express their views. I also encourage any member with a particular interest in this area to become part of the Publications' Committee and help steer the ASEG into this new and exciting era.

Andrew Mutton

Contents

The material published in *Preview* is neither the opinions nor the views of the ASEG unless expressly stated. The articles are the opinion of the writers only. The ASEG does not necessarily endorse the information printed. No responsibility is accepted for the accuracy of any of the opinions or information or claims contained in *Preview* and readers should rely on their own enquiries in making decisions affecting their own interests.

Material published in *Preview* aims to contain new topical advances in geophysical techniques, easy-to-read reviews of interest to our members, opinions of members, and matters of general interest to our membership.

All contributions should be submitted to the Editor via email at pdenham@atrax.net.au. We reserve the right to edit all submissions; letters must contain your name and a contact address. Editorial style for technical articles should follow the guidelines outlined in *Exploration Geophysics* and on ASEG's website www.aseg.org.au. We encourage the use of colour in *Preview* but authors will be asked in most cases to pay a page charge of $400 per page for the printing of colour figures. Reprints will not be provided but authors can obtain, on request, a digital file of their article, and are invited to discuss with the publisher, RESolutions Resource and Energy Services, purchase of multiple hard-copy reprints if required.

Deadlines for contributions to Preview for 2001

Preview is published bi-monthly, February, April, June, August, October and December. The deadlines for submission of all material to the Editor is as follows:

Preview Issue	Text & articles	Advertisements
90 Feb 2001	15 Jan 2001	22 Jan 2001
91 Apr 2001	15 Mar 2001	22 Mar 2001
92 Jun 2001	15 May 2001	22 May 2001
93 Aug 2001*	**29 Jun 2001**	**13 Jul 2001**
*** (Conf Edition)**		
94 Oct 2001	15 Sept 2001	22 Sept 2001
95 Dec 2001	15 Nov 2001	22 Nov 2001

Advertisers

Please contact the publisher, RESolutions Resource and Energy Services, (see details elsewhere in this issue) for advertising rates and information. The ASEG reserves the right to reject advertising, which is not in keeping with its publication standards.

Advertising copy deadline is the 22nd of the month prior to the issue date. Therefore, the advertising copy deadline for the February 2001 edition is the 22nd of January.

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February 18-21
Australian Society of Exploration Geophysicists &
Victorian Government
Bendigo, Victoria
Theme: ***Salinity Land Management & New Technologies***
Contacts: Greg Street,
http://www.aseg.org.au/vic/bendigo-conference,
or David Heislers, david.heislers@nre.vic.gov.au

March 4-7
The Annual Meeting of The Environmental and
Engineering Geophysical Society
Doubletree Hotel, Denver Colorado, U.S.A.
Theme: ***Geophysics: Reducing Risk in Environmental and Geotechnical Engineering***
Email: lcramer@expomasters.com
Website: http://www.sageep.com/

May 29-June 3
American Geophysical Union, 2001 Spring Meeting,
Boston, Mass., U.S.A.
Website: http://www.agu.org

June 11-15
63rd EAGE Conference & Technical Exhibition,
Amsterdam, The Netherlands
Website: http://www.eage.nl

August 5-8
Australian Society of Exploration Geophysicists
15th International Conference and Exhibition
Brisbane, Queensland
Theme: '2001: A Geophysical Odyssey'
Website: http://www.aseg.org.au
Event Manager: Jacki Mole
Tel: +61 7 3858 5579
Email: aseg2001@im.com.au

September 2-6
7th Environmental & Engineering Geophysical Society,
European Section, Birmingham, U.K.
Theme: ***Better and faster solutions***
Email: conference@geolsoc.org.wk
Website: www.geolsoc.org.uk/eegs2001/

September 9-14
SEG International Exposition & 71st Annual Meeting,
San Antonio, Texas, U.S.A.
Website: http://www.seg.org

September 24-28
4th International Archaean Symposium,
University of Western Australia, Perth
Convenor: Susan Ho
Tel: +61 8 9332 7350
Email: susanho@geol.uwa.edu.au

A Proposal for a National Program of Multidisciplinary Research in the Earth Sciences

A new initiative aimed at building collaboration in research across the university, industry and government research sectors has the potential to strengthen geophysics research and education in Australia. The initiative has been made possible by proposed changes to the way research will be funded in universities.

Emerging trends for funding university research are towards substantial, multi-year grants to research consortia rather than to individual researchers, research groups and institutions, and towards encouraging linkages between the university, industry and government research sectors. Such funding would allow a nationally networked group of Earth scientists concerned with a major set of related problems (a 'program') to mount a sustained effort involving expensive state-of-the-art facilities. The highly successful Australian ODP Consortium is an existing example.

National programs in the Earth sciences would help strengthen the university research community, provide it with a focus and create opportunities to embark on new types of research. In the paragraphs below, a proposal for one such program is summarised. Readers of *Preview* may be interested in this program because it recognises the central role that geophysics can play in studies of the continent at all scales.

The proposal is being prepared by a Working Group[1] that arose from a meeting held during the 15th Australian Geological Convention. The meeting was sponsored by the Australian National Seismic Imaging Resource (ANSIR), a Major National Research Facility (MNRF) that provides researchers with access to state of the art seismic equipment and expertise.

Australian universities have substantial research strength in a number of Earth science disciplines. However, they lack high-quality images of the inaccessible deep interior of the continent, from the surface to around 200-400 km. These can come from a range of geophysics disciplines - seismic imaging, electromagnetic and magnetotelluric methods, and the quantitative analysis of potential field data.

Poor access to geophysical equipment has been recognised for some time as a major impediment to geophysics research and education in Australia ("Towards 2005: A Prospectus for Research and Research Training in the Australian Earth Sciences." Prepared by the Australian Gesocience Council. National Board of Employment, Education and Training. Canberra, 1992).

The accompanying graph, which shows the sectoral sources of project funds for research conducted with ANSIR equipment, demonstrates this clearly. Whereas government research agencies, cooperative research centres and industry have been able to fund their research programs, Australian Research Council grants, which represent the quantum of university-based research, are very low.

(ASEG Members may note that "Other" includes several grants from the ASEG Research Foundation, although the bulk is ANU Block Grant funds).

The Nature of the Science — Australia as an International Laboratory

Many areas of research are turning to "systems science," whereby integrated multidisciplinary studies of the total problem are replacing single discipline science. In the Earth sciences, this is occurring at a range of geological scales, and in a number of sectors; for example, at the global science scale, the regional scale through geological survey programs, in exploration at the petroleum and mineral systems scales, and in environmental and groundwater studies. Systems science would underpin a national program.

A national program must be of international standard, and make an international impact. The range of geology coupled with the ease of working on a single continental plate within a single stable political system make the Australian continent is an ideal laboratory for studying many of the fundamental principles of geology.

The Working Group has identified a number of geological problems as potential research targets. The list is not exhaustive, and many other ideas are likely to come from consultation with the wider Earth science community. These problems can be linked on the basis of geological time and scale such that the longer term program of research would have broad appeal to the university, resource and government research sectors.

- Australia is almost uniquely placed of all the continents in its plate tectonic setting. It is ringed by earthquake-prone belts, allowing us to build seismic tomograms to asthenospheric depths. Coupled with other imaging techniques, tomograms would underpin studies of the evolution of the continent that considered not only the effects in the upper crust but also whole-of-lithosphere tectonics; for example, how lithosphere deforms when the crust is shortened or extended. Petrological, petrophysical, geochemical and isotope studies of igneous rocks and xenoliths would provide constraints on the composition of the lithosphere at depth.

- The results of this research would contribute significantly to our understanding of such features as the Tasman Line, which, although one of the fundamental and apparently most significant features crossing any continent, is relatively unstudied and therefore poorly understood.

- Studies at lithosphere scale would also place constraints on our understanding of how our intracratonic sedimentary basins formed, including the formation of rifts and why some fail.

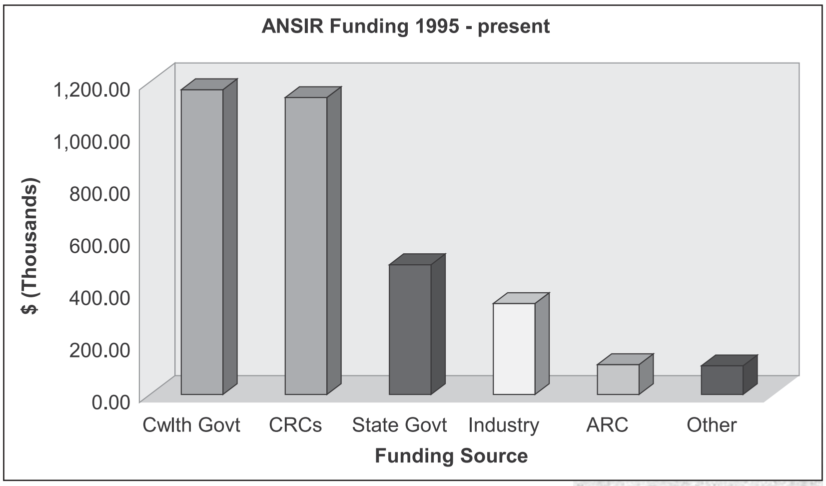
- These studies could be expanded to study the implications of lithospheric rifting for the development, nature and form of passive margins. The passive margins around Australia represent a broad sample of passive margin types.

- Australia has some of the best preserved and most accessible examples of
  - A Palaeozoic fold belt - the Lachlan Fold Belt
  - Intraplate deformation and intracratonic basins - the Officer/Amadeus/Ngalia/Lander system - including some of the largest intraplate gravity anomalies for an apparently stable region
  - A Grenvillian mobile belt - the Albany-Fraser Belt - in which both sides of the mobile belt are exposed
  - A Proterozoic orogen - the Capricorn Orogen - where cover sequences onlap the adjacent cratons with relatively little deformation, implying the orogen has been little disturbed since formation
  - Archaean blocks - Pilbara and Yilgarn - which have apparently different structural styles
  - Archaean platform cover - the Hamersley Basin - which appears to have formed across a stable platform at a time when tectonic processes as we currently understand them for the Archaean were unlikely to have led to stable platforms.

What next?

The Working Group plans to prepare an application for submission to traditional funding agencies. Before then, the science has to be more fully scoped. We therefore propose to hold a workshop in Melbourne in early 2001 at which the science will be discussed and focussed. The workshop would include people from the industry and government research sectors. Funding is presently being sought to provide at least partial support for the workshop.

This national program will be based on national need and national interest. All stakeholders should have an opportunity to have input. The Working Group welcomes input from individuals, groups and organisations. Readers of *Preview* who wish to have an input can contact any of the Working Group members.



Sources of project operating grants for research conducted with ANSIR equipment. Amounts shown are those registered through ANSIR Accounts, and are the field component of research projects. Standing costs, and resources spent within the research institutions are not recorded by ANSIR, and therefore are not included.

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Australian Capital Territory - by Nick Direen

On Thursday, October 19th, approximately 40 members and guests attended a very entertaining presentation by Dr Miriam Baltuck, the NASA Representative in Australia. The talk was entitled 'The NASA Shuttle Radar Topography Mission and the PACRIM II airborne remote sensing campaign: Australia's Role.'

The talk dealt with the technology behind the recent NASA mission to map > 90% of the Earth's surface to resolutions of better than 16 m, and some of the products and applications likely to flow from this work.

The ACT Branch also welcomed Terry Crabb to our number. Terry has recently transferred from the WA Branch, and is working in a management consultancy firm in Canberra.

Victoria - by Suzanne Haydon

Well another year is over and time seems to have flown since we were all in Perth at the start of the year. The Victorian Branch has had yet another busy year. The latest talks have been from:

- Julie Elders, who treated us to a rerun of the talk that she gave at the SEG this year comparing receiver technologies in downhole MMR surveys.
- Bill Mathew, who spoke about the uses of geophysical methods for the manufacturing industry. Bill had some very interesting tales to tell about the use of gamma radiation detectors for measuring how much soil comes in with the sugar cane, and some anecdotes about what happens when a radioactive source gets recycled by mistake!
- Ken Witherly also visited us and talked about the Ontario Government's Project Treasure Hunt. It was good to have the opportunity to see a comparison of different EM systems over the same ground.

Our Christmas party this year was held jointly with PESA and SPE.

Lastly, a couple of housekeeping matters. Our secretary, Trudi Hoogenboom, is moving on to greener pastures, so the Victorian Branch is looking for a new secretary. We will be having the AGM early next year, so please, if you know anyone who is up to the task, or would like to nominate yourself, let the Victorian President, Suzanne Haydon, know by phone or email. On the matter of email, the Victorian Branch has moved to sending out meeting notices by email rather than post (saving a lot of work for the new secretary). If you would prefer (or need) to get your notices by post please let Suzanne know so that she can ensure you get your meeting notices.

Queensland - by Kathlene Oliver

The Queensland Branch held a number of co-hosted events over the last three months to provide maximum opportunities for our members to attend premium quality presentations. On the 6th November we hosted an extremely well attended lunch and technical meeting in conjunction with PESA where the AAPG-SEG 1999/2000 Distinguished Lecturer Alistair Brown presented a modified version of his lecture *Let the Data Speak to You: How to Improve Your 3D Seismic Interpretation*. The lunchtime meeting was a new format for our branch meetings, proving to be successful and well attended. Prior to this technical meeting we hosted a joint technical meeting on the 10th October with AusIMM and AIG. The presenter for the AusIMM, AIG and ASEG meeting was Gary Fallon, MIM Exploration, who presented *The Use of 3D Seismic as a Primary Underground Coal Resource Definition Tool*, a subject of growing interest and successful application among the geophysical industry. The meeting was well attended and enjoyed by all.

The Queensland Branch hosted their annual student night on the 28th November at the Exploration Geophysics Laboratory of the University of Queensland. The evening provided an opportunity for graduating students to present the results of their work to members of the geophysical community in a relatively relaxed and social environment. Two of the students who presented their work were Eric Battig and Sebastian Nixon.

The Queensland Branch are kept very busy organising the next conference and exhibition, which will be held at the Brisbane Convention and Exhibition Centre between the 5th and 8th August 2001. Invitations to exhibit will be sent out to members and previous exhibitors over the next two months, if you do not receive an invitation please contact the Conference Secretariat via email at aseg2001@aseg.org.au or on +61 7 3858 5579. There are still sponsorship opportunities available, please contact the Conference Secretariat for more information. For more information about the conference please see the ASEG web page or the Conference Update in this edition of Preview.

New South Wales - by Phil Schmidt

NSW Branch held Students' Night on Tuesday 14th November, which attracted a fair crowd. It was quite gratifying to see such a large group of students interested in geophysics at Honours level.

Three presentations were made. The first two were given jointly by Carina Simmat and Matthew Levinson, both students of Iain Mason from Sydney University. They presented high quality radar data both from bore holes in the Witwatersrand Basin and from modelling using curved perspex sheeting in tanks. With a 0.1% death-rate/year, the driving force for bore hole radar in the Wits is pre-mining detection of structurally weak 'pot-holes' and increased mine safety.

The third paper, by Michael Brooks, a student of Derecke Palmer, UNSW, was on enhancing seismic reflections by stacking in the convolution domain. Michael showed fairly convincing improvements in resolution that he has achieved. All students were congratulated and given a token of appreciation by way of a contribution to their future careers, and may be memberships of ASEG!

Western Australia – by Mark Russell

Technical Meetings:
CELTIC CLUB, 48 Ord Street, West Perth
(5:30pm drinks and food, 6:00pm meeting commences)
ASEG members admission free; Non-members admission $10.00.

October Technical Meetings – Students Nights!!
Wednesday, October 18 and October 25, 2000
12 Geophysics Honours students from Curtin University WA presented their thesis papers over two grand nights, proudly sponsored by: Apache, BHP, GeoCom, Geosoft, Normandy, and WMC.

Details of students and their topics can be seen at our website: http://www.aseg.org.au/wa/wa_branch_cont.htm

If your company would like to present a paper and/or sponsor at ASEG WA meetings please contact: Kevin Dodds, CSIRO (9464 5005) or Guy Holmes, Encom (9321 1788) about speakers and sponsorship possibilities.

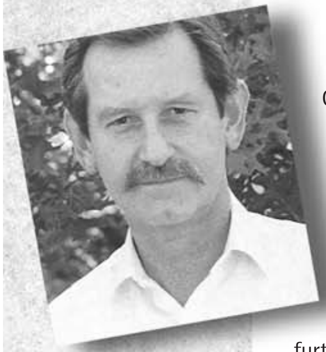
For information on upcoming events, check our Web Site: http://www.aseg.org.au/wa

Employment Service
Our Employment Service is running on the WA web site. This service is available to WA members to facilitate initial contact between employers and those seeking employment. To see who is currently available, or to register yourself, go to the Employment Section of our website: http://www.aseg.org.au/wa/employment_cont.htm

Our Website: http://www.aseg.org.au/wa
General Correspondence to:
ASEG WA Secretary C/-
PO Box 1679 WEST PERTH WA 6872
President: Jim Dirstein Tel: 9382 4307;
Vice President: John McDonald Tel: 9266 7194;
Secretary: Kevin Dodds Tel: 9464 5005,
Email: Kevin.Dodds@per.dpr.csiro.au;
Treasurer: John Watt Tel: 9222 3154

ASEG WA Branch News compiled by Mark Russell, Geosoft Australia, Tel: 9214 3905. www.geosoft.com.

Geoff Dickson 1938-2000



Geoff Dickson

By Peter Dalhaus, University of Ballarat

This Obituary was published in The Australian Geologist No. 116, September 2000 and is reproduced courtesy of the Geological Society of Australia. Geoff had been a member of the ASEG for over 25 years and will be sorely missed by the Society. Ed

Geoff Dickson, exploration geophysicist, died on Monday July 10th, 2000, after a long battle with cancer.

Born and educated in Sydney, Geoff graduated from the University of Sydney in 1961 with a BSc with majors in mathematics and geology, and was awarded an MSc in geophysics in 1962. His Masters research, which resulted in the publication of three papers on thermoremanent magnetism, led him to pursue further studies at Columbia University, New York City, USA. Geoff completed his doctoral thesis, entitled "Magnetic Anomalies in the South Atlantic Ocean", under the guidance of Dr. Maurice Ewing and was awarded his PhD in March 1968. His research made a significant contribution to the early theories on sea-floor spreading, shared by his co-researchers W.C. Pitman, X. LePichon, E.M. Herron and J.M. Heirztler.

During his PhD studies Geoff was employed on a part-time basis at Lamont- Doherty Geological Observatory, Palisades, NY, and spent several months in the North and South Atlantic on the Research Vessel Robert D. Conrad. Among his experiences, he was involved in the search for the USS Thresher, a nuclear submarine that sank off Boston in the mid 1960s. The search was undertaken using a deep towed magnetometer. In 1967, Geoff served as Chief Scientist on the RV Conrad during a ten-week cruise of the South Indian Ocean, starting in Cape Town and ending in Fremantle.

On gaining his PhD, Geoff joined Newmont Exploration Limited in Danbury, Connecticut, and worked with an exceptionally talented team of geophysicists, which included Arthur Brant, Maurie Davidson, Misac Nabighian, George McLaughlin, Brent Fuller, Colin Barnett and Jack Parry. Together they made an extraordinary impact on the then new discipline of mining geophysics. Geoff's work was mostly with Newmont of Canada, where he and W.M. Dolan mastered the range of techniques used in base metal exploration. In 1969, Geoff returned to Australia to take up the position of Chief Geophysicist at Newmont Holdings Pty Ltd, the Australian arm of Newmont. During the 1970s Geoff and the Newmont exploration group shared in the exciting discovery of the Telfer gold deposit in Western Australia.

In 1979 Geoff set up his consulting company, G O Dickson & Associates Pty Ltd. His list of clients, which included both Newmont and New crest, reads like a roll-call of Australian explorers. Geoff loved the challenges of geophysics and rarely accepted anything on faith. He possessed a remarkable talent to examine each problem from first principles, and would often devise a simpler, more practical solution. Geoff was an active member of the ASEG and SEG and a past member of the GSA. He served as the first president of the Victorian ASEG, and as a member of the ASEG Publications Committee.

For the past decade (1989 -99) Geoff was Lecturer in Geophysics at the University of Ballarat, on a sessional basis. He will be remembered by a generation of graduates as a kind, gentle person with a profound understanding of his subject. Highly respected and well liked as a teacher, he was admired for his sharp intellect and enjoyed for his dry sense of humour. Geoff's dedication in tracking the progress of each individual student made it impossible to slip anything past him. Geoff taught by setting practical problems for his students, often on work he had recently completed. To his students, his initials said it all - he was a G.O.D. of geophysics. Looking into his class on Friday afternoon, one would see groups of students tracing over images, plotting data and matching graphs. Many graduates count themselves lucky to have encountered him as their teacher.

Many of us feel blessed to have known him as a friend and colleague. Geoff is survived by his wife Leta, a music teacher, his sons Greg and Simon and his stepchildren, Rachelle and Phillip.

