Preview

Australian Society of Exploration Geophysicists

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Borehole Geophysics II

Application of Geophysical Well Logs in Geotechnical Evaluation of Subsurface Deposits and Geoengineering (Part 2)

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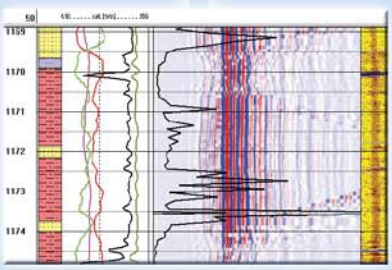

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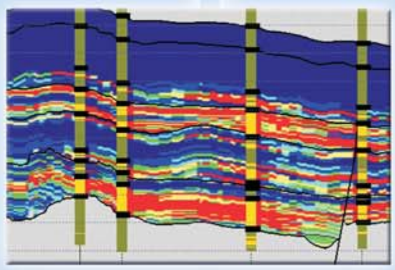

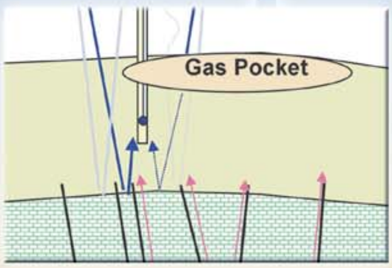

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Borehole Seismic Acquisition and Processing

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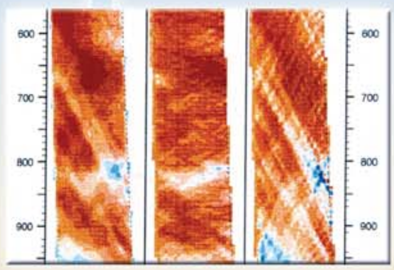

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In this Issue

This edition of Preview is the second of three 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 are reviewing these in the mineral, 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.

Due to space restrictions, we weren't able to include all the papers in the December issue, so some of the contributions were held over until this month. Therefore, we have here some geotechnical applications by Burkhard Unterstell, Peter Fullagar and Gary Fallon, that show how ore grades can be estimated from borehole measurements, a discussion of some advanced applications of geophysics in boreholes by Kevin Dodds, and an insight into borehole geophysics at Schlumberger by Henry Cao.

As one who has not practised borehole geophysics for at least 25 years, I have found these papers to be of great interest and am very impressed by the progress that has been made in recent years. In the April issue we will conclude with part three of Burkhard Unterstell's article and the contribution by Peter Hatherly, on rock strength determinations.

I would also like to draw your attention to Brian Spies' 'President's Piece', which discusses future directions for the ASEG, and Koya Suto's comments on the membership survey. It would be useful to have feedback on these contributions because they are very important in the context of wellbeing of our society. The 'Letters to the Editor' pages are open for discussion in the April issue, where Koya will provide a more comprehensive analysis of the results of the membership survey.

Backing Australia's Ability - An Innovation Action Plan For The Future

Eristicus provided me with his contribution before the Prime Minister made his statement on science, technology and innovation in Australia (January 29th). I will include here the main points of the PM's announcement because they are very important for us all.

Essentially, "the Innovation Statement outlines the next steps in the Government's strategy to encourage and support innovation and enhance Australia's international competitiveness, economic prosperity and social wellbeing."

Some may argue that it is too little too late, but it nevertheless marks a major change in the Government's policy on science and education. The Government recognises that 'success in the 21st Century will depend predominantly on the innovative capacity of nations, their industries and their research and educational structures.'