Geoff Garrett to Lead CSIRO

Dr Geoff Garrett, the British-born CEO of South Africa's national science agency, CSIR, is to head its sister science agency in Australia, commencing January 2001. His appointment follows a worldwide search for a successor to Dr Malcolm McIntosh who died in February.

Since 1995, Dr Garrett has served as President and Chief Executive Officer of the CSIR, South Africa's largest science and technology body whose activities span a similarly wide range of research areas to those of CSIRO. The two science agencies frequently work together, and Dr Garrett is familiar with the Australian counterpart from previous visits and professional contacts.

Geoff Garrett

Dr Garrett was educated at Cambridge University, UK, where he took a doctorate in metallurgy and was a University Boxing Blue. He has worked at universities in Canada and the USA and was a visiting Professor at Sheffield University and a Visiting Fellow of St Catherine's College, Oxford.

In 1998 Dr Garrett received South Africa's popular 'Boss of the Year' Award. In 1999 he was named 'Engineer of the Year' by the SA Society of Professional Engineers.

"I'm really looking forward to the opportunities and challenges of working for CSIRO - it's an organisation with an international name for scientific excellence", Dr Garrett said. "Both CSIRO and CSIR face similar challenges - the internationalisation of science and technology, the commercialisation of intellectual property, working effectively in partnerships and alliances, how to play a stronger role in innovation, and the need to generate fresh investment in S&T.

"CSIRO has a very strong scientific base and, to me, that is pivotal, absolutely critical. Excellence and brilliance in research are what differentiate a top science organisation from the others."

Has anyone told him about the Government's IT Outsourcing plans?

Spotlight on ASEG Education Committee

The ASEG Federal Executive has recently re-established its Education Committee to give greater attention to this important area of the society's activities. The new Committee is chaired by Professor Stewart Greenhalgh from Adelaide University. The other members of the committee, who provide both an academic and industry perspective, include Derecke Palmer (University of NSW), Steve Hearne (Velseis Pty Ltd and University of QLD), Mike Asten (Flagstaff Consulting and Monash University) and Mike Dentith (University of WA).

The primary **goals** of the Committee are to :

- promote the geophysics profession within the wider community;
- increase awareness among high school students of geophysics as a branch of physics and as a viable career path, so as to raise the quantity and quality of students entering university courses in geoscience;
- improve the education program at tertiary level by assisting universities where possible with equipment loans, demonstrations, field trips, provision of teaching data, guest lecturers, career information etc;
- advise and help organise continue education programs for professional geophysicists, so as to update their knowledge and skills.

We seek the assistance of ASEG members in achieving these goals. Some of the **proposed activities**, which the Committee has in mind, include the following:

- ASEG to organise an annual geophysics field camp, along the lines of SAGE in the U.S.A. (run by Los Alamos National Labs), for university students studying geophysics.
- Promote greater involvement of students at ASEG conferences, such as through student paper competitions.
- Get more SEG Student Chapters established at Australian universities. This gives students access to free books, scholarships etc.
- Improve the ASEG Web site, especially education and careers aspects, with links to SEG.
- Arrange a special Student Dinner at the ASEG Conference, at which industry and university people mix with the students (SEG does this each year).
- Offer ASEG undergraduate scholarships (say 2000/year) to lure bright high school students into geophysics courses (akin to AusIMM scholarships).
- Set up a special mentoring program for university students, whereby geophysics students are assigned a mentor at local branch level, and are encouraged to attend meetings and ask questions/seek advice (via email as well).

Stewart Greenhalgh

- Make greater use of SEG K-12 slide sets so that members can make presentations to primary and secondary school students about exploration geophysics on careers nights.
- Create a register of members willing to give guest lectures/demonstrations at university.
- Help organise vacation work experience for geophysics students.
- Put together a continuing education program for members, taking advantage of visiting lecturers like SEG Distinguished Lecturer, AAPG Distinguished Lecturer, Esso Distinguished Lecturer. Identify the current needs and seek to get the right people to offer short professional courses just prior to conferences or at other times.

If you can help with any of these tasks, or if you have other ideas for the Education Committee, then please contact: Stewart Greenhalgh (Ph: 08 83034960, email: stewart.greenhalgh@adelaide.edu.au or one of the other members. We are anxious to hear from you.

New Members

We would like to welcome the following new member to the ASEG. His membership was approved at the October 2000 Federal Executive meeting.

NAME	AFFILIATION	STATE
Ivan Philip Anglese Crabb	University of Adelaide	SA

Missing Members

Any member who knows the current contacts of the following members please contact the Secretariat on Tel: (07) 3855 8144 or Email: secretary@aseg.org.au

NAME	LAST KNOWN ADDRESS
Ing Huong Tuong	Malaysia
Densley Matthias	South Australia

ASEG 2001... The Odyssey Continues

The organisation for the ASEG's 15th Conference and Exhibition is well in hand. By the time members see this issue of Preview they will have submitted their expressions of interest and will be busy writing their extended abstract. Authors are reminded that the deadline for extended abstracts is the 26th of January 2001.

The Conference Organising Committee (COC) will be able to confirm the conference program shortly after submissions of the extended abstracts have been received. The registration brochure, which will detail the full program including keynote speakers, will be available in early March.

Co-hosts SEG, EAGE and SEGJ have confirmed their formal involvement with the Conference. We hope that their commitments will not be limited just to this event but to future conferences, which will continue to grow in stature.

Sponsors come on board

The COC is pleased to announce the full list of sponsors as confirmed by November 15th 2000. Opportunities for sponsorship are still available and those interested should contact aseg2001@aseg.org.au.

Gold Sponsors
Woodside Energy
Fugro Airborne Surveys

Silver Sponsors
MIM Exploration
Veritas DGN
BHP Petroleum

Bronze Sponsors
Origin Energy
Quantec Geoscience
Velseis Processing
Northern Territory Geological Survey
Anglo American Exploration

Trade Exhibition Invitation

Invitations to participate at the Trade Exhibition have been sent out to past exhibitors and others identified by the COC as potential exhibitors. Standard 3x3m booths are available for $2950 inc. GST. A 50% deposit is required at booking with full payment due by 30th May 2001. The Invitation brochure contains full details on the venue, times, booth information and other details.

Newcomers to Brisbane will be impressed with the city and the facilities at the Convention Centre. Those who are interested in exhibiting and have not received an invitation should contact the conference office at the address below.

Workshop Courses

There will be up to eight excellent workshop courses. Two have been confirmed to date: *Petroleum Geomechanics* by Richard Hillis (1-day) and *AVO and Inversion* by Brian Russell (2-days). Other courses under negotiation include *Borehole Logging for Minerals, Potential Field Methods, Airborne EM, Geostatistics, and Inversion for Minerals Exploration*. Course outlines and dates will be posted on the ASEG website www.aseg.org.au as soon as they become available.

Career Management Session

A special session for career management for geophysicists and explorationists will be organised at the Conference. This session will get together policy makers, potential employers, personnel agents, job seekers and those concerned with their careers. Topics planned include *Prospects for Employment, What Attributes Employers Seek, How to Open Your Consultancy Successfully, Plan Your Finance* and other tips for job search. There will be an opportunity to register yourself with personnel agents. Details will be posted on the website.

The Website

Remember that many details about the conference, including all-important dates are available at the ASEG website www.aseg.org.au. For those of you who haven't visited the website recently you should!

ASEG 15th Geophysical Conference & Exhibition
Brisbane Queensland
5th - 8th August 2001
Tel 61 7 3858 5579   Fax 61 7 3858 5510
Email aseg2001@aseg.org.au
www.aseg.org.au

Salinity Land Management and New Technologies Conference

18th-21st February 2001 - Bendigo Victoria

Greg Street
Conference Chairman
SKM PO Box H615
Perth WA 6001
Tel: (08) 9268 9672
Web: http://www.aseg.org.au/vic/bendigo-conference

David Heislers
Conference Secretary
CLPR Box 3100
Bendigo Victoria 3554
Tel: (03) 5430 4319
Email: david.heislers@nre.vic.gov.au

Land and catchment management in Australia, particularly in areas prone to salinity is a highly complex problem. New types of data, interpretation techniques and advances in GIS capability for integration of spatial datasets can assist in better understanding the problem. Geophysical techniques combined with better digital terrain models in particular are emerging as powerful new tools which can provide an understanding of catchments and how water moves through them.

The major challenge for land management is to incorporate the new generations of data into the decision making process when designing remedial actions at both catchment and farm scale. The conference will develop links between providers of emerging technologies and land management professionals.

The Conference aims to demystify emerging technologies to catchment and land managers, and convey to the technologists and researchers what the land managers actually require.

The Conference will be a mixture of technical presentations, which will be educational to a broad layman audience rather than specialist papers, plus workshop sessions. New technology applications will be presented to land management professionals and leading farmer groups as well as current thinking in remediation of saline landscapes. The workshops will tackle the issue of how these new technologies may be applied.

The Conference is to be held in Bendigo, Victoria, in the foothills of the Loddon River catchment leading into the Murray-Darling Basin. Dryland salinity is a well-documented in the Central Victorian Uplands, with irrigation salinity occurring only an hour to the north.

Program

Day One - The first day of the conference will be dominantly papers (20 minutes) describing the new technologies, with a balance of papers introducing the issues in land management. The final session on the first day will be a workshop where the synergy between new technologies and land management will be explored.

Day Two - The second day will start with a brief of workshop results followed by a series of short papers (5-10 minutes) from technology suppliers, balanced by short case histories in environmental management where these new technologies have or could have assisted. Workshop sessions will follow the short papers.

A site visit to an airborne geophysics test area and a salinity rehabilitation site will take place on the afternoon of second day.

Day Three - The third day will start with a review of workshop results followed by further workshop sessions and a plenary session review in the afternoon.

Eötvös: 100 Years On

By Roger Henderson

Email: sales@geoinstruments.com.au

The first torsion balance instrument for measuring gravity variations invented by Lorand Eötvös was given an award at the World Exhibition in Paris in 1900. It was first used in the field to make gradient measurements, observed by Eötvös himself, in 1891. The torsion balance was used in Germany in 1920 and was attributed with the discovery of the Nash Dome oil field in the United States in 1924. It is said that sixty-four oil fields were subsequently discovered in the period 1924 to 1929 using this torsion balance instrument.

During a recent short holiday in Eastern Europe I managed to escape from the usual round of sight seeing to visit the well-organised museum displaying Eotvos's instruments and aspects of his life. This museum is located in the headquarters building of the Eötvös Lorand Geophysical Institute (ELGI) in Budapest. In addition to the many instruments on display there are photos showing the use of the instruments in exotic places such as India where the instruments were transported on the backs of elephants and in China where a Hungarian geophysical expedition discovered the first oil field there.

An interesting coincidence occurred when I was being shown around the exhibits. I remembered that a Chinese friend of mine who used to interpret for me in China had told me that he learnt Hungarian from a geophysical team in China in the 1960's. When I mentioned this to my guide at the Eötvös Museum he revealed that he was in fact the leader of that expedition and that he knew my Chinese friend very well. He also went on to say that whilst he could speak several foreign languages, he learnt English for the first time from my friend in China.

The contents of the museum can be viewed without having to travel to Budapest via an excellent website of a virtual museum whereupon you can visit each of the five rooms and even sign the visitors book. The address is www.elgi.hu/cgi-bin/cnt_eng.

Lorand Eötvös was quite a distinguished person in Hungary and very instrumental in promoting science there. In 1885 he helped form the Mathematical and Physical Society of which he was President in 1891. He has given his name to the unit of gravity gradient and the effect related to the phenomenon that the weight of a body will change depending on the direction of its motion on the Earth. The Eötvös Effect is of particular importance now (100 years on) with the advent of airborne gravity gradiometry. As he was a keen mountain climber in his early days there is a peak named after him in the Dolomites in Italy, as well as is the Physical Society of Hungary, a University in Budapest and ELGI.

In 1890 he worked out a method for measuring the fundamental gravitational constant and also used his sensitive torsion balance to examine the proportionality of the inertial and gravitational mass, a central tenet of Einstein's then recent (1916) theory of general relativity. In 1915 Eotvos constructed a special instrument to demonstrate the Eötvös effect which is yet another proof of the Earth's rotation and has even greater significance than Foucault's Pendulum for this purpose.

Aside from designing torsion balance instruments to measure gravity gradients, Eötvös also designed an instrument analogous to the torsion balance to measure the Earth's magnetic field, called a magnetic translatometer. He used this instrument, not only to measure the magnetic moment of rocks but also because of its sensitivity, to measure the permanent magnetisation of ancient clay bricks and. In 1900 he gave a lecture on his studies on this subject entitled "Magnetic Inclination In The Past".

It was also interesting to learn that as a student at Heidelberg University in 1867 his teachers were Kirchhoff, Bunsen and Helmholtz (what a list of physical terms!).

ASEG (Victoria) and Monash Bring First SEG Webcast Workshop to Oz

By Michael Asten

Email: masten@mail.earth.monash.edu.au

A Webcast Workshop on the Practical Applications of Wavelets in Potential Fields, held in Houston last October 27, is believed to be a first for the ASEG-SEG relationship. The Colorado School of Mines arranged the workshop, with support from Shell Oil and the SEG. By means of broadcasting live on the web to twelve sites in North America, Europe and Australia, the workshop was able to include attendees from around the globe. For the local site, the Victoria Branch of ASEG sponsored the webcast fees, with the SEG sponsorship covering enrolment fees for students and full-time faculty members. The local site used a high-speed net link out of Monash University.

Unfortunately the interactive nature of webcast workshops comes at a personal price; the 8 a.m. - 5 p.m time slot in Houston became Midnight-9 a.m. on Saturday morning in Melbourne. Three hardy souls enrolled, with two lasting the distance.

The quality of the webcast was adequate, but not spectacular; sound is compressed in frequency for web transmission, to become reminiscent of that from Edison phonographs. Powerpoint slides in some presentations take up to 15 s to form on the local screen (it helps if authors avoid use of 24 bit color BMP images!). However, just as the phonograph has progressed over 100 years, we can be sure that webcasting will improve dramatically (and probably in a time span of only one to 10 years).

Continued on page 18

Rio Tinto Finally Captures Ashton Mining

In the October Preview we reported that De Beers had increased its bid to take over Ashton Mining by offering $2.28 a-share cash. This was higher than Rio Tinto's initial bid of $1.85 a share made in August this year. At the time it looked as though the De Beers bid would be successful. However Rio were not about to be beaten.

It increased its offer to $2.20 cash per share, or one Rio Tinto Limited or Rio Tinto Plc share for every 14 Ashton shares, or a combination of these. Although this is lower than the De Beers bid, Rio Tinto had already received acceptances from Ashton's largest shareholder, Malaysia Mining Corporation, in respect of its entire 49.72% shareholding. Consequently Rio Tinto had received acceptances for 51.89% of Ashton shares by mid-November and now has control of Ashton Mining.

De Beers has announced its intention to withdraw its takeover bid in order to 'provide Ashton shareholders and the Ashton Board with clarity on the status of De Beers' offer, and adequate opportunity to effect their investment decisions'. Those shareholders who have accepted De Beers' bid will be required to withdraw their acceptance before they can accept Rio Tinto's offer. It looks as though they will lose 8c per share.

There were also changes to the Board of Ashton Mining. Ashton Chief Executive, Douglas Bailey and Chairman, Justin Gardener, tendered their resignations from the Board, as did four Directors from Malaysian Mining. At the same time Gordon Gilchrist, Brendan Hammond, Terry Appleby and Mike Mitchell have been appointed to the Board, and Doug Ritchie has been appointed interim Chief Executive Officer and will be appointed Chairman.

Douglas Ritchie, Chairman Designate and Chief Executive is aged 44, and has been Managing Director of Dampier Salt since 1997. He joined the Rio Tinto Group in 1986 and has held senior management positions in Exploration, and Aluminium. Ian Falconer, Company Secretary of Rio Tinto Limited, has been appointed co-company secretary of Ashton Mining Limited.

Battle Now for Diamonds in Canada

With the battle for Ashton Mining won by Rio Tinto, the diamond focus is now on the Ekati mine in Canada. BHP has a 51% stake in the mine but the Canadian Company Dia Met, which owns a 25% share in the mine, has advised that it wants to sell its holdings.

With De Beers missing out on Ashton Mining, it might be interested in bidding for a share in Canadian Diamonds.

National Action on Salinity and Water Quality

The Prime Minister has announced that the Federal Government will commit $700 million to the first comprehensive national strategy to address salinity and water quality problems. The States and Territories, because of their constitutional responsibilities for land management, are being asked for a matching dollar for dollar commitment.

This proposal is important for ASEG members because the 'Action Plan' specifically identifies '*ultrasound*' salinity mapping and related technologies in priority catchments/ regions. It calls for a nationally coordinated effort to identify salinity deposits and flows as a basis for focused catchment/region management action using 'ultrasound' salinity mapping. However, when the report says 'ultrasound' it really means airborne EM – just a problem with terminology.

As we all know, Australia has critical salinity and water quality problems:

- At least 2.5 million hectares (5% of cultivated land) is currently affected by dryland salinity - this could rise to 12 million hectares (22%) at the current rate of increase.
- One third of Australian rivers are in extremely poor condition - within 20 years Adelaide's drinking water will fail World Health Organisation salinity standards in twodays out of five.
- Land and water degradation, excluding weeds and pests, is estimated to cost up to $3.5 billion per year. (In addition dryland salinity has adversely affected biodiversity, eg. CSIRO estimates a resultant reduction in bird species of 50% in agricultural areas).
- Infrastructure (buildings, roads, etc) is being severely damaged by salt in many rural urban centres.'

The goal of the government's Action Plan is to 'motivate and enable regional communities to use coordinated and targeted action to:

- prevent, stabilise and reverse trends in dryland salinity affecting the sustainability of production, the conservation of biological diversity and the viability of our infrastructure, and
- improve water quality and secure reliable allocations for human uses, industry and the environment.'

It is envisaged that action will be taken in 20 highly affected catchments and regions, spread right across Australia. These include:

Burdekin-Fitzroy (Qld); Lockyer-Burnett-Mary (Qld); Balonne-Maranoa (Qld-NSW); Border Rivers (Qld-NSW); Namoi-Gwydir (NSW); Macquarie-Castlereagh (NSW); Lachlan-Murrumbidgee (NSW); Murray (NSW); Goulburn-Broken (Vic); Avoca-Loddon-Campaspe (Vic); Glenelg-Corangamite (Vic); Midlands (Tas); Lower Murray (SA-Vic); Mt Lofty-Northern Agricultural Districts (SA); South East (SA); Avon (WA); South Coast (WA); Northern Agricultural Region (WA); South West (WA); and Ord (WA-NT).

However there are other more serious concerns.

The first is that 'The centrepiece of the plan is community-driven action supported by block funding to regional communities'. This is all well and good but how do you solve the problems of the Murray Darling Basin and the Great Artesian Basin by action plans developed and implemented at the community scale?

How are governments going to convince farmers in the head waters of a catchment, where there are no salinity problems, that they should not be growing this or that crop or clearing trees?

The second is that the Action Plan contains no specific 'actions'. As it presently stands the plan identifies goals and issues but there are no specific actions on how to get to the goals or address the issues.

It is surprising that, when there are national research institution like CSIRO, a Commonwealth Government Department focussed on Land and Water issues, and various Universities, State Agriculture Departments and at least one CRC, enough research has not been done already to identify some of the key actions required.

The third is that the money will probably not flow into actions, for another year. Unfortunately the process is complex, and time consuming.

Firstly, the Commonwealth has to get detailed agreements in place with the States, secondly a Ministerial Council will be established to oversee the Program, then there will be a call for proposals, primarily from local community groups, so that the funding can flow. How community groups are going to develop integrated catchment/regional plans, is not at all clear.

However, the solutions to these problems are not easy. There are issues of property rights, land clearing and appropriate compensation, but let us hope that the plan will have a national scope, and that the actions will start soon because time really is running out.

Continued from page 16

The workshop content included strong Australian representation, with Tom Ridsdill-Smith presenting a tutorial paper on wavelet transforms, and an applications paper on wavelet processing of aeromagnetic data (http://wavelet.freeservers.com/#Publications), and Fabio Boschetti contributing a paper on wavelet edge-based filtering.

(http://www.agcrc.csiro.au/publications/?project=3054%2A&start=1&count=all).

Strong coffee at 4 a.m. isn't as much fun as icebreaker cocktails at an international conference, but at about $3000 per person cost saving, it will continue to have its place.

IT Outsourcing in Difficulties

IT outsourcing in the Commonwealth government has been fraught with difficulties since it was introduced during the first Howard Government. Apparently only the Departments of Finance & Administration and Prime Minister & Cabinet supported its implementation, but it went ahead anyway.

In the 1997-98 Budget, the Government announced the Whole-of-Government Information Technology Infrastructure Consolidation and Outsourcing Initiative. The measure was directed at achieving 'long-term improvements in the structuring and sourcing of information technology (IT) services across agencies to facilitate greater integration in the delivery of programs and realise significant cost savings.'

In 1997, the Government estimated that the IT Initiative would result in savings of approximately $1 billion over seven years. In anticipation of these savings being realised, reductions were made to the forward estimates of Budget-funded agencies. The reductions totalled $37.9 M in 1998-99, $87 M in 1999-00, and on-going annual reductions in agency budgets of $99.2 M from 2000-01.

Unfortunately, it didn't quite work out this way. A recent report on the four tenders in place earlier this year, by the Australian National Audit Office on the implementation of the IT outsourcing initiative reported serious shortcomings.

The ANAO found, among other things that:

- The implementation of the Initiative is now expected to be completed in 2001, some two years after the initial date (at present six tenders have been let and four are in the pipeline); and to cost nearly three times as much as was originally budgeted.
- Payments to the Strategic Adviser to the IT Initiative accounted for over 60 % of the total expenditure on advisers to May 2000. For the period June 1996 to June 1998, this amounted to $7.18 million for assignments that *were not competitively tendered.*
- The initial contract management effort required has exceeded the plans of many agencies.
- Within the multi-agency groups, the transaction costs incurred by smaller agencies were considerable in comparison to the larger agencies, and in fact the smaller agencies usually got a poor deal out of the process.

Needless to say this report caused some angst. It is interesting to note that when it was circulated for comment to other government institutions, only the Department of Employment, Workplace Relations and Small Business and the Department of Defence commented individually, and in support of the Audit Office's findings. The Department of Finance and Administration provided a formal 'whole-of-government' response to the report on behalf of the other 11 agencies being reviewed and came up with a somewhat different viewpoint. So will never know the opinions of these individual agencies.

Anyway following the audit, the Minister for Finance and Administration, John Fahey announced an independent review in relation to aspects of the IT Outsourcing Initiative. The specific focus of the review is to identify and assess the implementation risks to be managed when transitioning from in-house IT operations to an outsourced environment managed by an external service provider.
In particular the reviewer should:

- report on the implementation of the initiative to date;
- identify the sources of implementation risk;
- identify how implementation risks are addressed and managed in the context of initiative tender processes; and
- raise any other issues related to the scope of this inquiry.

The review is to be conducted by Mr Richard Humphry, Managing Director of Australian Stock Exchange Limited. Mr Humphry will report before Christmas to a Steering Committee comprised of the Secretary of the Department of Prime Minister and Cabinet, Max Moore-Wilton; the Secretary of the Department of Finance and Administration, Peter Boxall; and the Chief Executive Officer of the Office of Asset Sales and IT Outsourcing (OASITO), Ross Smith. The Steering Committee will in turn provide advice on any recommendations to the Minister for Finance and Administration.

However, for those institutions not yet outsourced who think they may escape the process, the news is not good. Mr Fahey clearly spells out that 'the Government remains committed to the completion of the initiative'. Although tenders for those groups not currently in the market place (Group 9, Group 10 and the Department of Defence) will not proceed to requests for tender until the review has been completed and the Government has considered its findings, the preparatory work on these groups will continue.

This review is important to our members because Group 9 comprises the main science and technology arms of government:

Australian Geological Survey Organisation ~430 staff,
Australian Institute of Marine Science ~200 staff,
Australian Nuclear Science and Technology Organisation ~815 staff,
CSIRO ~6640 staff,
Bureau of Meteorology ~1425 staff, and,
Australian Antarctic Division ~300 staff.

The service requirements for Group 9 will include the provision, support and maintenance of approximately 10 000 desktops and substantial mid range equipment and systems. Request for tender will be released in November 2000.

How one tenderer will be able to manage such a geographically diverse and multi-functional scientific institutions is not obvious, but the government seems determined to proceed. Ideology gone mad?

Eristicus, November 2000

Written by:

Natasha Hendrick

In this edition of Preview I share with you some of the geophysical websites ASEG members have brought to my attention throughout the year in response to the Web Waves column. Thanks to those of you who have contributed!

ASEG 15th Geophysical Conference and Exhibition
www.aseg.org.au/conference/Brisbane/2001.htm

I can't let the year go by without highlighting the website for our upcoming ASEG conference. You can register on-line to receive further information about sponsoring, exhibiting or attending the conference. And it's not too late to submit a technical presentation. Extended abstracts are due 26th January, 2001. Abstract submission kits can be downloaded from the conference website.

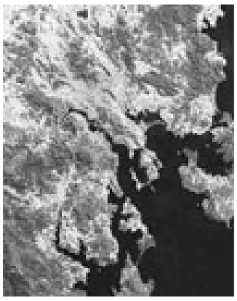
AIG - Australian Institute of Geoscientists
www.aig.asn.au

AIG is a non-profit organisation aimed at advancing skills, status and public perception of geo-scientists throughout Australia. From this site you can find out details about AIG publications (and download an order form); check the calendar for AIG events around Australia; promote employment vacancies free of charge; download AIG fact sheets highlighting issues of importance to geoscientists in Australia; and keep up to date with the latest happenings in the industry via the Geoscience and World Mining News pages. Well worth a visit.

AUSLIG - Australian Land Information Group
www.auslig.gov.au

This site promotes information and products of Australia's National Mapping Agency. Great for viewing digital maps of Australia and searching for place names. Standard map sheet areas and boundaries can be viewed, and all the information necessary for working with the new Geocentric Datum of Australia (GDA) is available on-line, or via a downloadable technical manual. Visitors can also compute their own sunset and sunrise times, and test their skills with the Fab Facts interactive quiz.

Can anyone guess which capital city in Australia this satellite image was taken over? (Email me to find out the answer.)



IPS Radio and Space Services
www.ips.gov.au

IPS is a unit of the Department of Industry Science and Resources. From this site visitors can view the latest solar images and magnetograms. IPS also maintain a magnetic storm warning service - useful when performing magnetic surveys - and information is available either on-line or via email to registered users.

CWP/SU: Seismic Un*x
www.cwp.mines.edu/cwpcodes/index.html

A popular seismic processing package, Seismic Un*x (SU) has been developed at the Center for Wave Phenomena (CWP), Colorado School of Mines. The software (including full source code) is available for free download from the website. SU requires a computer running some form of Unix operating system (e.g. HP, Linux, FreeBSD, Sun, Apollo etc). However a Windows 95 and NT version of SU (not supported by CWP) is available through www.wgeosoft.ch. On-line Users Manual and other SU related web-resources are also available from the CWP site.

Internet Mathematics Library
forum.swarthmore.edu/library/

An extremely useful site if you haven't got your old maths textbooks on hand when reading geophysical papers or coding up new algorithms. And for those of you who are mathematically challenged, maths topics are available at K-12, College or Advanced levels.

Another extremely valuable web-based mathematical resource is Eric Weisstein's MathWorld (mathworld.wolfram.com/index.html) - although regrettably it is currently unavailable due to a copyright dispute.

OSRS - Open Source Remote Sensing
www.remotesensing.org

This site is dedicated to making remote sensing algorithms, code and technology freely available to all interested parties. Software is available for Unix, Windows and Macintosh machines. Although still quite a young Internet community, OSRS has a number of packages available for download. There is also a useful Related Links page pointing visitors to sites for additional free software, reference material, educational and other useful resources, including a number of on-line remote sensing tutorials for those unfamiliar with the technology.

If you have any favourite sites (not necessarily geophysical) that you would like to share with our members please email me, Natasha (natasha@geoph.uq.edu.au). An ASEG Favourites list will be published in the next edition of Preview.

Application of Geophysical Well Logs in Geotechnical Evaluation of Subsurface Deposits and Geoengineering

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Deutsche Steinkohle AG, Germany

This is the first of a three-part article on borehole geophysics. Part 2 is a case history of a geotechnical evaluation in a deep coal mine, and Part 3 a case history of geophysical well logging for underground tunnelling in carbonate rocks. These contributions will be published in subsequent editions of Preview.

Introduction

Lithological, structural and rock mechanical information can be derived from geophysical well logs. Over the last years log interpretation techniques have been developed to achieve an objective and reliable interpretation of well logs.

There is also an increasing demand for geotechnical engineering with respect to the careful exploitation of material and energy resources, the protection against natural disasters, and the development of complex, integrated supply, transport and communication systems. It is important to consider the relationship between ground conditions and construction design for the planning, realisation, and long-term preservation of any construction. The engineering of tunnels, caverns, slopes, walls, dams and foundations is based on soil and rock mechanics, which describe the behaviour of soil and rock masses based on the measurement of physical parameters e.g. elastic parameter, shear strength, density, and permeability, combined with structure information like dip and dip direction of bedding planes, fractures and faults. It should be the aim to get a good knowledge of the properties of the subsurface during the early design phase of a construction project and to take advantage of all available information in the planning phases. This saves time and costs for support measurements during excavation. Furthermore, costs can be reduced by minimising unexpected problems during the construction phase.

Borehole geophysics provides valuable information to solve many problems encountered in geotechnical investigation of the underground (Schepers, 1996, Schepers & Toumani, 1997). The borehole measurements of density and velocity of compression and shear waves are used to calculate the elastic parameter of formations. Different lithological units with different petrophysical properties can be reliably determined by the combined evaluation of their log responses. Mechanical and hydraulical properties can then be estimated based on field experience and laboratory measurements. Acoustic imaging of the borehole wall provides exact mapping of fractures, joints and strata as well as a high-resolution borehole calliper image (Schepers, 1991). Acoustic Borehole images serve also to orient cores by matching their structural features (Schepers et al., 1999). Acoustic reflectivity of different formations can be determined from acoustic images. It provides a measure of acoustic hardness of rock or soil. Usually the constrained vertical resolution of conventional logging tools does not allow reliable estimates of thickness and log responses of thin layers. The lithology of thin layers can be better defined, when their thickness is determined from acoustic images. The knowledge of mechanical behaviour such as thin layers can be very important for sliding surface and slope stability analysis.

For detailed modelling of the mechanical behaviour of rock and soil, the previously mentioned parameters are required. Bore-hole geophysics has the advantage of providing formation parameters continuously and *in-situ*.

It is the aim of this paper to demonstrate the benefits gained by geophysical borehole logging in boreholes drilled for geotechnical site exploration. The paper contains three parts. The first section deals with interpretation techniques, the second includes a case history for geotechnical evaluation in deep coal mining to demonstrate the methods of obtaining geotechnical information from borehole geophysical data. The third and last part deals with another example for geotechnical evaluation of carbonate rocks from well logs in underground tunnelling.

Part 1 - Interpretation Techniques

1.1 Lithology determination from well logs

1.1.a Lithological zonation: Lithofacies zonation from well logs is based on the set of log responses which characterise a formation and permits it to be distinguished from other formations (Serra, 1986). In multi dimensional log space, the lithofacies are materialised as a cluster in this space, that is, an area of relatively high concen-tration of points, as the log responses are similar. Determination of lithology is then based on recognition of clusters residing in the data. In the classical log analysis, cross plots are used to visualise the clusters in 2- or 3-dimensional log space. The cross plot techniques are however limited to a small number of logs. An advanced fully automatic statistical clustering method, based on the theory of fuzzy logic, which is known as fuzzy c-means clustering, is utilised for lithology determination (Toumani et al., 1994). The objective function is the minimisation of the log data scatter within the clusters. The method allows gradual membership of the log data into the clusters. Therefore, the overlapping of clusters can be effectively handled and consequently the clusters are better quantified. The fuzzy hybrid classification combines the widely used methods of supervised/unsupervised classification and is well suited for multiple lithological well studies, where diagenetic changes in the lithologies are expected and have to be adequately treated (Toumani, 1997).

1.1.b Volumetric analysis: A volumetric analysis including minerals contents and porosity can be done using an iterative optimisation procedure (Mitchell & Nelson, 1988, Serra, 1986). The method minimises the difference between the measured and reconstructed theoretical log responses according to given minerals volumes. The volumes of rock components including porosity will be changed until a good correspondence between theoretical and measured logs has been achieved. A measure of the inconsistency between the measured and theoretical logs is provided. The

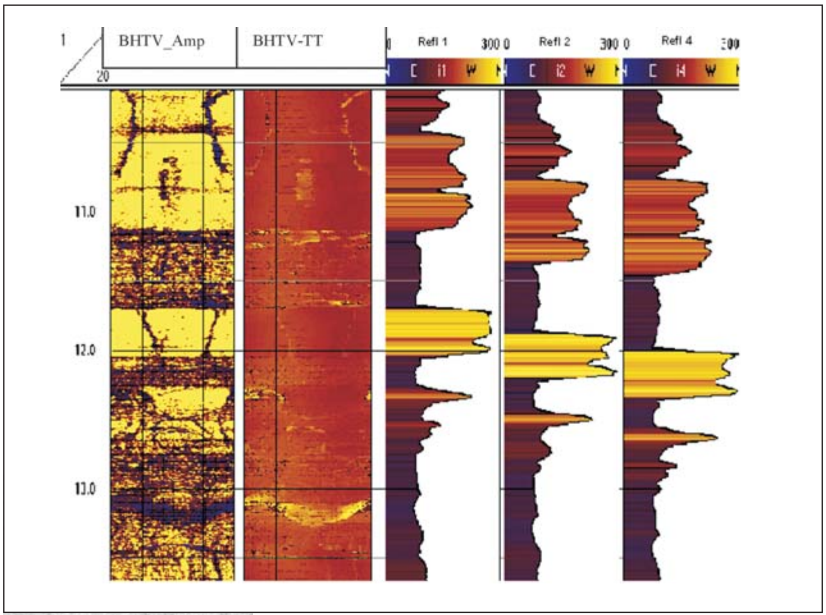


Fig. 1. Acoustic reflectivity logs.

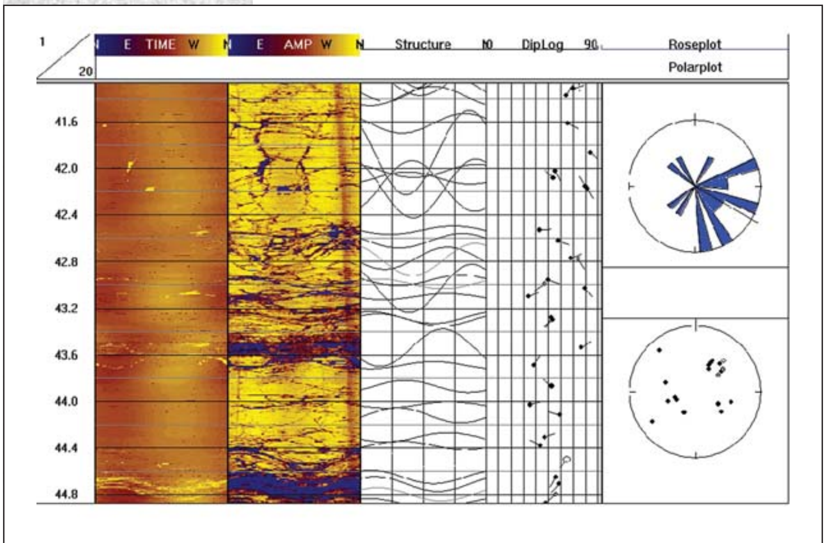


Fig. 2. Interpretation of amplitude image for structure analysis

computation will be made for a defined mineralogical model and the accuracy of calculated volumes of rock components depends on the model used. The inconsistency measure is helpful to recognise those depth intervals, where the model does not fit the rock composition or where the well logs are falsified by bad well conditions. Fuzzy classification can be usefully imbedded in volumetric analysis using multiple formation models (Quirein et al., 1986), as membership values into different models are provided in advance. Rock constituents can be then calculated for a combined formation model.

1.2 Elastic parameters from well logs

The stiffness modulus M provides a basis for comparing the strength of various formations. It is calculated from the velocity of P-wave V_p and formation density ρ_b (Serra, 1986, Schön, 1983):

$$M = \rho_b * V_p^2 \qquad (1)$$

If ρ_b is given in t/m^3 and V_p in km/s, then M will be calculated in GPa. The strength index has the following relationships between the dynamic elasticity modulus E, bulk modulus K and shear modulus μ:

$$M = K + 4/3\,\mu \qquad (2)$$

$$M = [E(1-\nu)] / [(1+\nu)(1-2\nu)] \qquad (3)$$

Where ν is the Poisson's ratio, which is related to V_p and V_s (S-wave velocity) as follows:

$$\nu = (V_p^2 - 2V_s^2) / [2(V_p^2 - V_s^2)] \qquad (4)$$

The bulk and shear modulus have the following relationships to V_p , V_s and ρ_b :

$$\mu = \rho_b * V_s^2 \qquad (5)$$

$$K = \rho_b (V_p^2 - 4/3\, V_s^2) \qquad (6)$$

The stiffness modulus should be interpreted as an indication for the maximum of the bed competence, as a competent appearing formation could be micro fractured in such a way, that it weakens the rock structure, but does not create an observable effect on the logs. On the other hand, formations appearing weak on the strength index could not considered stronger than the calculated value (Bond et al. in Hoffman et al. 1982). The value of M/E varies between 1.2 and 2.1 by increasing ν from 0.25 (elastic body) to 0.4. This means the values of M and E will diverge for weaker formationa and hence the interpretation of M as an upper limit of the formation strength is justified.

1.3 BHTV Acoustic Reflectivity

The derivation of acoustic reflectivity from acoustic borehole televiewer (BHTV) amplitude images usually employs the evaluated bedding dip and dip directions. Summed histograms of amplitude data along the bedding planes are calculated at each depth. An amplitude value corresponding to 85% of the summed histogram is determined for each depth in the examples used. This value represents the acoustic reflectivity at that depth across all azimuth directions along the bedding plane. This means a conversion of a 2D-Amplitude image into a 1D-reflectivity curve has been carried out. The reason for selecting high values of the histogram instead of using a statistical median or average calculation is justified by non-lithological effects, which influence the recorded amplitude; mainly breakouts. Low reflection amplitudes are caused not only by a variation of petrophysical parameters and structural discontinuities but also by borehole effects. High reflection amplitudes however can only be caused by high acoustic impedance of the formation and reduced distance between the tool and the borehole wall (i.e. tool decentralisation). As variation in tool decentralisation is slow and smooth compared to the variation in acoustic impedance of the formation, the main variation derived from acoustic reflectivity of the borehole wall is due to the true variation in acoustic impedance of the formations.

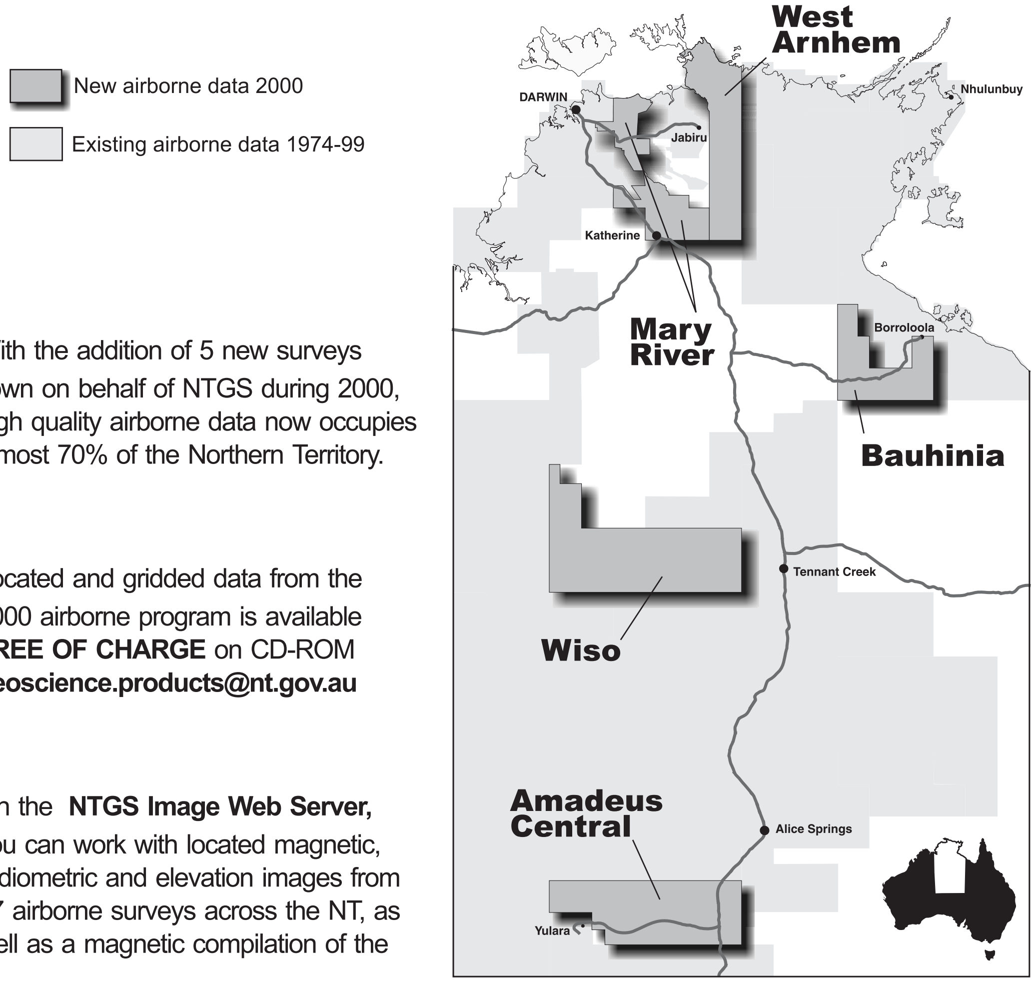
Figure 1 shows the calculated acoustic reflectivity logs of three different boreholes (1,2,4) drilled for a dam site investigation. The amplitude image of well 1 is shown on the left of Figure 1 together with the travel-time image.