According to the joint press statement issued by Ministers, Alston, Kemp and Minchin, backing Australia's ability provides a comprehensive package with an additional Government investment of $2.9 billion over five years. It turns out that it will spend only $160M in 2001/02, rising to $950M in 2005/06.
The new funding over the five-year period will provide:

- An additional $736M for Australian Research Council competitive grants, doubling funding by 2005-06,

- A boost to research infrastructure funding by $583M,

- An additional $176M for world class centres of excellence in the key enabling technologies of Information and Communications Technologies (ICT) and biotechnology,

- $155M to support investments in major national research facilities,

- A continuing commitment to the R&D Start Program with funding of $535M over five years,

- Reforming the R&D tax concession including the provision of a premium rate of 175% for additional R&D activity, and a tax rebate for small companies, amounting to an estimated $460M,

- Expanding the Cooperative Research Centres Program with an additional $277M and encouraging greater access by smalland medium enterprises,

- Increasing funding to universities by $151M to create 21 000 additional fully funded undergraduate university places over five years with priority given to ICT, mathematics and science - to be backed by adjustments to existing immigration arrangements to attract more migrants with ICT skills,

- Encouraging lifelong learning by introducing an income-

  contingent loans scheme for postgraduate fee-paying students. An estimated $995M in loans will assist around 240 000 Australians to upgrade their skills and gain new qualifications, and,

- Delivering $130M to foster scientific, mathematical and technological skills, and innovation in government schools in those States where the Enrolment Benchmark Adjustment (EBA) is triggered.

More information on the initiatives from the Government's innovation statement is available from the Commonwealth Government Innovation Websiteat:www.innovation.gov.au. However, when I tried to access it on the day of the announcement the site was clogged up and almost inaccessible, better luck now.

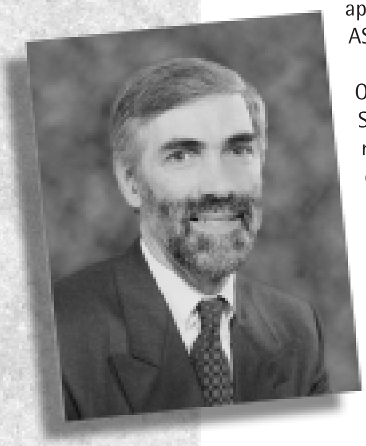
Most of the recommendations have direct impact in the geoscience sector. We have been arguing for some time for an expansion of the CRC Program to include smaller companies, and also more funds for the ARC. The reform of the tax concession will also be good news for many of our smaller service companies, but Treasury is still concerned about the rorting that went on during a similar scheme some years ago so I am sure they will be on the lookout for abuses of the system.

I invite all readers to look closely at the website and see how the new initiatives can help their R & D activities.

Congratulations to the Chief Scientist, Robin Batterham, for tirelessly mounting an effective and persuasive campaign since his appointment.

A Renewed Vision for the Society

As the world changes at an ever-increasing pace, so does our profession, the technology we develop and use, the applications of our science, the role of the ASEG, and the needs of its members,



On January 16th, the Federal Executive held a Strategic Planning Meeting to examine the role and function of the ASEG, and directions in which it should move to remain a vigorous and dynamic society, serving the needs of our profession and membership. Kevin Dodds, President of the W.A. branch, also attended the meeting, and added valuable input on the views from state branches. Background information for the meeting was solicited from all state branches and committee chairmen, as well as others actively involved in the society. Preliminary results of the recent membership survey and founding papers of the society dating back to 1970 were also used as input to the meeting.

Membership Survey

The survey, which covered about 20% of the ASEG members, showed that the membership is generally satisfied with the society's activities and its value for money, and felt that the things we do are done correctly. Perhaps the most interesting result is that members overwhelmingly feel the society should broaden its scope of activities into other, non-traditional areas of geophysics, such as environmental, geotechnical and groundwater. Around one-quarter of members attended all three of the ASEG conferences in the last five years, while one-quarter of members attended none, mainly due to travel costs or limits imposed by employers. Clearly, the latter members' main advantage of belonging to the Society is our publications. Koya Suto's preliminary report is on page 9. He will present a summary of the member survey in the next issue of Preview, and a full version will be posted on the ASEG web site.

Our Founding Fathers

The ASEG was formed in 1970 by a small group of active SEG members, and the society grew to 295 within the first year. The ASEG was based in Sydney for its first 12 years and actively encouraged the formation of state branches. Today the society has 1280 members, of which 20% are overseas residents. Interestingly, around half the members who responded to the survey are also members of the SEG. Members' employment is concentrated in minerals and petroleum.