NORTHERN TERRITORY GEOLOGICAL SURVEY

NEW AIRBORNE SURVEYS NOW AVAILABLE ON THE INTERNET

NTGS IMAGE WEB SERVER

www.dme.nt.gov.au/ntgs/geophysics/air_map/air_geo_map.html



- With the addition of 5 new surveys flown on behalf of NTGS during 2000, high quality airborne data now occupies almost 70% of the Northern Territory.
- Located and gridded data from the 2000 airborne program is available **FREE OF CHARGE** on CD-ROM **geoscience.products@nt.gov.au**
- On the **NTGS Image Web Server,** you can work with located magnetic, radiometric and elevation images from 47 airborne surveys across the NT, as well as a magnetic compilation of the

Make a diary entry for the NTGS Annual Geoscience Exploration Seminar (AGES) to be held in Alice Springs on 20-21 March 2001. Register on line today.

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Department of Mines & Energy Northern Territory

Northern Territory Government

Even in small details the three acoustic reflectivity logs correlate very well.

1.4 Fracture Evaluation

Quantification of fractures (dip, strike, spacing, frequency, aperture, hydraulic conductivity etc) is important for geotechnical studies, as it reveals the tectonic history and hydraulics of an investigated area. A fair characterisation of fractures often requires integration of several well logs. However, non-fractured rocks could induce fracture-like responses. Advanced borehole logging techniques such as electrical, acoustical and optical imaging are perfectly suited for fracture characterisation and can only be challenged by the investigation of core samples.

Different measures for fractures, such as fracture frequency, spacing and Rock Quality Designation (RQD) are established parameter in the rock quality classification. They are defined as followings:

Fracture frequency: is the number of fractures per unit length.

Fracture spacing: is the distance between fractures.

RQD: is the sum of lengths of rock pieces (intact lengths) greater than 10 cm expressed as a percentage of the total length of the scan line (normally 1 m). RQD includes the information about fracture frequency and spacing simultaneously.

The mechanical and physical properties of a fractured medium are influenced by the geometry of fractures, fracture length, aperture, spacing between the fractures, fracture density, type of infilling material (viscosity) and the aerial fraction of opposing fracture faces in contact. Sonic P- and S-wave velocities are influenced by the above mentioned fracture parameters. The *fracture score*, which includes the characteristics of each fracture beside fracture frequency, is introduced as a new fracture parameter. Fracture values are given to each fracture by assigning a value of 1 to a thin fracture and progressively increasing the score to 5 where fractures were wide and extensive, resulting in a substantially damaged borehole. The boundaries of weathered zones are defined in similar way according to the thickness of the weathered zones. *Fracture score* is then defined as the sum of fracture values divided by unit length (normally 1 m).

Many fracture properties can be measured or estimated by acoustic borehole televiewer measurements. The amplitude image log gives detailed structure information on bedding planes, fractures, faults, foliation etc. Figure 2 displays the amplitude and travel-time image logs from a borehole in metamorphic rock. The structure information extracted from the amplitude image log is plotted as a standard dip log. Statistical summaries of the interval are displayed as rose- and polar-plot.

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Borehole Seismic Review

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Introduction

Borehole seismic methods arose since surface seismic data first became used to interpret subsurface geology. Until then, most fields were discovered through surface geology mapping and lots of drilling. A great step forward for seismic methods came through common mid point (CMP) stacking which resulted in a continuous profile of the Earth; a seismic section. By their nature, seismic sections were always scaled in time, which was no use to the drillers. When told they needed to drill until 2 seconds, they figured that not very much hole would be made at all. Thus a time depth calibration was required to convert the time predictions into depth. Geophones were lowered into wells and transit times recorded between a surface initiated source and the downhole geophone. These check-shot or velocity surveys became the norm.

Survey Type	Applications
Checkshot	Time depth calibration.
	Synthetic seismogram.
Reverse checkshot	Drill bit used as source, similar applications.
Salt proximity	Defining the extent of salt domes.
	Can also be used to delimit other velocity anomalies.
Vertical well VSP	Seismic reflection trace to QC surface seismic.
	Transmission characterisation of seismic energy through the Earth. (Q estimation).
	Depth to target estimation.
	Acoustic impedance inversion. (Overpressure prediction).
	Lateral coverage in presence of dip.
	Zero offset multiple estimation.
Reverse VSP	Drill bit used as source, similar applications.
Vertical Incidence VSP	Lateral seismic reflection image beneath well bore. (Higher resolution).
	Fault identification.
	Locating well in 3D seismic volume by seismic character matching.
Offset VSP	Lateral seismic reflection image.
	Shear wave propagation characteristics. (9C surveys).
Walkaway VSP	Lateral seismic reflection image.
	Transmission characterization with offset.
	Anisotropy determination. (Evaluation of Thomsen's parameters).
	Sharper seismic imaging through invoking real earth transmission model, anisotropy and refined velocity model.
	Shear wave propagation characteristics.
	Shear wave imaging.
	Time lapse monitoring. (4D).
3D Walkaway VSP	All of above but in a 3D volume.
AVO walkaway	Independent measurement of target formation AVO character.
	Characterisation of seismic transmission to target formation.
Cross well seismic	High resolution image between wells.
	Identification of permeability barriers.
Micro seismic	Determine location of active fault planes.
	Determine water flood passages.

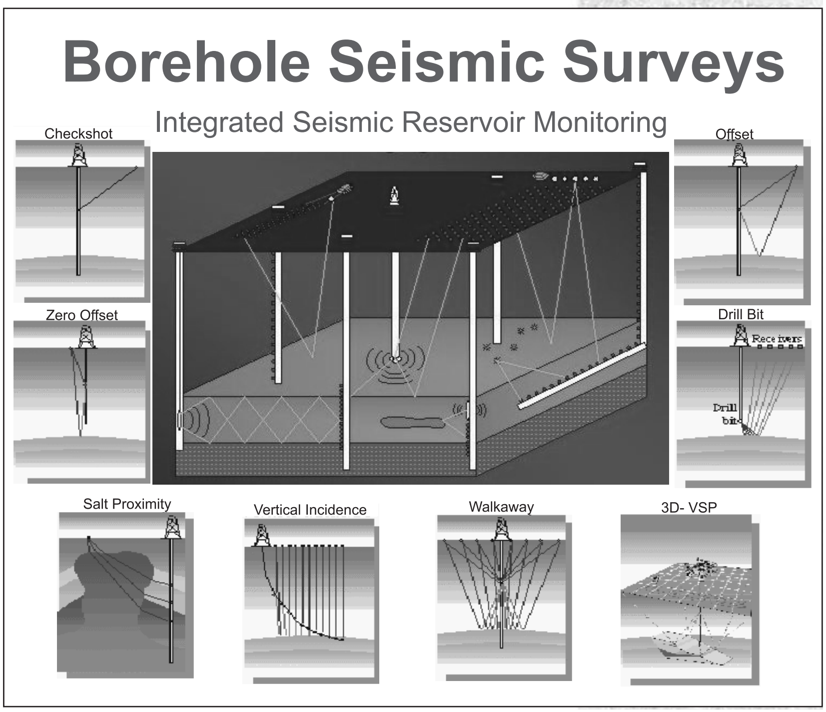
Table 1. List of current applications of borehole seismic methods.

In the 1950s, Russian geophysicists developed the technique of recording reflections of the surface source from geological interfaces below the down-hole geophones to produce a real seismic response at a well location. These methods eventually made it into the West and have been called Vertical Seismic Profiles or VSPs. VSPs have the advantage of providing an independent seismic trace to compare with the surface seismic record, rather than just a time depth relationship.

For many years, the term 'borehole seismic' referred to checkshot surveys and VSPs. As our ability to image the Earth through surface seismic has improved, borehole seismic methods have also improved to more finely calibrate the surface seismic data where wells exist.

The diversity of borehole seismic techniques and applications are listed in Table 1. Schematic illustrations of different acquisition geometries are displayed in Figure 1. This article covers some applications that have either been used in Australia or are likely to be used more frequently. It is not intended to cover every aspect of the borehole seismic business.

Fig. 1. Intergrated seismic reservoir monitoring.



Company	CGG	Schlumberger	Baker Atlas
Tool Name	SST-500	VSI	MLR-13
Max levels per string	12	20	13
Separation	10 m	Selectable, 15 m standard.	Selectable, can be large.
Components per geophone	3 standard, hydrophones possible.	3	3 standard, hydrophones possible.
Geophone type	Velocity	Accelerometer	Velocity
Clamping	Hydraulic	Hydraulic	Mechanical drive.
Borehole size	10-40 cm	9-56 cm	11–76 cm
Shakers fitted	No	Yes	No
Temperature	150°C	175°C	204°C
Pressure	140 MPa	140 MPa	140Mpa (200 MPa coming)
Sample rates	2 ms (12 shuttles)	0.5, 1.0, 2.0 and 4.0 ms	0.25 to 2 ms
A/D conversion	24 bit	24 bit	24 bit
System dynamic range	>110 dB		96 dB

Table 2. Specifications of contractors commercial state of the art tools.

Hardware Review

Technological advances of borehole seismic hardware have progressed in parallel with surface seismic hardware. The trend is towards more geophones in one string and more components, which means that more levels can be acquired in less time. It is mainly because of this that VSPs are replacing single level checkshot surveys as the standard borehole seismic service.

Table 2 summarizes the capabilities of the best 'standard' tools available (or soon to be available) from contractors operating in Australia. The SST-500 system from CGG is the most mature of the three new systems presented and currently (October, 2000) has been used in five surveys in Australia.

Examples

Correlation

The most widespread use of borehole seismic methods in Australia has been to assess the quality (that is, believability) of the surface seismic observations at well locations. The surface seismic trace along a well, the synthetic and the VSP results should all be consistent. If they aren't, then either the processing of the respective reflection images is poor or some geological effect occurs that manifests itself differently on each image (for example, out of plane dip or the different depths of investigation of the three methods). In any case, there are lessons to be learned and analyses should be persevered with until all discrepancies are understood. Over the past fifteen years, surface seismic methods and borehole seismic methods have improved to the extent that a good tie is the norm rather than the exception (this is opposite of the situation that existed in the mid 80s).

Processing of the VSP is the most robust of the three methods, so if a bad tie results, it is best to check the VSP first (because it's easy) and use it as the reference. The synthetic is the next thing to work on and normally suffers from spurious readings of the input logs (at borehole washouts or casing shoes) or poor checkshot corrections (logs and times not referenced to the same datum, well deviation corrections not properly applied, poor transit time picks). Synthetic generation packages that are part of surface seismic interpretation workstations have improved enough over the last few years to put these analyses in the hands of the interpreter and on a par with the dedicated borehole seismic contractor.

After the VSP and synthetic have been processed optimally, it is time to look at the surface seismic. In Australia the biggest problem is that most of the surface seismic is 2D, so out of plane effects often harm the tie. Another problem, particularly on the North West Shelf, is multiple contamination. Surface seismic gathers corresponding to the well location are very helpful in identifying problems.

Vertical Incidence VSP surveys (VI-VSP, also called 'walkabove' surveys) are extremely useful in the case of deviated wells. Ramsden et al. (1987) pointed this out for

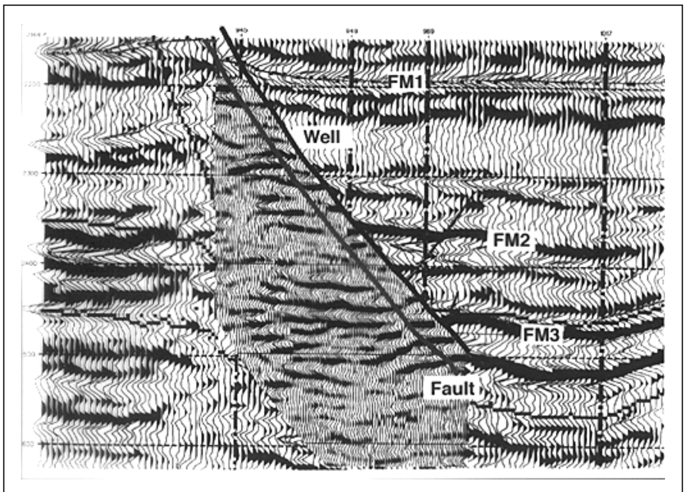


Fig. 2. Surface seismic showing locations of an old and new well.

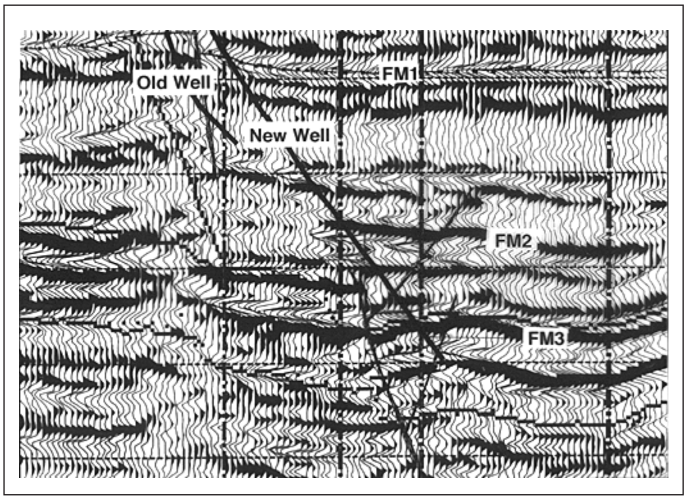


Fig. 3. Surface seismic with results of the VI-VSP spliced in.

the Harriet Oilfield. In the North Sea, these types of survey are more common than vertical well surveys and as Australian fields become more developed, it is expected that this trend will be followed here also.

Figure 2 shows a section of 3D seismic and the trajectory of an 'Old Well' that had to be abandoned because it penetrated a fault plane and lost circulation. A new well was started from a shallower kick-off point and its trajectory is also shown. Note that the fault is not visible on the seismic data.

A VI-VSP was carried out in order to find out what went wrong. The results are spliced into the seismic and displayed in Figure 3. The location of the fault is now obvious. This has significant impact for volumetric calculations and future drilling in the area. Also note the higher resolution of the VI-VSP image.

It is now also possible to obtain useful VSP images in horizontal wells (Smith et al. 1995, Randall et al. 1998).

Transmission Analyses

Something that has been underutilized is the transmission information available from VSP data. Seismic processing methods make assumptions about how a seismic pulse is battered around during its journey through the Earth; VSPs actually measure what happens to it. This information is particularly useful in the North West Shelf where the more interesting sediments are concealed beneath a sheath of Tertiary carbonates of greatly varying thickness and quality. Measuring the transmission effects of the Earth on the seismic energy enables more accurate compensation schemes to be devised for the surface seismic data. This, in turn, means that we don't have to mix the data up with automatic gain control and trace equalization processes that hide amplitude information which should really be interpreted.

Figure 4 displays the amplitude information recorded from Well-1 and Well-2 in the North West Shelf. The grey curve measures the first peak amplitude whereas the black curve measures the RMS amplitude in the first 60 ms from the first break. The Tertiary carbonates in Well-1 are fairly thin and were deposited in a quiet environment some distance from the continental shelf. The Tertiary carbonates at Well-2, on the other hand, were deposited in a channel sequence at the base of the shelf and are fairly heterogeneous in quality. The Tertiary section is also thicker (approximately 1340 m) at this location.

The amplitude decay in Well-1 varies smoothly and nicely fits the theoretical decay curve defined below with Q=100.

$$Decay_Q = \frac{Depth_{ref}}{Depth} e^{\frac{\pi f (T - T_{ref})}{Q}}$$

The amplitude decay in Well-2 is a lot different, on the other hand, exhibiting anomalous behaviour in the Tertiary channel sequence from 1400 m to 2500 m. Deeper than this, the decay follows a theoretical decay curve with Q = 40.

Obviously, the surface seismic amplitudes need to be handled differently in the two regions represented by these wells.

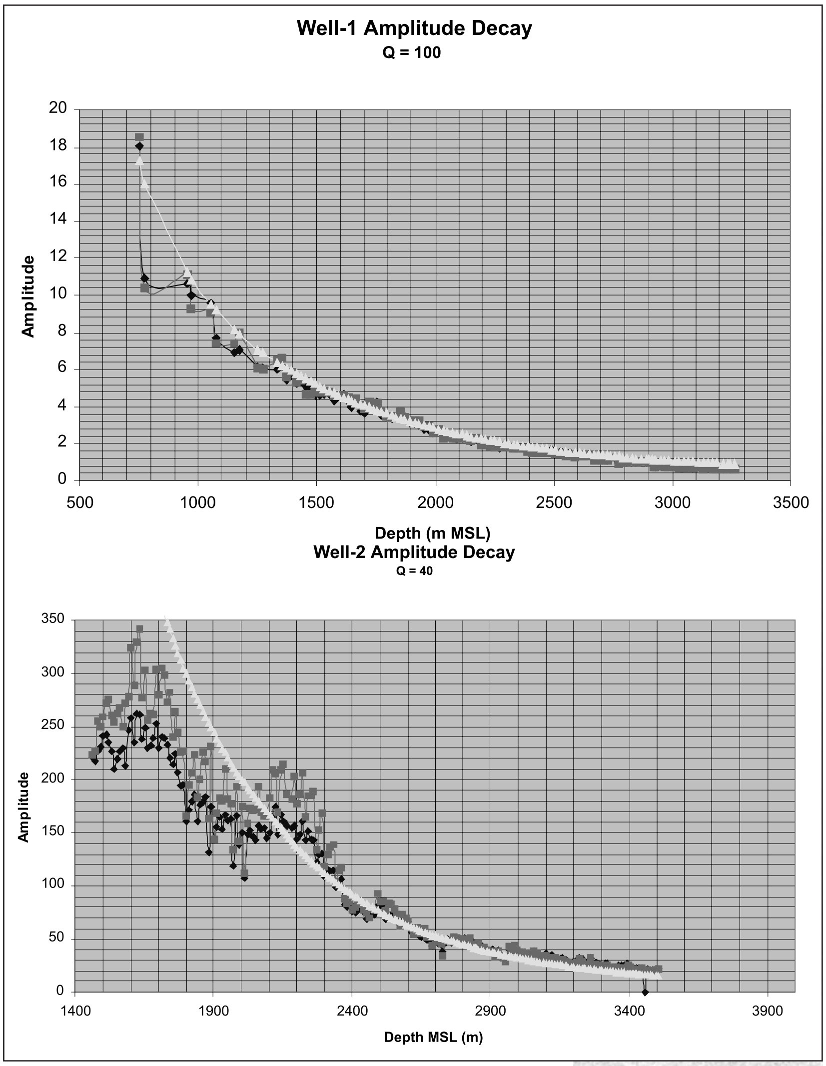


Fig. 4. Amplitude decay measured from VSP in Well-1 and Well-2 from the North West Shelf. White curve represents the theoretical decay with a Q value indicated. The grey curve measures the first peak amplitude and the black curve is a measure of the RMS amplitude in a 60 ms window of the first break.

Multiple content, particularly interbed multiples, can also be evaluated from the downgoing wavefield extracted from the VSP data. Post stack multiple removal strategies can be tested on the downgoing wavefield and applied to the surface seismic data.

Walkaway Applications

Transmission

Walkaway surveys, where the borehole geophone array is fixed whilst a source is moved ('walked away'), make measurements of transmission even more relevant to surface seismic. If the geophone array is locked at a target horizon, the one-way transmission characteristics down to that target can be measured through the range of offsets sampled by the surface seismic data.

Smith (1992) makes use of transit time information recorded in walkaways to resolve a near surface velocity anomaly over the Skua Field. The amplitude information can also be extremely useful.