Building a Strategic Plan

Using the results of the membership survey and the combined experience of past and present executive committees and state branches, the assembled group set about examining the original goals of the society to determine whether they are still relevant today and what changes may be appropriate. Reassuringly, the original goals are largely still as valid today as when the Society was formed, and after much discussion a set of revised goals was developed. The proposed goals cover the science and application of geophysics, the profession, people, outreach and linkages, Australian focus and safe work practice.

Goals for the Society

1. To promote the science of geophysics, especially as it relates to resource, geotechnical and environmental applications;
2. To promote and strengthen the profession of geophysics and its good standing in the community;
3. To promote fellowship and co-operation among practitioners, users, educators and researchers of geophysics;
4. To promote co-operation and links with other professional groups;
5. To promote and facilitate Australia-wide involvement and focus, while maintaining international relevance;
6. To promote and encourage safe practice throughout the industry.

Governance, Operation and Empowerment

The committee also examined the current operation of the Society and developed a list of suggestions that would enable us to function more efficiently, better meet our goals and serve the needs of our members. Of course a detailed business case for any change from current practice would need to be developed before implementation, and changes to the ASEG Constitution made where necessary. The following list is a short

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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
91 Apr 2001	Mar 15 2001	Mar 22 2001
92 Jun 2001	May 15 2001	May 22 2001
93 Aug 2001*	**Jun 29 2001**	**Jul 13 2001**
*** (Conf Edition)**		
94 Oct 2001	Sept 15 2001	Sept 22 2001
95 Dec 2001	Nov 15 2001	Nov 22 2001
96 Feb 2002	Jan 15 2002	Jan 22 2002

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 April 2001 edition is the 22nd of March.

Print Post Approved – PP3272687 / 0052.

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Omission

The advert for Northern Territory Geological Survey (NTGS), which ran on page 23 of the December edition of Preview (Number 89) ran with one line of text missing. The third bullet point should have read:

**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 NT at 100 m resolution.*

Continued from page 4

summary drawn from a larger document that will be sent to state branches and posted on the ASEG web site, for input and discussion by the Council and state branches.

- The Federal Executive should be truly representative of the membership as a whole, and be drawn from members from different states;
- An ASEG 'Council' could become the governing body of the society, with representation based on the diverse geographic location and interests of its membership;
- The Society should evaluate the benefits of employing a full-time Executive Director to coordinate all activities of the society, ensure efficient operation of Secretariat functions, and take a key role in conference organisation;
- Activities of the society should be coordinated to an annual cycle to facilitate efficient use of its volunteer workforce serving on state branches, Federal Executive, standing committees and Council;
- There are compelling reasons for the ASEG conferences to be held at approximately the same time each year. This would allow, for example, better forward planning for exhibitors, organisers and delegates. Meetings of the Annual General Meeting, Council, committees and elections could be timed to coordinate with such an annual conference;
- More effort needs to be put into recognition and non-monetary rewards for the society's volunteers.

Where to from here?

Obviously, there will need to be much discussion within the Society on the recommendations listed above. I encourage you all to read the full report on the ASEG web site (www.aseg.org.au) and pass on your comments and thoughts to your local branch or join the discussion forum on the ASEG Web site. State branches will be asked to develop possible strategies to refine and implement the goals listed above, and these will be discussed at the ASEG Council meeting on the afternoon of Sunday, August 5th, at the Brisbane ASEG conference, immediately before the Icebreaker Reception. We welcome your feedback and suggestions, to help make the ASEG the type of society that will serve your needs for many years into the future.