Figure 5 displays two plots of the first arrival amplitude measured in a walkaway survey that was recorded in the same Well-2 mentioned above. As on the previous amplitude decay figures, the grey curve is a measure of the

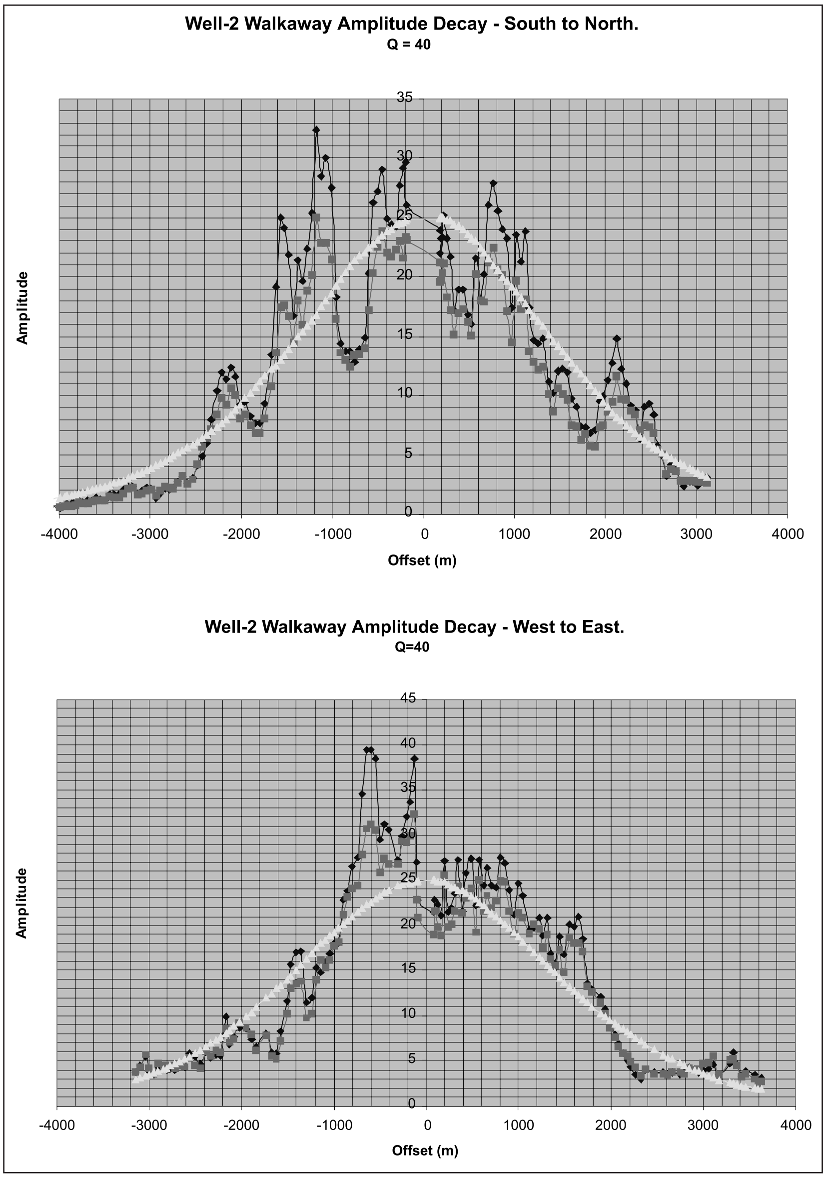


Fig. 5. Walkaway amplitude decay. The symbols are the same as those on Figure 4.

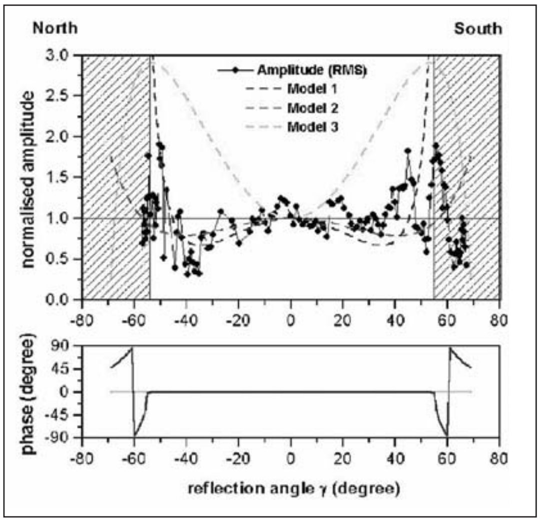


Fig. 6. Results of an AVO walkaway.

peak amplitude of the first arrival and the black curve measures the RMS amplitude in the first 60 ms from the first break. The white curve plots a theoretical decay curve calculated as above and using a Q value of 40 (consistent with the VSP). The two lines plotted were recorded perpendicular to each other.

The most startling observation to be made from these plots is the significant lateral amplitude variation. It seems that, in this area, a constant Q compensation is not going to work at all on the surface seismic data. In fact, the same sort of lateral amplitude variations can be found in raw surface seismic gathers taken from the area. Depending on whether the CDP location analyzed corresponds to an amplitude low or high, the AVO gradient can be a large positive or a large negative; very confusing for AVO analyses. In fact, any sort of amplitude attribute extracted from uncorrected surface seismic in this area will be extremely noisy.

AVO Calibration

Henderson et al. (1993) first introduced the concept of an AVO walkaway. Since then, many have been shot around the world and at least six surveys have been conducted in Australia by companies like Wapet (now Chevron) and Apache.

The aim of these surveys is to provide an independent measurement of the compressional wave reflectivity with offset of a target horizon so that the surface seismic can be calibrated and ultimately inverted for lithology and fluid content. The need has arisen because for most areas of the world the only other option to calibrate the surface seismic is through modeling. No matter how sophisticated the modeling, however, it still makes assumptions. Complicated overburden effects (as discussed above), interbed multiple effects, mode conversion effects and anisotropy effects may not be modeled correctly but are measured by an AVO walkaway. Thus, as VSPs provide the key to tying zero offset synthetics to surface seismic, so AVO walkaways provide the key to tying AVO synthetics to real seismic data.

Figure 6 is a display of some AVO walkaway results compared with modeling. The survey was acquired for Apache, Kufpec and Tap who, in the case of this line, wanted to assess the impact on AVO of a thin carbonate stringer overlying a target horizon. It was intended to answer questions like, will the carbonate conceal the AVO effect of the reservoir horizon top? What can any AVO behaviour observed in the surface seismic data likely be due to?

Three models were constructed and the theoretical reflectivity of the target interface with offset is plotted in Figure 6.

Model 1	Shale on Carbonate
Model 2	Carbonate on sand
Model 3	Shale on Sand

The reflectivities extracted from the AVO walkaway as a function of angle are displayed in black.

More work has been done in the analyses than presented here but it can be seen that the presence of the carbonate stringer does not necessarily destroy the usefulness of AVO analyses to examine the target.

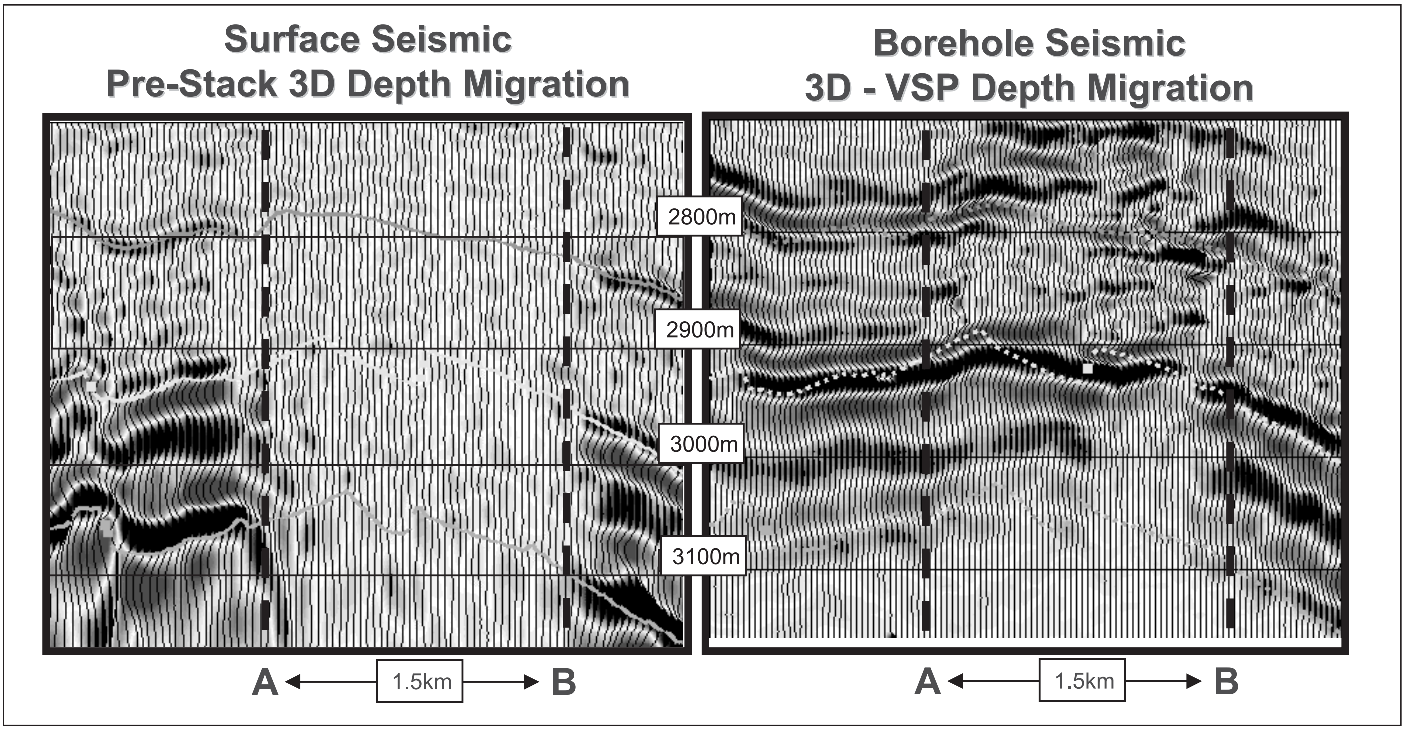


Fig. 7. 3D-VSP Migration - Final Pass

Prestack Depth Migration (PSDM) Refinement

Walkaway data can have a great impact on the success of PSDM projects. Practical application of PSDM shows that as the underlying model becomes closer and closer to reality, the migrated image sharpness improves. Walkaway seismic data help by providing real information on velocity distribution and anisotropy.

Chevron recently completed a prestack depth migration project on one of their North West shelf gas fields with the intention of using walkaway information to optimize the result. The first improvement to imaging came from matching the initial velocity model (derived from tomographic inversion of stacking velocities) to the well velocities. Many different velocity models can explain the same times; a key is to distribute the velocities correctly. The next improvement came from measuring parameters of anisotropy (in this case, Thomsen's (1986) epsilon and delta) in the walkaway data and applying them in the PSDM migration algorithm. The walkaway data were recorded at three separate depths and so a vertical profile of anisotropy could be constructed. Different parameters were measured in different directions. The final PSDM image was not only sharper, *but it was on depth with respect to the well*. (Unfortunately the data have not been released and so cannot be shown here).

3DVSP

The Earth is 3D. Just as the limitations of 2D seismic have led to it's replacement with 3D seismic, 2D walkaways shot for imaging purposes are being replaced by 3D surveys. Figure 7 shows a comparison of 3D seismic and 3D VSP over the gas obscured Ekofisk field in the North Sea. This example was presented by Farmer et al. in 1997.

Seismic while Drilling

This has been an interesting development of borehole seismic methods; actually using the drill bit as a seismic source. At least six surveys have been conducted in Australia to date. Murphy (1995) describes a survey for Ampolex where, the data were of sufficient quality to produce a VSP image that was used to 'find' the drill bit in the seismic section and determine where the kick off point for deviating the well was required. Western Mining, BHP and Nippon have also used this technology in Australia. The main application, though, is where drilling hazards are predicted on the surface seismic data and real time checkshots are required for safe approach.

Vertical Cable Surveys

The development of vertical cable seismic has blurred the boundary between borehole seismic and surface seismic. This is an emerging technology that has more widespread use in the United States at the moment. Ikelle and Wilson. (1998) (1999 IN THE REFS) outlined the potential of vertical cable arrays, especially for land. Cornish et al. (2000) presented the results of a survey they carried out in Chevron's Lost Hills Field in California. The technology is still emerging but as geophone strings and downhole sources become cheaper, wiring a producing field up for continuous monitoring will become cost effective.

No vertical cable 3D surveys have been acquired in Australia until this time although the option has been considered in the case of fields that are difficult to image with conventional surface means (Barrow Island, for example). Like the VSP, vertical cable derives most of its advantages from being able to undershoot near surface terrain that hampers data quality recorded by surface receivers.

Continued on page 30

Continued from page 29

Conclusion

The term 'borehole seismic' should be replaced by the term 'in earth' seismic as sources and receivers are placed in the earth in alternatives to traditional boreholes. The fundamental idea has not changed, however. As long as the results of surface seismic measurements are used to image the Earth, 'in Earth' seismic will be required to tie those results to reality.

Acknowledgements

I would like to acknowledge Baker Hughes (Peter Murphy), CGG Borehole Seismic Division (David Thorne), Schlumberger (Henry Cao), Halliburton (Bruce Cornish), Chevron and Apache who provided data to use in the various examples. I would also like to acknowledge the companies Chevron, Apache, Tap and Kufpec who provided permission to publish data used in this review.

Finally I acknowledge and commend those that dare to be different and who try things that attempt to push both their data and their knowledge further.

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Borehole Geomechanics in Petroleum Exploration and Development: From Controlling Wellbore Stability to Predicting Fault Seal Integrity

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Introduction

Few in the Australian oil patch were familiar with the term 'borehole breakout' when David Lowry alerted PESA Journal readers to this phenomenon (1990, v.17, p. 43-44). Ten years later, few are unfamiliar, with breakouts having been reported in every Australian basin subject to significant drilling activity. This change witnesses the dramatically increased awareness of borehole geomechanics in the Australian oil patch that has developed over the last decade. One driver for this increased awareness has been the increasing quality and use of borehole imaging tools, and the geomechanical information yielded by these tools. Furthermore, borehole geomechanics has applications that are particularly significant for, although by no means restricted to, deviated wells. Hence the increased incidence of deviated drilling has been another driver. That significant fundamental research on the origin of crustal stresses and their application in the oil patch has been undertaken in Australia, both in the universities and at CSIRO, has been another driver for the uptake of borehole geomechanics in the Australian oil patch over the last decade. This article provides a contemporary snapshot of borehole geomechanics in the oil patch, addressing specifically, the methodology of *in situ* stress determination, and some key applications of knowledge of subsurface stresses.

Initially, breakouts gained prominence as a drilling problem responsible for stuck pipe, lost time, and even lost holes. However, utilising the breakouts themselves to help ascertain the *in situ* stress field has led to drilling strategies that minimise such wellbore stability problems. More recently, there has been rapidly growing recognition that the *in situ* stress field controls both natural and induced fluid flow in the subsurface, impacting on:

- reservoir flooding and drainage patterns;
- hydraulic fracture stimulation;
- fluid flow in naturally fractured reservoirs, and;
- seal integrity of fault-bound prospects.

Knowledge of the *in situ* stress field can optimise exploration and development strategies pertaining to these issues. Hence the applications of borehole geomechanics have grown from their early roots in wellbore stability to a wide range of exploration and field development issues.

Borehole Geomechanics: Determining the In Situ Stress Tensor

Assuming that the vertical stress (σ_v) is a principal stress, the full stress tensor is constrained by the orientation of the other two principal stresses, i.e. the maximum and minimum horizontal stresses (σ_H and σ_h respectively), and by the magnitude of all three principal stresses.

The orientation of the horizontal stresses is given by the orientation of borehole breakouts and drilling-induced tensile fractures commonly seen on borehole image logs such as Schlumberger's FMI (Formation MicroImager: resistivity image) and UBI (Ultrasonic Borehole Imager: sonic image), and Baker Atlas' STAR II (Simultaneous Acoustic & Resistivity Imager). In vertical wells, the long axis of breakouts is oriented in the σ_h direction, and drilling-induced tensile fractures strike in the σ_H direction (Figures 1 & 2). Breakouts occur where the circumferential stress acting around the wellbore wall exceeds the compressive strength of the rocks forming the wellbore wall (Figure 1). Failure of intersecting, conjugate shear planes leads to pieces of rock breaking off the wellbore wall. The central pad on Figure 2 shows both breakout (poorly resolved zone of low resistivity), and, at the periphery of the breakout, the fracturing of the wellbore wall that precedes breakout formation.

Vertical stress magnitude can be determined from the weight of the overburden, which is given by inte-grating density log data that have been carefully edited for bad hole conditions. It is imperative to determine the site-specific σ_v magnitude, and not to use the commonly applied value of 1 psi/ft (22.6 MPa/km), because the 1 psi/ft value may be in error by as much as ±30% at different depths in different basins.

Ideally, horizontal stress magnitudes are determined from hydraulic fracture-tests. Such tests are not performed in petroleum exploration wells. However, leak-off tests, which resemble the first part of a hydraulic fracture test, are routinely undertaken. The lower bound to leak-off pressures is widely considered to give a reasonable estimate of σ_h. An improved estimate of σ_h may be obtained from extended leak-off tests, a procedure for which has been developed by Jim Enever of CSIRO based on extensive experience with hydraulic fracture testing in the mining industry (APPEA Journal, 1996, v. 36, p. 528-535). An extended leak-off test is simply a leak-off test in which several cycles of pressurisation of the wellbore are undertaken in order that repeatable fracture closure pressures (a better estimate of σ_h than leak-off pressures) can be obtained. Under ideal circumstances, an extended leak-off test can also help constrain σ_H magnitude.

The most difficult parameter of the *in situ* stress tensor to constrain is σ_H. The occurrence, or indeed non-occurrence, of breakouts and drilling-induced tensile fractures can constrain σ_H if rock strength is known. The change in azimuth of breakouts or drilling-induced tensile fractures

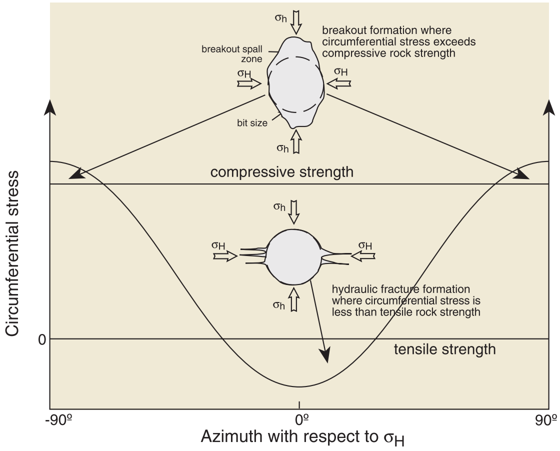

Fig. 1. Circumferential stresses acting around an open wellbore and the stress concentrations that lead to the formation of borehole breakouts and drilling-induced tensile fractures.

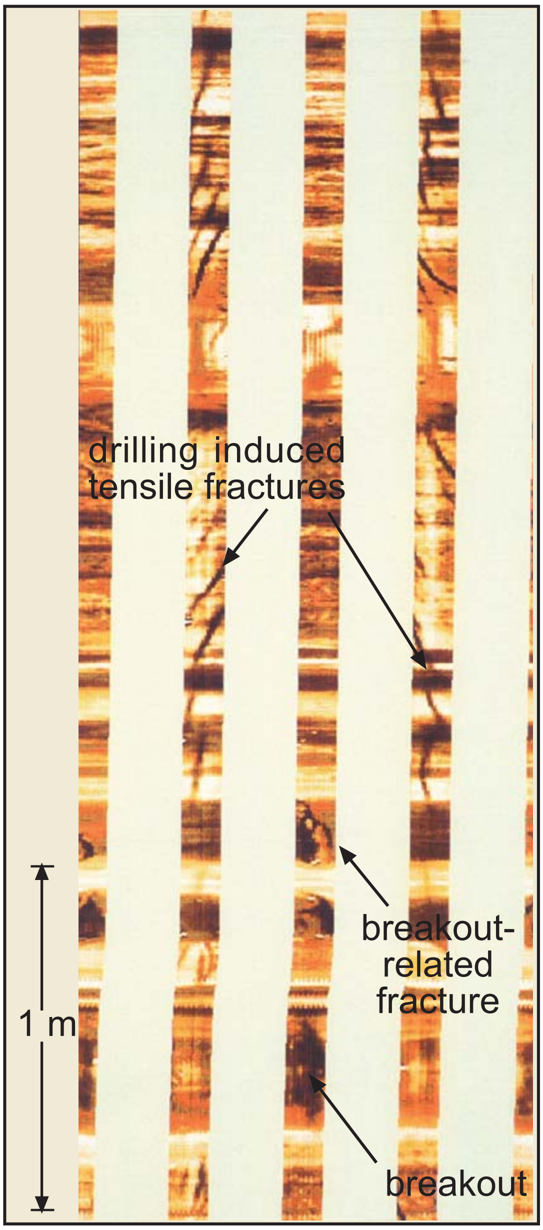

Fig. 2. Resistivity image of borehole breakouts and drilling-induced tensile fractures (darker = more conductive).

with wellbore deviation can also constrain σ_H. In situations where σ_H is poorly constrained, subsequent analysis of stress-sensitive processes should incorporate sensitivity studies of the response within a range of possible σ_H magnitudes.

It is worth emphasising that the only two key pieces of non-standard data that should be acquired during drilling to help constrain the *in situ* stress field are a good quality leak-off, or preferably extended leak-off test and an image log (preferably both resistivity and sonic). Given the very wide significance of *in situ* stress data outlined below, operators should give serious consideration to acquiring these data as standard practice.