Brian Spies
President

ASEG Officers

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Events for 2001/2002

2001

March 4-7

The Annual Meeting of The Environmental and Engineering Geophysical Society
Doubletree Hotel, Denver Colorado, USA.
Theme: Geophysics: Reducing Risk in Environmental and Geotechnical Engineering.
Email: lcramer@expomasters.com
Website: http://www.sageep.com/

May 8-10
SEG-GSH Spring Symposium 2001, Houston , Texas, US.
Theme: Reservoir Resolution Through Comprehensive Use of Seismic Data Attributes
Call for papers deadline: 17 April, 2001, to seg.papers@texseis.com
Contact: Mike Graul, Tel: 713-465-3181
Email: symposium.info@texseis.com
or
Contact: Tury Tanner
Tel: 713-783-5593
Email: mt.taner@rocksolidimages.com

March 20
Annual Geoscience Exploration Seminar, Alice Springs, Northern Territory Geological Survey
Contact: Richard Brescianini Tel: 61 8 8999-5389
Email: richard.brescianini@nt.gov.au,
Website: http://www.dme.nt.gov.au/ntgs.

March 27-29
5th National Forum on Information Management in the Geosciences
CSIRO Discovery Centre, Canberra
Theme: Geoscience Online
Contact: Jenni Castles, AGSO
Email: jenni.castles@agso.gov.au
Tel: 02 6249 9794
Website: http://www.gov.au

March 29
Annual Open Day of the Geological Society of Western Australia
Novotel Langley Hotel
Theme: *GSWA 2001*
Contact: Tim Griffin, GSWA
Tel: 08 9222 3333
Email: geological_survey@dme.wa.gov.au
Website: http://www.dme.wa.gov.au/geology

May 29-June 3
American Geophysical Union, 2001 Spring Meeting, Boston, Mass., US.
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, Qld.
Theme: '2001: A Geophysical Odyssey'
Website: http://www.aseg.org.au
Event Manager: Jacki Mole
Tel: +61 7 3858 5579 or 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, US.
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

2002

May 12-17
International Association of Hydrogeologists, Australian National Chapter, International Groundwater Conference, Darwin, Northern Territory, Australia.
Theme: Balancing The Groundwater Budget
Contact: Gary Humphrey
Email: Gary.Humphreys@nt.gov.au

May 27-30
64th EAGE Conference & Technical & Exhibition, Florence, Italy
Website: http://www.eage.nl

June 30 - July 5
16th Australian Geological Convention
Theme: Geoscience 2002: Expanding Horizons
Adelaide Convention Centre, Adelaide, SA
Contact: info@16thagc.gsa.org.au
Website: http://www.16agc.gsa.org.au

September 22-27
SEG International Exposition & 72nd Annual Meeting, Las Vegas, Nevada, U.S.A.
Website: http://www.seg.org

October 20-23
West Australian Basins Symposium (WABSIII), Burswood Convention Centre, Perth
Organised by PESA
Contact details: Peter Baillie, Tel: 0417 178764
Email: peterb@tgsnopec.com.au

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
For information on upcoming meetings/events/agendas, please see: http://www.aseg.org.au/wa

Annual General Meeting - WA Branch:
The AGM was held on December 7th. The items presented were:

- Highlights 2000
- Reports from the Treasurer and Secretary
- ASEG Silver Certificates were presented to:
  - David Isles, Mick Micenko, Stephen Mudge, Robert Nunn, Andrew Svalbe, and Norm Uren.
- Student Nights Awards
  - CSIRO Award to:
  Jodie Crystal: *Geophysical case history of the Brockman Creek Kimberlite dykes, Marble Bar,* and Trang Nguyen: *The recovery of elastic parameters for lithology from multi-offset VSP data.*
- Nomination and election of 2001 executive committee members (see below)
- Nomination of 2001 committee members
- Goals for 2001
- Any other business.

Full details available through our website.
Next general meeting scheduled for February 2001 available on the website.

Sponsorship
If your company would like to present a paper and/or sponsor at ASEG WA meetings please contact Kevin Dodds, CSIRO (08 9464 5005) or Guy Holmes, Encom 08 9321 1788) about speakers and sponsorship possibilities.

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

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South Australia - by Michael Hatch

We apologise for missing the deadline for this column in the last issue of Preview. I guess that we will just have to make up for it here.