Borehole Geomechanics: Applications

The remainder of this article illustrates some of the key applications of in situ stress data with reference to the in situ stress tensor at approximately 2.8 km depth in the Penola Trough, Otway Basin, South Australia. The stress tensor there is given by:

- σ_h: 46 MPa;
- σ_v: 64 MPa;
- σ_H: 82 MPa;
- σ_H orientation: 156°N, and;
- pore pressure: 28 MPa.

This stress tensor was determined using the techniques outlined above, including an extended leak-off test that was undertaken by Origin Energy, in collaboration with the authors, for the purpose of improved σ_h determination. For further details on the determination of the in situ stress field of the Penola Trough, and for a more extensive discussion of fault seal issues in the area, see Jones et al. (2000, APPEA Journal, v. 40, p. 194-212).

Borehole Stability

Perhaps counter-intuitively, a vertical wellbore is the most prone to breakout-induced instability in a strike-slip stress regime (i.e. $\sigma_H > \sigma_v > \sigma_h$), such as that of the Penola Trough (Figure 3). The extensive breakout development seen in vertical wells in the area is a consequence of this stress regime. Any deviated wellbore is more stable than a vertical wellbore in this environment, and hence lower mud weights can be used in deviated than in vertical wells (Figure 4). Horizontal wells drilled towards 150-160°N (i.e.

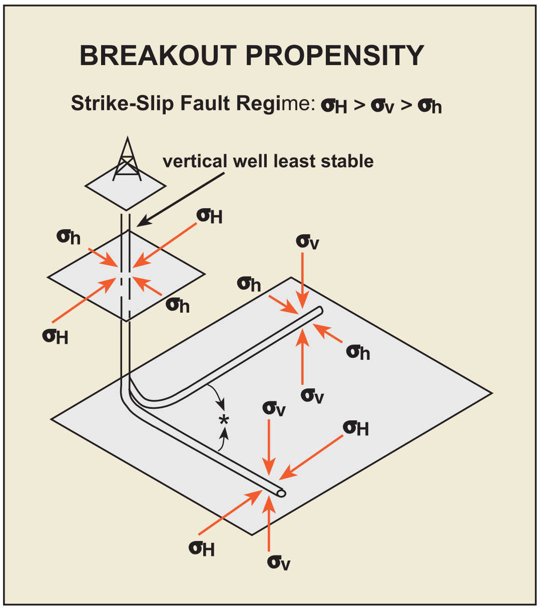

Fig. 3. Stresses acting on vertical and deviated wellbores in the strike-slip stress regime.

σ_H direction) are the most stable. Wells drilled in less optimal trajectories require a higher mud weight to prevent breakouts developing (Figure 4).

Depending on rock strength, underbalanced drilling may be an option in such an environment, particularly in wells deviated at high angles towards 150-160°N. In areas prone to formation damage, or mud losses into natural fractures, wellbore stability analysis such as that presented is a critical tool for assessing the viability of underbalanced drilling.

Figure 5 illustrates the maximum mud weight that can be run without exceeding the fracture gradient, and thus causing mud losses, in the stress environment of the Penola Trough. Again it is perhaps counter-intuitive that the vertical well can sustain the least mud overbalance without fracturing. Combining the propensity for breakout and fracture development, the safe mud weight envelope for vertical wells is very tight in this stress environment, whereas a wider mud weight envelope can be tolerated in horizontal wells.

In Situ Stress and Fluid Flow in Hydrocarbon Reservoirs

There are numerous studies demonstrating the control of the *in situ* stress field on subsurface fluid flow, especially in hydrocarbon reservoirs, the most extensive being those of Kes Heffer (BP). Preferential directionality of reservoir floods in the σ_H direction has clearly been demonstrated by Heffer, based on data from some 80 fields in North America, North Sea, continental Europe, Middle East and China (water, surfactant/polymer and gas floods). Using half a million well pair histories, Heffer also demonstrated that rate correlations between injector and producer well pairs are best developed in the σ_H direction. Similarly, at the geological timescale, his study of 423 faults in the North Sea revealed that non-sealing faults (those across which there is no change in the hydrocarbon-water contact) are strongly preferentially aligned in the σ_H direction.

Reservoir Flooding and Drainage Patterns

Hydraulic fractures induced by reservoir flooding may be responsible for the observed directionality of reservoir floods and well pair rate correlations. Hydraulic fractures open normal to the minimum principal stress (σ_h in most basins), hence they are generally vertical and strike parallel to σ_H. The recognition of such can aid the efficient planning of flooding operations. In order to maximise sweep efficiency in flooding operations, injector-producer pairs should not be aligned in the σ_H direction. If injector-producer pairs are so aligned, injected fluids tend to flow directly from the injection well to the production well, by-passing much of the reservoir. If injectors are aligned in the σ_H direction, flooding fluids from the injectors rapidly link up, forming a 'curtain' that sweeps hydrocarbons to producing wells, which should be offset from the injectors in the σ_h direction.

Reservoir drainage is anisotropic and sensitive to the *in situ* stress field, even in reservoirs not subject to fracture stimulation, perhaps because of stress-sensitive natural fractures and/or micro-fractures. Again the recognition of such can help optimise plans for field development (Figure 6).

Hydraulic Fracture Stimulation

Where hydraulic fracturing is undertaken to stimulate low permeability reservoirs, the *in situ* stress field is the critical

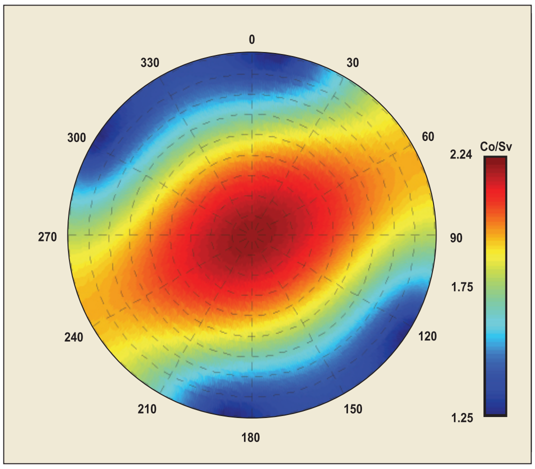

Fig. 4. Polar plot of rock strength (closely related to minimum mud weight) required to prevent borehole breakout development in the strike slip stress regime of the Penola Trough. Vertical wellbores plots at the centre, horizontal wellbores around the perimeter according to the azimuth of deviation.

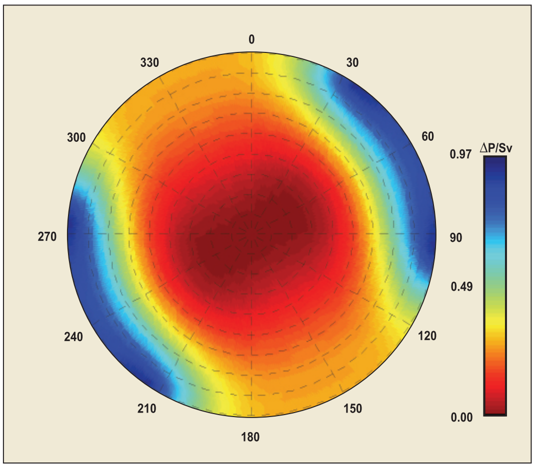

Fig. 5. Polar plot of maximum mud weight overbalance (normalised by vertical stress) that can be sustained without fracture development (mud losses) in the strike slip stress regime of the Penola Trough.

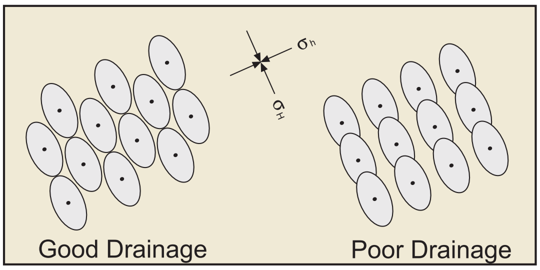

Fig. 6. Schematic reservoir drainage patterns assuming the 156°N σ_H orientation in the Penola Trough.

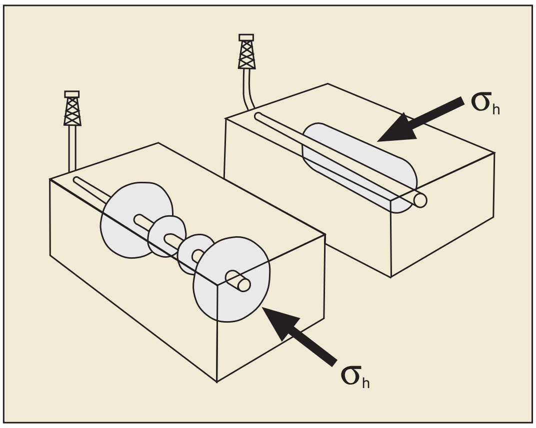

Fig. 7. Axial and transverse hydraulic fractures in horizontal wells.

control on the nature of the induced fracture, controlling not only fracture orientation but also fracturing pressure and fracture height/containment. A full discussion of the influence of *in situ* stresses on hydraulic fracturing is beyond the scope of this article. However, the issue of fracture stimulation from deviated wells has received considerable attention, some of it potentially misleading, and is briefly discussed herein. Hydraulic fractures generated in wells deviated in the σ_h direction tend to be transverse to the wellbore, because induced fractures are oriented normal to σ_h (Figure 7). In wells deviated towards σ_H, hydraulic fractures tend to be axial (Figure 7). It has thus been suggested that hydraulically fracturing wells deviated in σ_h direction affords optimal reservoir drainage per well. The authors urge caution in this approach, because hydraulic fractures tend to form axial to the wellbore in the immediate vicinity of the wellbore, and only in the far-field (several wellbore diameters distant) are they normal to the minimum principal stress. Hence fractures formed in wells deviated in σ_h direction may twist from axial to transverse as they propagate away from the wellbore. Such fracture twisting may lead to a loss of hydraulic conductivity, and indeed to an inability to place proppant beyond the twisted zone. The planning of hydraulic fracture stimulation from deviated wells should include careful analysis of fracture orientation in both the near- and far-field, and the key issue may be to minimise the propensity for fracture twisting.

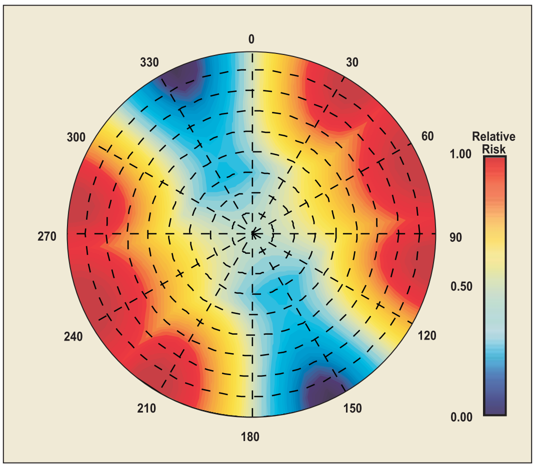

Fig. 8. Stereonet of the risk of reactivation of planes as tensile or shear fractures within the in situ stress field of the Penola Trough. Equal angle, lower hemisphere, stereographic projection of poles to planes.

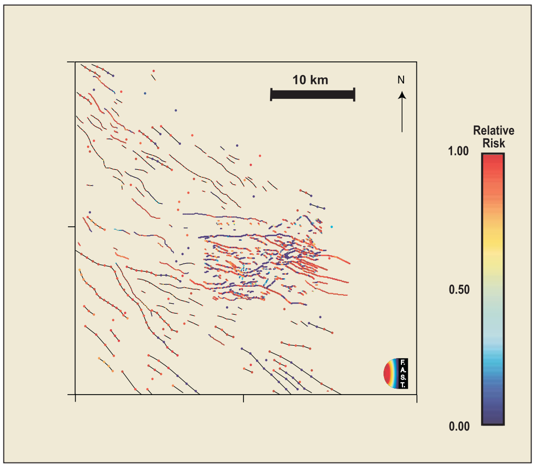

Fig. 9. Fault Analysis Seal Technology (FAST) map of risk of reactivation of seismically-mapped fault segments in the Penola Trough.

Fluid Flow in Naturally Fractured Reservoirs

The relationship between natural subsurface fluid flow and *in situ* stress is due to the focusing of fluid flow along planes suitably oriented to be tensile or shear fractures within the *in situ* stress field. Pre-existing natural fractures in these orientations tend to be open and transmit fluids. Hence, although pre-existing natural fractures may have a wide variety of orientations, those suitably oriented to be tensile or shear fractures within the in situ stress field tend to be open and hydraulically conductive (Figure 8). Deviating wells in the σ_h direction maximise the probability of intersection with such fractures, and in many fractured reservoirs, such as the Austin Chalk, drilling in the σ_h direction is the key to obtaining commercial production rates. The authors do, however, note that not all natural fractures are stress-sensitive and where fractures are partially cemented, or the rocks indurated, significant production may come from natural fractures that are not optimally oriented within the in situ stress field. Nonetheless, in the absence of a well-constrained, and clearly preferentially oriented pre-existing natural fracture set, deviating in the σ_h direction otpimises intersection with open natural fractures. Hence in the Penola Trough, where there have been minor recoveries of oil from fractured basement, wells designed to take advantage of this play should be deviated towards 060-070°N (or 240-250°N).

It is clear from the above that in a strike-slip stress environment like that of the Penola Trough, different imperatives may lead to different decisions on deviation direction. Wells deviated towards 150-160°N are least prone to breakout, and may be fracture stimulated without twisting-type problems occurring, but are poorly oriented to intersect open natural fractures. Borehole geomechanics provides the requisite data from which to make informed decisions about deviation direction, given the key imperatives for a well. In many cases, especially offshore, deviation direction may be driven by the need to access a particular reservoir compartment, and may not be open to selection. However, if such trajectories are, for example, non-optimal with respect to wellbore stability, more aggressive mud weights should be planned, and the significance of such with respect to the ultimate objective of the well, e.g. in terms of formation damage, can be assessed.

Seal Integrity of Fault-Bound Prospects

Open natural fractures may be desirable in tight reservoirs, but such open natural fractures may also provide conduits for seal breaching, especially in fault-bound prospects. The same principles used to predict which fracture orientations are likely to be open and productive in the reservoir can be used to predict fracture orientations likely to be associated with seal breaching. Seal breaching due to fault/fracture reactivation is a key exploration risk factor in the Otway Basin, and indeed in a number of other Australian basins. Planes in hot colours in Figure 8 are suitably oriented within the *in situ* stress field of the Penola Trough to act as tensile and shear fractures, hence these planes are at the greatest risk of reactivation and associated seal breach. These data can be transposed onto a fault map to risk fault segments with respect to the likelihood of seal breach due to reactivation (Figure 9). Such provides a tool for pre-drill assessment of the likelihood of seal breach due to structural reactivation subsequent to hydrocarbon charge.

Developments

The greatly increased awareness of borehole geomechanics in the Australian oil patch over the last decade has been the result of increased quality and use of borehole imaging logs, of increased application of deviated drilling, and of fundamental research carried out in the Australian universities and CSIRO. The next decade is likely to see further expansion in the application of borehole geomechanics which the authors predict will be driven by continued improvement in borehole imaging tools, and by yet more case studies of the importance of in situ stresses in subsurface fluid flow. Key areas of ongoing research are likely to be in the evolution of the stress tensor with time as fields are developed and reservoir pressures decline, and in stress modelling. The latter is already a growth area with recognition of the significance of in situ stresses at the wellbore driving a demand for improved stress prediction prior to drilling.

A public domain database of *in situ* stress data for the Australian Continent, and further information on the origin, determination and application of *in situ* stresses can be found on the web at www.ncpgg.adelaide.edu.au/asm.

Reducing Noise in Airborne Gamma-ray Spectra

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Introduction

The past few years have seen the development of methods for removing noise from multichannel gamma-ray spectra through spectral component analysis. There are two methods in current use. These are the MNF method (Maximum Noise Fraction, Green et al., 1988; Dickson and Taylor, 1998) and the NASVD method (Noise Adjusted Singular Value Decomposition, Hovgaard, 1997; Hovgaard and Grasty, 1997). The application of these methods can be enhanced through the use of clustering (Minty and McFadden, 1998). While the new methods have been enthusiastically embraced by Australian industry, they are still not well understood. Exactly how they work, and what the differences are between them, are still not clear to many. This is not a healthy situation, as processed data can be seriously compromised if a method is not correctly implemented. The purpose of this article is to describe the new methods in layman's terms, and illustrate through example how they remove noise from raw spectra. I will show that the differences between the two methods are, in fact, small. I will also offer a few guidelines that both the processors of data and their clients can use to ensure that their data are adequately processed.

Both methods use some form of spectral component analysis. Principal component (PC) analysis is the most widely used method for doing spectral component analysis, so I will use this to demonstrate the noise reduction methodology.

Principal Component Analysis

A multivariate dataset is one in which each data unit is comprised of many observations or variables. There is often a significant amount of redundant information in such datasets - the same patterns appear over and over again. This is because of a high correlation between the variables. The PC transformation is a linear transformation of multivariate data that produces uncorrelated variables. It is a mathematical way of transforming the data such that the new components best span the data space.

Take 256-channel gamma-ray spectra as an example. The principal components are the dominant spectral shapes in the input dataset. As a rough approximation, the first principal component (PC1) is the average of the input spectra. If you subtract the best fit of PC1 to each of the input spectra from the input spectra, then the average of the residuals will be the second principal component (PC2). This is only an approximation to the truth. Each of the variables in a multivariate dataset will span a range of values. This variability is called the variance, and comprises two components. The first is due to variations in the signal within the input dataset (signal variance), and the second due to noise (noise or error variance). Measurement errors, for example, are a source of noise. For our gamma-ray spectra example, PC1 is the spectral shape that explains most of the total variance (signal plus noise) within the dataset, and PC2 explains most of the variance not explained by PC1, and so on for subsequent components.

The principal components of a set of m spectra S ($m \times 256$ where $m \geq 256$) are the eigenvectors of the covariance matrix, cov(**S**). This type of analysis yields 256 eigenvectors and 256 eigenvalues. Think of the eigenvectors as the dominant spectral shapes (or PCs) within the dataset. The eigenvalues are a measure of the contribution that each eigenvector makes to the shape of the input spectra. They are the variances of each eigenvector, and add up to the total variance within the input spectra. The eigenvectors are mutually orthogonal - in a geometrical sense, they are at right angles to each other. The eigenvectors are also usually sorted, by eigenvalue, into descending order. Thus, the lowest-order eigenvector (PC1) has the largest eigenvalue, and explains most of the variance within the input dataset.

Each of the observed spectra can be reconstructed exactly from the eigenvectors by multiplying each eigenvector with an appropriate amplitude, and summing these products. In matrix notation, this can be represented as

$$\mathbf{S} = \mathbf{AV} \qquad (1)$$

where $\mathbf{A}$ ($m \times 256$) is a matrix of amplitudes, and $\mathbf{V}$ (256×256) are the eigenvectors.

PC analysis may be used to remove noise from multichannel spectra if the signal is highly correlated within the input spectra and the noise is not. This is because the signal might concentrate into the lower-order components. As the noise does not correlate highly between variables (channel count rates), it will tend to be spread amongst all of the components. So if the conditions are good, it may be possible to remove a lot of the noise by dropping off the higher-order components, and reconstructing 'smoothed' spectra from the lower-order components only.

Now, I said the signal 'might' concentrate into the lower-order components, because there is another important consideration. Figure 1 shows a typical airborne gamma-ray spectrum. Note that the low-energy channels have count rates up to 150 times larger than the high-energy channels. This means that these low-energy channels completely dominate the PC analysis. Now there is nothing fundamentally wrong with this - after all, the channels (variables) are all expressed in the same units (counts/s). The problem is that the low-energy channels have much higher error variances than the high-energy channels (up to 150 times higher). This means that the noise in some channels will get greater weight in the analysis than the signal in others. An appropriate way to weight each channel is so that the noise in each channel is the same.

This is where the MNF and NASVD methods come in. Both methods do what is essentially a PC analysis of the input

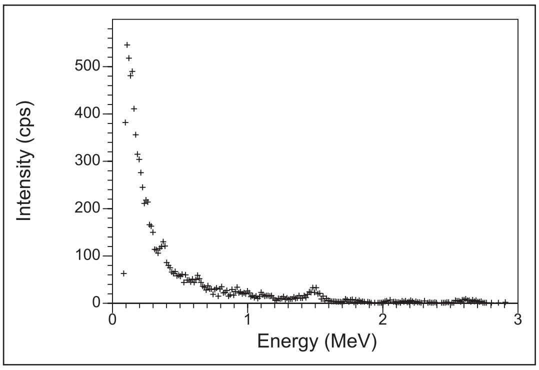

Fig. 1. A typical 1s spectrum acquired 60 m above the ground using a 33 litre detector.