Let's start at the beginning. On September 26th, we held our annual Industry Night. This year's speakers came from most walks of geophysical life around Australia; we had speakers from Beach Petroleum, Schlumberger, PIRSA, and Zonge Engineering. Thanks to all of these companies for giving us their insights into what makes them tick. And thanks to Beach, Schlumberger, PIRSA and Zonge for their sponsorship.

Then on the October 17th we enjoyed having Dennis Cooke, Chief Geophysicist - Corporate of Santos give his presentation titled: *What is the best seismic attribute for quantitative seismic reservoir characterisation?* A most enjoyable evening, with a good turnout, and many thanks to our sponsors for this evening: Western Geophysical.

Continued on page 9

New Members

We would like to welcome the following new members to the ASEG. Membership was approved by the Federal Executive at its December meeting.

Name	Affiliation	State
Terry Visser	PGS	WA
Sergei Tcherkashnev	Schlumberger	UK
Roman Tykajlo	Geo-Digit	Canada
Brett Adams	Curtin Uni	WA

Continued from page 8

On November 2nd, Tim Flannery of the South Australian Museum gave the penultimate talk in the Millennium Series. This one was hosted by PESA, and was titled: *Extinctions, Past and Future.*

Our annual Melbourne Cup Luncheon was a huge success. More than 70 locals attended. Apparently Richard (the wily Scotsman) Hillis' table managed to have shares in first through third places. Good show Richard, and many thanks to event organisers Rod Lovibond and Suzanne Roberts.

Then on December 6th, Don Henry of the Australian Conservation Foundation gave the final Millennium Series Lecture, this one hosted by SPE. His talk was titled: *Environmental Challenges in the New Millennium.*

On November 29th we held our Annual Honours Students Presentation Night. Four students, representing four local universities, presented their honours projects. The presenters were: Alex Dunbar of the NCPGG whose talk was titled: *The search for submarine fan complexes in the Upper Cretaceous Browse Basin, North West Shelf, Australia;* Derick Zurcher of the University of South Australia and the NCPGG whose talk was titled: *The relationship between coal thickness and sandstone reservoir development in the mid Patchawarra Formation, Tirrawarra Field, Cooper Basin;* Volmer Berens of Flinders University, whose talk was titled: *Marine magnetotellurics and sub-salt exploration in the Gulf of Mexico;* and finally Matt Hutchens of the Adelaide University, whose talk was titled: *An investigation of the Para Fault, Adelaide using the micro-gravity method.* Two prizes were awarded. Volmer Berens won the award for Best Paper, and Alex Dunbar won the award for Best Presentation. Congratulations to the winners, and many thanks to all of the students for their efforts. Also may thanks to our sponsors Adelaide University, NCPGG and Flinders University.

For the final event of the year, Richard Hillis, local branch president, hosted the annual Christmas party. Attendance was quite good with more than 50 South Australian geophysicists hanging around until all hours of the night.
We are pleased to tell you that 205 cases of wine (about 60% red and 40% white) were sold this year. Which of course means that all of you should have received your wine selections by now. If you haven't please let us know. We all hope that you enjoy these for the next few months (and years?).

As for the near future, things are just firing up after a restful holiday season. See you at the meetings.

ASEG Membership Survey: Preliminary Analysis[1]

Who responded to the survey?
230 members provided returns for this preliminary analysis. (Additional responses came later, and the number for final analysis will be 236.)

Geographical Distribution
6.2% of Australian members responded (179 out of 1109)
10.5% of overseas residents responded (29 out of 276)

Age, Tenure, Employment
The distribution of the respondents is consistent with that of the total membership.

Membership of other societies
55% of the respondents are SEG members; this is much higher than the ratio of SEG members in the total ASEG membership.

Brief Summary of the Preliminary Analysis
In many aspects the respondents are, on average, quite satisfied with the current range of services provided by the ASEG. The scores (out of 10) are:
periodical publications (7.4-7.8),
special publications (6.8),
conference (7.4),
secretariat services (6.9),
branch activities (6.9),
and over-all satisfaction (7.7) resulting in a good rating of value for money (7.5).
The current frequency of the periodical publications, delivery media of the publications, frequency of conference and membership fee are supported as appropriate.