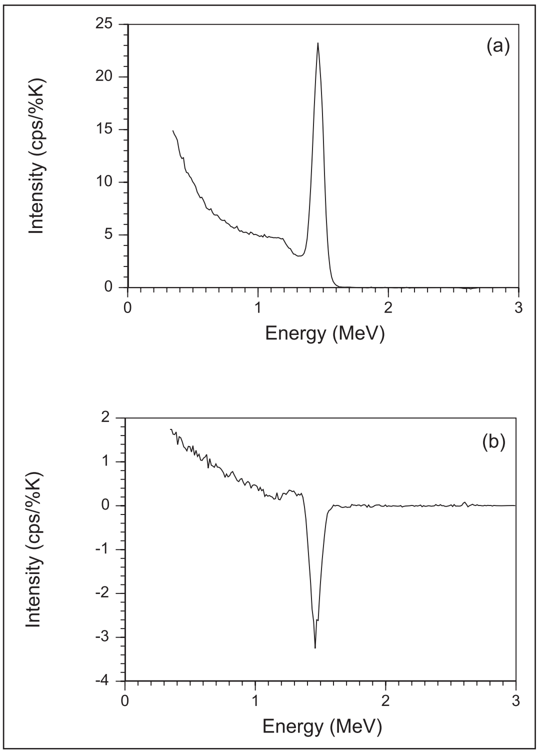

Fig. 2. Spectral components required to model the change in K spectral shape with height: (a) average K spectrum; (b) height adjustment factor.

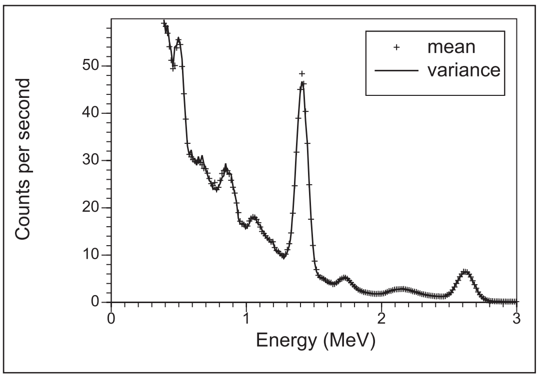

Fig. 3. Channel means and variances for spectra from a background line recorded with the aircraft stationary on the ground.

spectra. The main difference between the two methods is how they normalize the input spectra for noise. So before we look at the MNF and NASVD methods, it is appropriate to first look at the nature of signal and noise in airborne gamma-ray spectra.

The Nature of Gamma-ray Spectrometric Signal

Gamma-ray spectra can be considered as a linear combination of discrete spectral components. This is a fundamental concept in gamma-ray spectrometry.

There are three natural terrestrial sources of radiation - K, U, and Th, if we assume no man-made contamination. At the airborne observation height, each of these sources gives rise to a fixed spectral shape. But these shapes change with the height of the detector. This is because the gamma rays are attenuated by absorbing material between the source and the detector (mainly air). However, Dickson (1980) showed that changes in spectral shape with height can be explained by just two components for each of K, U and Th. For example, the two K spectral components are shown in Figure 2 – (a) is a K spectrum for a fixed height, and (b) is a component that accommodates changes in height. The K spectrum at any height can be reconstructed by adding these two components together in different proportions. Similarly for U and Th.

There are also three background sources of radiation - aircraft, cosmic and atmospheric radon. But the aircraft spectrum is a combination of K, U and Th spectra, and the radon spectrum has the same shape as a U spectrum measured at ground level. So just seven spectral components (two for each of K, U and Th, plus cosmic) should be sufficient to model all observed variations in spectral shape of airborne gamma-ray data.

The Nature of Gamma-ray Spectrometric Noise

The 'noise' in gamma-ray spectrometric data derives, in large part, from the statistical nature of radioactive decay. The average number of atomic disintegrations of a particular radioactive isotope during a fixed sampling interval is proportional to the concentration of the isotope in the ground. But as each radioactive disintegration is a random event, the number of recorded events during a particular sampling interval will be different from the average. Each atomic disintegration during radioactive decay occurs completely independently of every other decay. This means that the number of radioactive decays (and hence the number of associated measured gamma rays) of an isotope in a particular interval of time, follow a Poisson statistical distribution. A property of this distribution is that the variance is equal to the mean, which is often exploited in gamma-ray spectrometry. If we can get a good estimate of the mean count rate for a particular channel, then we have a good estimate of the error variance for that channel.

It is easy to demonstrate that the error variance of a sample is, in fact, equal to the sample mean. Figure 3 shows the computed mean count rates and associated variances for a background line recorded over 2461 s while the aircraft was stationary on the ground. Because the aircraft is stationary, each one-second measurement provides a new random sample from the same distribution. As you can see, the measured means and variances are almost the same.

Another important issue is whether there is a covariance between channel count rate errors. Recall that the variance is a measure of the variation of instances of a variable about the mean value. The covariance of a pair of variables, on the other hand, is a measure of the mutual variability of these about their common mean. We know that there is a large signal covariance between channel count rates in gamma-ray spectrometry. After all, most spectra look vaguely similar with high count rates at low energies, and low count rates at high energies. But is there a covariance between channel count rate errors? In other words, if a particular measured count in a spectrum channel is above the channel mean, does this increase the probability that a count in another channel of the same spectrum will be above (or below) its mean? The answer is no - there is virtually no covariance between channel count rate errors in airborne gamma-ray spectrometry. This stems from the fact that radioactive disintegrations are independent events, and a single gamma ray can only be recorded in one channel. There is a small potential for covariance through accidental summing (see discussion in Minty, 1998), but this effect is small. Figure 4 shows the correlation matrix for the noise on the 2461s background line described earlier. This is the noise covariance matrix normalised to unit variance along the main diagonal. As the aircraft was stationary, deviations from the mean are due to noise, and it is these deviations that have been used to calculate the correlation matrix. The off-diagonal elements (representing between-channel correlations) are close to zero and show no evidence of structure. This demonstrates that the covariance between channel count rate errors is small.

Spectral Smoothing Methods

The MNF and NASVD methods are a form of noise-adjusted PC analysis. As the PC method will be familiar to many readers, I'll use this to demonstrate a few features of this type of analysis before describing the MNF and NASVD methods. The test data I will use is flight 137 from the Fowler's Gap survey flown in 1996 by the Australian Geological Survey Organisation (AGSO). This consists of 11 721 256-channel spectra acquired at 60 m height with a 32 litre detector.

Principal Component Analysis

Consider a PC analysis of the test flight spectra. We hope to concentrate the signal into 7 or fewer spectral components. Figure 5 shows the first 16 components (eigenvectors) from the PC analysis. The first 100 eigenvalues from this analysis are shown in Figure 6. These represent the relative importance of the components. The eigenvectors that represent signal can be recognised by their coherent spectral shapes. Figure 5 shows that higher-order components (components 8 and above) contain signal. In fact, signal persists even beyond component number 100. The eigenvalues tell the same story – they do not trend rapidly to low values. So we are not achieving the anticipated separation of signal and noise. The reason for this is that the data have not been normalized for noise.

A limitation of the PC method is that it is not scale-invariant. The analysis depends on the units of measurement of the original variables. It is therefore common practice in PC analysis to 'standardize' the variables by scaling them to the same range of values before doing the analysis. The problem we have with gamma-ray spectra is slightly different. Although the variables (channel count rates) are of the same units (counts/s), the errors vary considerably from one channel to the next. As indicated earlier, it is standard practice in cases like this to normalize the variables to unit error variance before applying the PC method.

As a first approximation, let us assume that the error variance of a channel count rate is the mean count rate for that channel within the input spectra. So if channel 10, for example, has a mean count rate of n, then we can normalise channel 10 of each spectrum by dividing the channel count rate by $\sqrt{n}$. Why divide by $\sqrt{n}$ and not n? Well, recall that if a variable, x, has a variance of var(x), then the variance of the function

$$f(x) = \frac{x}{a}$$

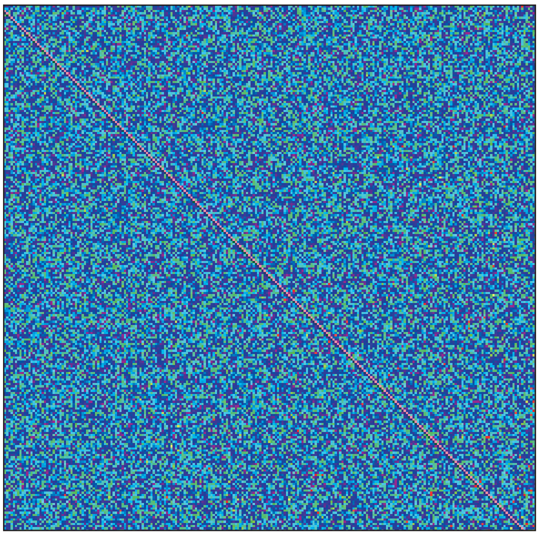

Fig. 4. Noise correlation matrix for a background line recorded with the aircraft stationary on the ground. The diagonal elements are 1. The absolute values of the off-diagonal elements are generally less than 0.05.

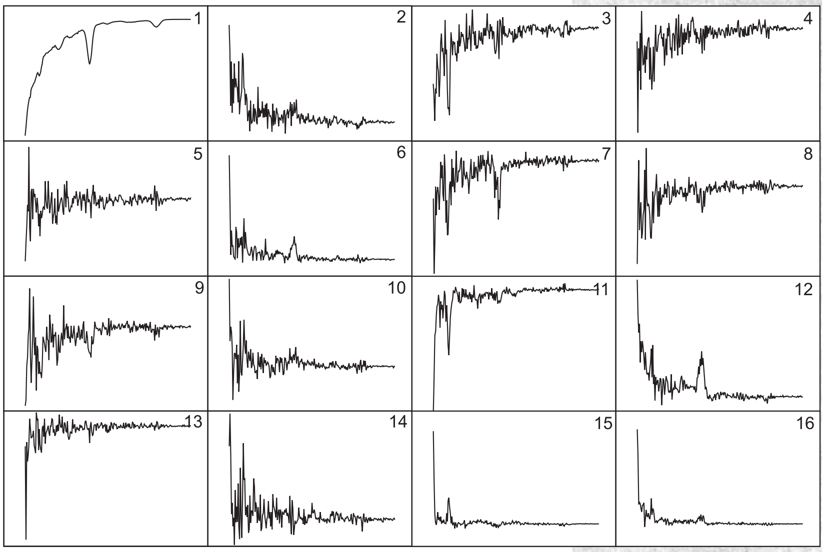

Fig. 5. Eigenvectors for the Fowlers Gap test flight calculated using PC analysis with no prior normalization of the spectra for noise.

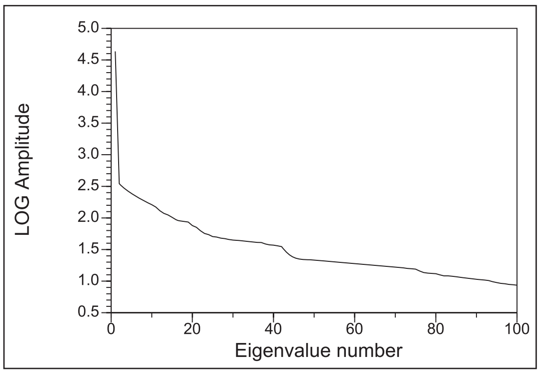

Fig. 6. (Left) Eigenvalues for the Fowlers Gap test flight calculated using PC analysis with no prior normalization of the spectra for noise.

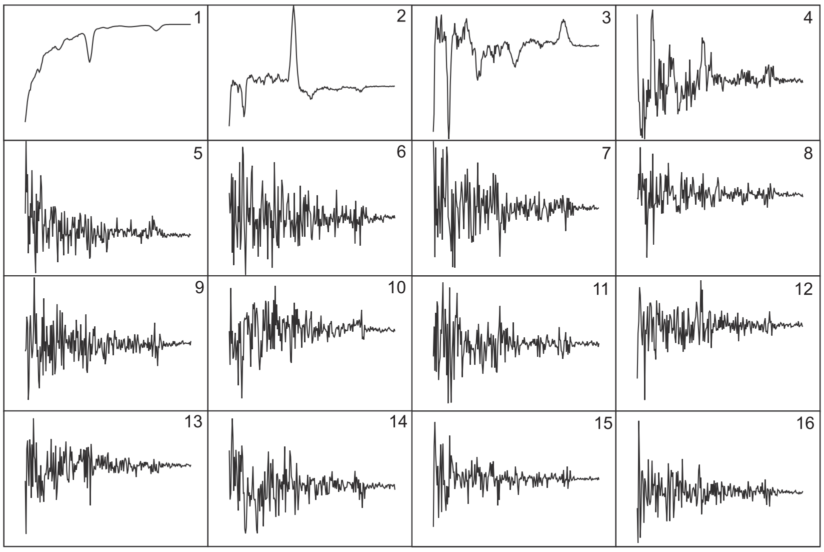

Fig. 7. (Above) Eigenvectors for the Fowlers Gap test flight calculated using PC analysis after normalizing the spectra for noise.

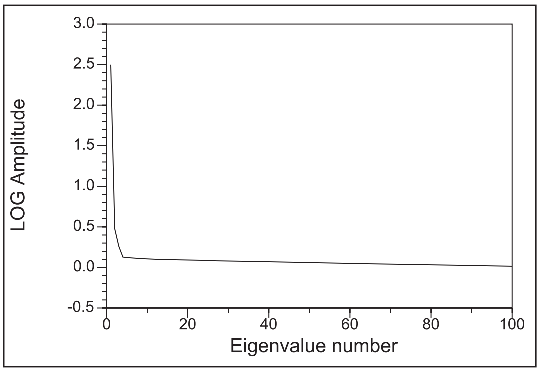

Fig. 8. (Left) Eigenvalues for the Fowlers Gap test flight calculated using PC analysis after normalizing the spectra for noise.

where a is a constant, is given by

$$\mathrm{var}(f) = \frac{\mathrm{var}(x)}{a^2}$$

It follows from this that if our function has an error variance of n, and we divide by $\sqrt{n}$, then var(f)=1.

Figure 7 shows the first 16 components from the PC analysis of our test flight after normalizing for noise. The first 100 eigenvalues from this analysis are shown in Figure 8. Now we have good separation of signal and noise. The signal is represented by perhaps four or five low-order components. Higher-order components mainly represent noise. The spectra may now be smoothed by reconstructing them from the PCs using only the lower-order components.

The eigenvalues shown in Figure 8 are typical for airborne gamma-ray spectra. The eigenvalue for PC1 is by far the largest (note the log scale). This reflects the fact that the shape of airborne gamma-ray spectra does not vary much within an airborne survey. Variations in the ratios between the radioelements are reflected as small changes in the relative amplitudes of the photopeaks. The eigenvalues rapidly drop (over perhaps 4-7 components) to a constant value that represents the noise. Knowing what we do about the nature of the gamma-ray noise, this is exactly what one would expect. As the noise is uncorrelated, you need 256 channels to describe it. And as we've normalised the input spectra to unit error variance, the amplitudes of the noise components should be about the same.

An interesting feature of this experiment is that we appear to have achieved a good separation of noise and signal even though the way we modelled the noise was very much an approximation. We used the average spectrum as a measure of the channel error variances. The true errors would reflect both deviations from the average due to changes in count rate as we moved from low- to high-radioactivity areas traversed during the flight, and changes in spectral shape as the ratios between the radioelements changed during the flight. When I asked Jens Hovgaard (Exploranium) about this, he pointed out that the greatest difference in error variances is between low and high-energy regions of the spectrum. These differ by a factor of about 150. Differences in error variance due to changes in intensity along a flight are generally less than a factor of 5. Differences due to changes in the ratios between the radioelements are probably an order of magnitude smaller again. So most of the variations in errors are accommodated by the simple model of the error variance used here.

The MNF method

Switzer and Green (1984) introduced a new method for orthogonalizing multivariate data called Minimum/ Maximum Autocorrelation Factors (MAF method). This allows for the spatial nature of multichannel data by seeking to minimize the autocorrelation between spatially adjacent samples. Thus, whereas the first PC component maximises the total data variance, the first MAF component minimises the autocorrelation between neighbouring data, and so on. In the MNF method (Green et al., 1988), the noise fraction is maximised. This gives the same eigenvectors as maximising the signal/noise ratio.

Lee et al. (1990) describe a noise-adjusted principal component transform that is equivalent to the MNF transform. The method consists of two transformations. The data are first transformed so that the noise covariance matrix becomes the identity matrix. In the case of radiometric data this means that each channel will have unit noise variance with no covariance between channel count rate errors. The second transform is then a standard PC transformation. Where no model of the noise is available, Green et al. (1988) suggested that a sample of noise can be obtained by sampling the differences between adjacent observations (essentially the MAF transform) or using the residuals of a low-pass filtering of the data. These are then used to calculate the noise covariance matrix. In summary, the MNF method can be applied as follows to reduce noise in a multivariate dataset.

(a) Get a sample of noise and calculate the noise covariance matrix. Use the noise covariance matrix to find a transformation (the 'noise transformation') which, when applied to the input data, will result in each variable having unit error variance, and no error covariance between variables.

(b) Apply this noise transformation to the input data.

(c) Do a standard PC transformation on the noise-adjusted data. Do the reverse PC transform using only the significant components that represent signal.

(d) Do the reverse noise transformation.

As a thought experiment, consider now the application of the MNF method to gamma-ray spectra under ideal circumstances. We know something about the nature of the noise in gamma-ray spectra and this should give us some insight into how the MNF method works. Let us assume that we can accurately sample the noise in each spectrum of our input dataset - perhaps by taking the difference between successive spectra or using the residuals after filtering. Recall from Poisson statistics that the noise variance of each channel is just the mean channel count rate. As there is no covariance between channel count rate errors, the noise covariance matrix will be a 256×256 symmetric matrix with the mean spectrum down the main diagonal and zeros elsewhere. The inverse of this matrix has the reciprocal of the mean spectrum in the main diagonal. And a matrix with the reciprocal of the square root of the mean spectrum in the main diagonal will successfully transform the input data to unit error variance.

When viewed in this way, the MNF procedure can be seen to be exactly the same as preconditioning our input data by dividing each channel by the square root of the channel mean, and then doing a standard PC analysis. So, under these ideal circumstances, the noise-adjusted PC transform example I gave in the previous section will have the same effect as the MNF method.

The MNF method was developed for the reduction of noise in remotely-sensed satellite imagery. These data often have a covariance between the errors in different bands. This is the real power of the MNF method – the ability to accommodate this covariance. But in airborne gamma-ray spectrometry there is no covariance between channel count rate errors, and the full potential of the MNF method is not used.

Figure 9 shows the first 100 eigenvalues for our test flight processed using the MNF method. The eigenvalues drop rapidly to a plateau after only 5 components, suggesting good separation between noise and signal. As expected, the eigenvalues are similar to those for the noise-adjusted PC analysis performed earlier (Figure 8).

The NASVD method

There are two issues relating to the use of standard PC analysis for the reduction of noise in multichannel gamma-ray spectra. The first is the normalizing of the input spectra to unit variance in each channel. Hovgaard (1997) suggested a simple approach to this. As the variance of a channel count rate is the same as the mean count rate for that channel, and as changes in spectral shape (as opposed to amplitude) in gamma-ray spectra are typically small, the best fit of the mean spectrum to each of the input spectra gives a good estimate of the mean count rate (and hence variance) for each channel. So we can scale the spectra to unit variance in each channel by dividing each channel by the square root of the best fit of the mean spectrum to each of the input spectra. This is an improvement on the normalization used by the MNF method where the error variances are essentially assumed equal to the mean spectrum channel count rates. That is, the NASVD scaling accommodates changes in the amplitudes of the spectra during a flight. However, the normalization is still not exact, as the shape of the spectra is assumed constant throughout the flight.

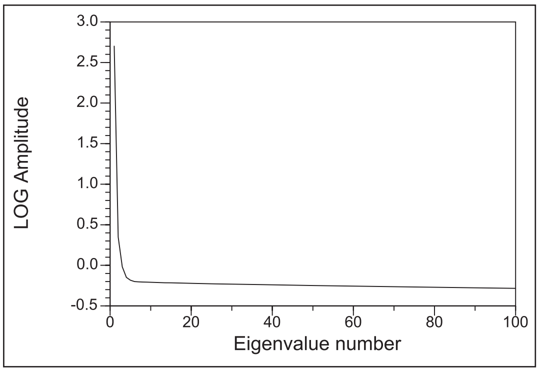

Fig. 9. Eigenvalues for the Fowlers Gap test flight calculated using the MNF method with along-line differencing to calculate the noise covariance matrix.

The second issue is that of mean-centring. The PC method is an analysis of variance about the origin, and best results are obtained if the data are mean-centred first. The NASVD method uses singular value decomposition to analyse the dispersion of the data around the sample mean rather than the origin. This gives eigenvectors that are used in the same way as in the PC method.

Figure 10 shows the eigenvectors obtained for the test data using the NASVD method. Again, we can see good separation of signal and noise.

Which is Better - NASVD or MNF?

The NASVD method is versatile and easy to implement. As the eigenvectors and amplitudes can be saved, it is a neat way of compressing the multichannel gamma-ray data. Smooth spectra can be reconstructed at a later time with any number of components. Thus, the eigenvectors can be studied to determine how many components should be used for smoothing. The amplitudes can be gridded and studied for the same purpose. This analysis of the eigenvectors and associated amplitudes is a useful form of quality control. Any significant spikes in the data, or excessive energy drift in the spectrometer, are easily recognised. Whether the MNF method can be used for this type of quality control depends on the particular implementation of the method. If the noise normalization and PC transformation are tied up into one transformation you don't get to see these eigenvectors. However, if the method is implemented along the lines of the noise-adjusted PC transform of Lee et al. (1990), then the eigenvectors can be saved and used in the same way as for the NASVD method.

In practice, there is little difference between the methods. Any comparison should look at both noise reduction (precision) and accuracy. Table 1 shows the noise reduction for the test dataset using the NASVD and MNF methods. The results are very similar. Tests for accuracy using synthetic data show that the methods produce similar results. If there is a discernible difference between the methods, it will be in the detail – i.e. which method better accounts for subtle components. A comparison of this type can only be done with synthetic data and is beyond the scope of this article.

What Happens When Things Go Wrong?

When things go wrong it is usually due to either poor application or poor implementation of a method. Noise

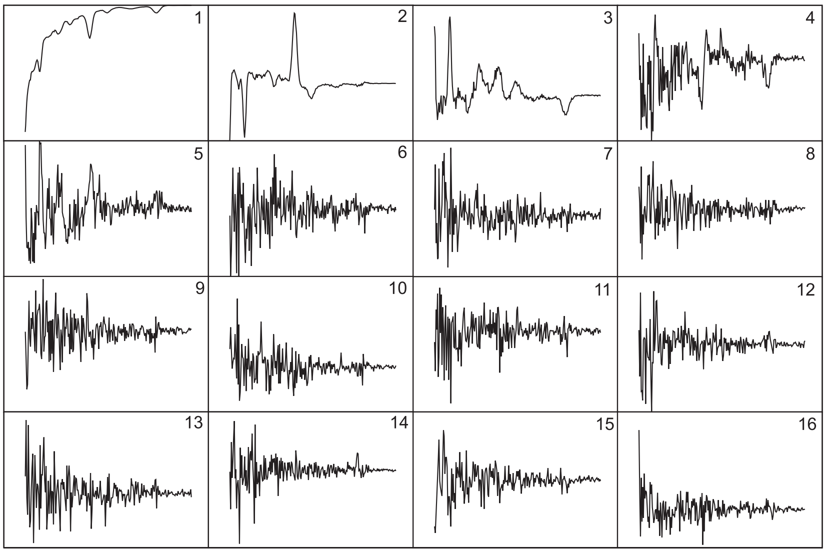

Fig. 10. (Above) Eigenvectors for the Fowlers Gap test flight calculated using the NASVD method.

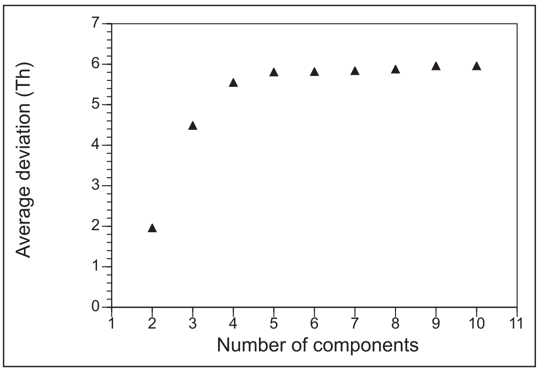

Fig. 11. (Right) The average deviation as a function of the number of components used to reconstruct the smooth spectra using the NASVD method. The average deviation is a measure of the noise envelope on the processed Th profiles.

reduction, on its own, is not a good indicator that a method is working properly. This is because large apparent reductions in noise occur when signal is removed from the data. Figure 11 shows the Th errors for our test data as a function of the number of lower-order NASVD components used to reconstruct the smooth spectra. The eigenvectors for this analysis are those shown in Figure 10. This shows that the effect of reducing the number of components from, say 10 to 5, is small, as these components mainly represent noise. However, as soon as we start removing signal by reducing the number of components further, the result becomes a lot smoother. This is a common trap, and represents poor application of a method. Remember, the noise is more or less evenly represented in all of the components. So each component will represent about 1/256 of the noise. If you reduce the number of components in the reconstruction and achieve a much larger reduction in noise than expected, it may well be because you have removed signal.

Implementation	Fractional error (%) K	U	Th
3-channel method	7.90	42.24	8.81
MNF	6.64	25.71	6.49
NASVD	6.80	27.20	5.88

Table 1. Fractional errors for AGSO's Fowler's Gap (flight 137) gamma-ray data processed using the 3-channel method, the MNF method and the NASVD method. Eight components were used to reconstruct smooth spectra.

Implementation	Fractional error (%) K	U	Th
PC (no noise adjustment)	5.22	13.83	2.26

Table 2. Fractional errors for AGSO's Fowler's Gap (flight 137) gamma-ray data processed using the PC method without any prior noise adjustment of the data. 25 components were used to reconstruct the smooth spectra.

If a method has been poorly implemented, the signal will not be represented by the lower-order components only. The PC analysis of our test flight without noise normalization is an example (Figures 5 and 6). The signal is not confined to the lower-order components, and the eigenvalues do not reach a plateau after only 5-6 components. Even if we use a whopping 25 components to reconstruct smooth spectra, we still get a much greater apparent reduction in noise than the MNF/MAF or NASVD methods (Table 2), but this is at the expense of removing signal. Figure 12 shows ternary images of the Fowlers Gap survey area for data where there has been good (Fig. 12a) and poor (Fig. 12b) separation of signal and noise. The same colour enhancement has been used on both images. The elemental concentrations used in Figure 12b are far smoother than those in Figure 12a, but these results have been significantly compromised by the removal of signal. The effect of this is a limited range of ratios between the radioelements resulting in a ternary image lacking the range of hues normally seen in gamma-ray images.

Finally, poor data can also be a source of errors. The spectral component methods must be applied to raw gamma-ray spectra. If the spectra have been energy calibrated, for example, the error variance associated with each channel count rate is no longer predictable, and the error normalization procedures used by the MNF/MAF and NASVD methods will fail.

Towards Guidelines for Spectral Smoothing

So how can we be sure that we are doing the right thing? With the NASVD method we can look at both the eigenvectors and eigenvalues. If our implementation of the method is correct, and for good quality gamma-ray data (minimal spectral drift), the signal should be represented by fewer than 8 components - i.e. there should no coherent spectral shapes in the components higher than 8. If you are uncertain, use more components (10-15) to reconstruct the smooth spectra. If these extra components represent noise only, they will not contribute significantly to the noise level in the smoothed spectra. With the MNF method the eigenvalues will give some indication that the method has been implemented correctly. The values should reduce rapidly to a relatively constant value within 8 or fewer components. But the eigenvalues should not be relied upon solely when deciding how many components to use for smoothing. One alternative is to grid the amplitudes of each component. If a component represents a significant amount of signal there should be some suggestion of coherent structure in the grid.

The ultimate test of whether a new implementation of a method is working correctly is to test the method using synthetic data. The Australian Geological Survey Organisation has the facility to generate synthetic datasets based on smoothed versions of real survey data. These datasets can be used to test the results of spectral smoothing methods against the true values. If you are interested in testing your processing methodology in this way, contact me (Brian.Minty@agso.gov.au) and I will send you a synthetic dataset.

Can real anomalies be removed through spectral smoothing? The answer is most certainly YES! It all depends on the amplitude of the anomaly and how discrete the anomaly is in terms of its spectral shape. This is a difficult issue. Spectral smoothing has enormous benefits in that it allows us to see subtle anomalies that would otherwise be obscured by noise. But at the same time, if a spectral shape is not well represented in a dataset, anomalies based on this shape can be removed during the smoothing. Jens Hovgaard and I are collaborating to try and find ways of minimising this problem, and to formulate guidelines for the spectral smoothing of gamma-ray data. We hope to be able to present the results of this research at the ASEG Conference in Brisbane in August 2001.

Acknowledgements

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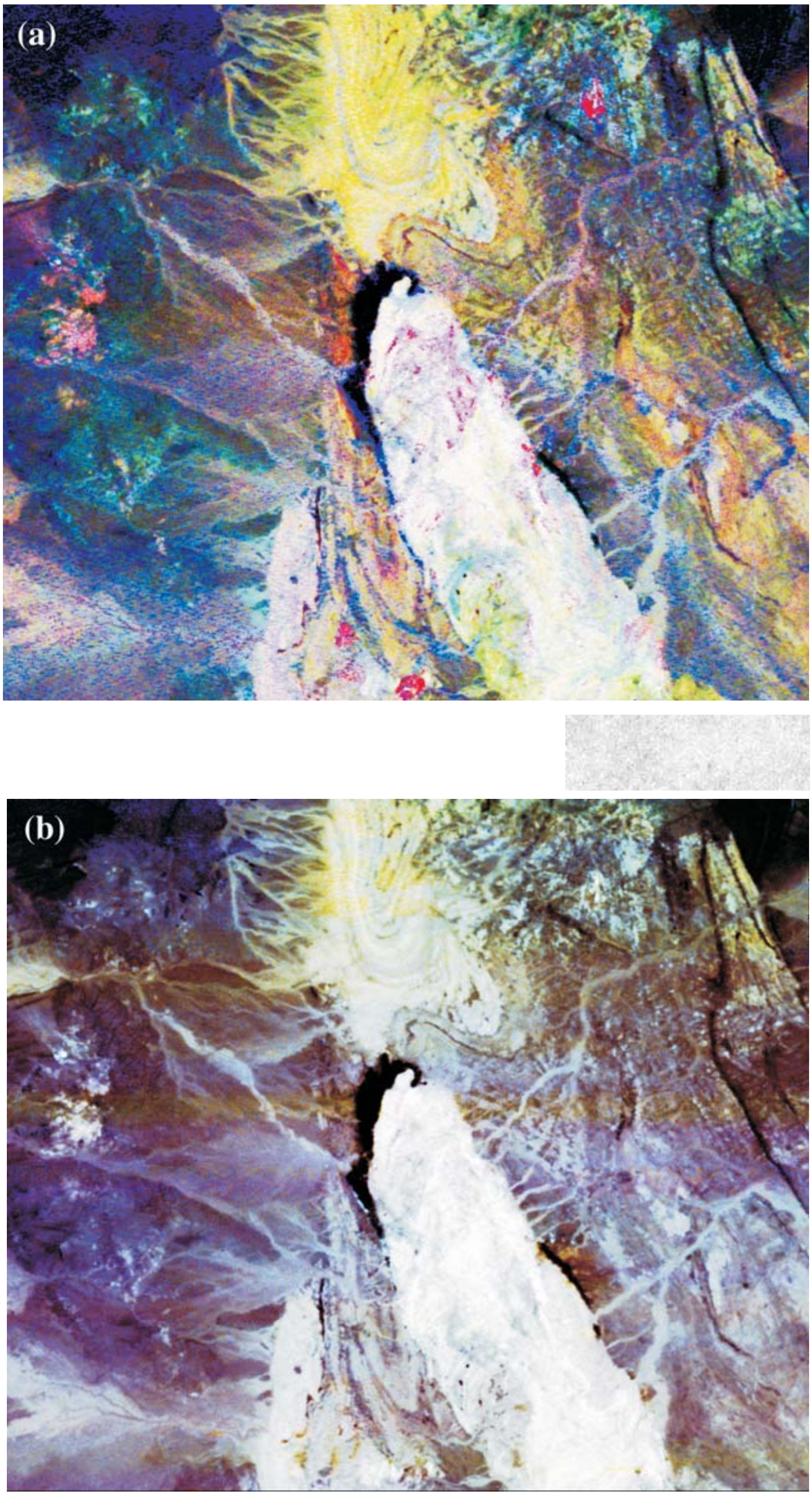

Fig. 12. Ternary images of the Fowler's Gap survey area: (a) good separation of signal and noise, and (b) poor separation of signal and noise.

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The Northern Territory Geological Survey has announced the release of the latest in a series of integrated geophysics and geology interpretation maps produced to encourage further minerals exploration in the Northern Territory.

The new maps cover the Tanami goldfield region north-west of Alice Springs and part of the Musgrave Block in the south-west corner of the Northern Territory.

They are an important new addition to the existing series of geoscientific products and are a direct result of $16 million in additional funds provided by the NT Government over the period 1998 - 2003 specifically to stimulate further exploration activity. This increased funding recognises the importance of the mining industry to the Northern Territory economy and allows the NT Geological Survey to provide data **free** to the exploration industry.

The latest project to be finished as part of this initiative are the new 'Integrated Geophysics and Geology Interpretation' maps.

Geophysical interpretation maps are used extensively by exploration companies in the initial stages of exploration. In many regions of the Northern Territory, particularly those that are poorly exposed, airborne geophysics is the most comprehensive representation of the geology available.

Other products in the series include new 1:2.5M geological and magnetic synoptic maps of the entire Northern Territory, the index of company mineral exploration reports available on-line, open-file company mineral exploration reports from 1983 - available on CD ROM, computer images from the best airborne geophysical datasets in Australia, electronic pre-releases of maps and reports and exploration geochemical GIS dataset of the Tanami Goldfield.

The latest map release of the Musgrave and Tanami regions is an exciting addition to a comprehensive series of products produced by the Northern Territory Geological Survey. Most importantly, the provision of free data is working to stimulate increased minerals exploration activity in the Northern Territory.

New Magnetic Map of the Northern Territory

The Northern Territory Geological Survey announced in October this year the public release of the 1st edition Magnetic Map of the Northern Territory.

This product was produced by Andrew Johnstone and Kerry Slater and accompanies the recently released Geological Map of the Northern Territory.

The Magnetic Map of the Northern Territory represents the culmination of several decades worth of work since BMR first acquired airborne magnetic and radiometric data in the Northern Territory at Rum Jungle in 1952.

Approximately 55% of the area of NT is covered by data from 38 separate NTGS and AGSO semi-detailed airborne surveys flown since 1981. These data were acquired along flight lines spaced 200-500 m apart. Specifications for individual surveys are shown on the NTGS Airborne Geophysical Index Map. The remaining portion of the map is made up of old BMR surveys, which typically employed flight line spacings of around 1.5-3.2 km.
More information on this map, including how to order the hardcopy (1:2 500 000 scale) or digital versions, is available on the NTGS website at:
http://www.dme.nt.gov.au/ntgs/reg_geoscience_prgms/nt_wide_map.html

The Magnetic Map of the Northern Territory will be updated annually as new regional surveys are flown and added to the public domain database. The 2nd edition Magnetic Map of the Northern Territory is scheduled for release at the Annual Geoscience Exploration Seminar (AGES) scheduled for March 20th 2001 in Alice Springs.

NTGS hosts the annual exploration seminar which is designed to report to explorers the results of current geoscience programs and to present an overview of future directions. This is an occasion where exploration geologists from around Australia are invited to attend and interact with Survey staff.

Earth System Science From Biogeochemical Cycles to Global Change

Edited by:

Michael C. Jacobson, Robert J. Charlson, Henning Rodhe and Gordon H. Orians

International Geophysics Series, Volume 72Academic Press, 2000

ISBN 0-12-379370-X

Reviewer:

Ted Lilley

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This book is the second edition of one published in 1992 under the title Global Biogeochemical Cycles, and edited by Samuel S. Butcher, Robert J. Charlson, Gordon H. Orians and Gordon V. Wolfe. It is stated that 5000 copies of the first edition were distributed.

The second edition contains all the material in the first, in an updated form, and adds a fourth part. The co-editorship has changed accordingly. The title thus records some history. In the years since 1992, the idea of a whole-Earth system has become a most satisfying concept, and global change is one of the present most-studied subjects.

The nineteen chapters have been contributed by a total of 28 authors. Their range is international, with some 13 from the University of Washington, Seattle. The co-editors are from the University of Washington (three) and the University of Stockholm (one), and it is clear that the book has developed from courses given at these two institutions, in particular. Possibly there has been beneficial wider feedback after the first edition. The material shows the benefits of usage in, for example, problems set at the ends of chapters (with answers at the back of the book). The book has handy lists of physical quantities and basic physical data inside the covers (in SI units, increasingly the accepted standard now). The International Geophysics Series of Academic Press is in fact edited by James R. Holton, of the University of Washington, Seattle.

This is a remarkable book, ultra topical in today's Earth science, and a treasure-house of information. So much is here, in fact, that it will be mainly a reference book to dip into, rather than to read straight through.

In four parts, it starts with basic concepts for Earth System Science. It makes the point that the Earth is effectively a closed system from the point of view of matter, and that the most important characteristic from a human perspective is that it has abundant life in a biosphere. The first part has foundation chapters on biogeochemical cycles, on the origin and early evolution of the Earth, on the evolution and the biosphere, on the principles of modelling biogeochemical cycles, and on the concepts of equilibrium and rate in natural systems.

Part two then has chapters on the properties of and transfers between the key reservoirs. Five reservoirs have a chapter each, these being water and the hydrosphere; the atmosphere; soils, watersheds and marine sediments; tectonic processes and erosion; and the oceans.

Part three moves to biogeochemical cycles particularly, with chapters on the carbon cycle, the nitrogen cycle, the sulphur cycle, the phosphorus cycle, and trace metals.

Part four then brings it all together (and is indeed called Integration), with chapters on the acid-base and oxidation-reduction balances of Earth, and on the couplings of biogeochemical cycles and climate. Then a chapter on ice sheets and the ice-record of climate change, and finally a chapter on human modification of the Earth system, and global change.

The book has four colour plates, included together at the centre of the book. They give a sample of the range of the book: the first is a diagram of the whole Earth as seen from say the Moon, with radiation from and to space, the atmosphere and the oceans driving sediment transport, and mantle convection driving the tectonic plates. At Earth's surface the rain causes erosion, and the rivers carry sediments to the sea. Biological processes are closely involved.

Plate 2 is of a section of the atmosphere derived from space-shuttle data, showing (for example) dust clouds from the Sahara carried over the Atlantic Ocean by the trade winds. Plate 3 is a world map showing the different global soil regions. Plate 4 is an image of the sea-floor topography for the Pacific Ocean and surrounding continental areas.

A hazard of a multi-authored book of this kind is that the different chapters will be disjointed and not flow together seamlessly; they will either have gaps between them, or else overlap and repeat material. My impression is that careful editing has countered any such tendency in this case.

There is another point about a book, which is very intentionally 'integrative'. Students meeting various concepts (in physics, chemistry, biology or mathematics) for the first time in this book may pick up much basic science as they go along. However, some prior foundation is needed to fully appreciate the application of these disciplines to the Earth.

Pondering this point led me to think of the pre-twentieth century natural philosophers, faced with the world being revealed in front of them. They were armed with a developing strategy of scientific thought, and started to work through the observed phenomena with a 'divide and rule' approach. Natural phenomena were divided into the subjects of physics, chemistry, biology, etc., and within these subjects analysis continued until each subject was reduced to a fundamental level. Only thus, it was accepted, could the observed phenomena be correctly understood. The present book in a way completes a grand cycle, with these individual disciplines (conquered?) now synthesized again, and the whole Earth system, as we see it, analysed together as a unit.

A wealth of information can be found inside. How well can you explain El Nino to your neighbour? Go to the diagram on page 239. Wondered what the 'conveyor belt' model for global ocean current circulation is? Go to page 244. And, on the most important point of whether global warming is a reality, go to page 507, and find: "As much as we know about the increase in CO2, the forecast of climatic response is unclear..."

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However this book is not the place for solid-Earth geophysics information. Generally it stays clear of the long-time-scale processes of mantle convection, plate tectonics and subduction zones, and also the generation of the main geomagnetic field in Earth's core, and the significance of geomagnetic reversals. The editors would surely agree that the total Earth system includes such phenomena. It is clear they have had to draw the line somewhere, and they may very justifiably have the view that such traditional material is now found elsewhere. Their focus is generally on events of shorter time-scales, such as occur in the atmosphere and oceans.

For exploration geophysicists, used to thinking in terms of the Earth as a place of hard physical quantities (the gravity field, seismic wave-speeds etc.) I think this book brings a very mind-expanding exercise of paying attention to chemistry and biology, and recent and current geological processes. After all, the profession can not know what aspects of Earth it will be called on to measure, map and interpret in the future, and the last ten years have emphasized the importance of environmental matters.

What is Earth System Science in a nutshell? Let me quote from the final chapter: "We have learned much about the individual parts and processes of the Earth's atmospheric, oceanic, continental, physical, chemical, and biological systems. However, we have just started to understand the linkages and feedbacks that make these systems function as a single entity. ...we do know that the global system is changing as a result of known processes... ...and that current changes are large compared to natural ones in the past."

A phone call to a Canberra bookshop brought the advice that this book is published in paper-back only, at price $147 (including GST). I understand this price is on the expensive side both generally, and for Academic Press in particular. However let me again say that there is a lot of information contained in the book's 527 pages, and if it is what you want it will be a very rewarding investment.

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