The above result led to a suspicion that the respondents may be biased towards the conservative end of spectrum of the whole membership. However a preliminary analysis of the demography does not show any particular bias.

Overall the results indicate that what the ASEG is doing, it does well.

So what is not highly regarded? In section C of the survey (Enhancement of Profession), most members want to broaden the scope of ASEG (rated 7.4). The ratings of the following are relatively low, but still higher than 5:
contribution to certification (current rating 5.3),
to advocacy (5.8),
to standards (6.3),
to networking (6.6)
and to education (6.7).

These are the areas for the ASEG to work on to improve its membership service. A full report will appear in the next issue of Preview.

Koya Suto

[1] *This is a preliminary report of the Membership Survey distributed late last year. Koya will provide a summary of the final analysis in the April Preview.*

ASEG 2001: the Year of the Odyssey

Over 200 expressions of interest have been received for the ASEG 15th Geophysical Conference and Exhibition to be held in Brisbane later this year. Potential authors from 23 different countries have submitted their expressions of interest. The themes include:

- 3D Data Visualisation
- Borehole Geophysics
- Tomography
- Coal Seismic
- Amplitude Versus Offset (AVO)
- Seismic Attribute Extraction and Application
- Gravity Inversion
- Airborne Electromagnetics (AEM)
- Radiometrics
- Ground Penetrating Radar

There are also a high number of case studies being presented, where several geophysical techniques have been applied. These case studies come from the petroleum, mineral, coal and ground water domains.

At the time of writing there are only six months to the conference and the Organising Committee is about to enter its most challenging phase that culminates in the first registration brochure.

For this conference, industry leaders have been sought to give the Keynote Addresses, and the following speakers have agreed to make presentations:

Dr. Agu Kantsler,
Director New Ventures Woodside Energy Ltd
Mr. Vince Gauci,
Group Executive - Operations MIM Holdings Ltd
Professor Ken McCracken,
Jellore Technologies

Intending exhibitors are reminded to return their trade application forms with a 50% deposit as soon as possible. Full payment is due by May 31st. Spaces are filling fast, with one of our Silver Sponsors (Veritas DGC) taking up nine booths for their display.

Sponsors

The Conference Organising Committee is pleased to announce the full list of sponsors as confirmed by January 24th 2001. Opportunities for sponsorship are still available and those interested should contact the conference organisers at the address below

Gold Sponsors

Woodside Energy
Fugro Airborne Surveys

Silver Sponsors

BHP Petroleum
CSIRO
MIM Exploration
PIRSA
Veritas DGC
WMC

Bronze Sponsors

Anglo American Exploration
Dynamic Satellite Surveys
Green Mountain Geophysical
Jonmich Biodiagnostics
Origin Energy
Northern Territory Geological Survey
Queensland Department of Mines and Energy
Quantec Geoscience
Velseis Group of Companies

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
August 5 - 8 2001
Tel 61 7 3858 5579
Fax 61 7 3858 5510
Email aseg2001@aseg.org.au
www.aseg.org.au

Henk van Paridon

ASEG Honours and Awards: Calls for Nominations

During the 15th ASEG Conference to be held in Brisbane in August 2001, up to six categories of honours and awards will be presented to people who merit recognition for distinguished service to the Society and or to Exploration Geophysics. These honours and awards are:

- ASEG Gold Medal - for distinguished service to geophysics.
- Honorary Membership - for distinguished contributions to the profession of Exploration Geophysics.
- Grahame Sands Award - for innovation in Applied Geophysics. It is made to a person or persons who has or have been responsible for a significant practical development of benefit to Australian applied geoscience. This could be in the field of instrumentation, data acquisition, interpretation or theory.
- The Lindsay Ingall Memorial Award - For the promotion of geophysics to the wider community. The award is intended for an Australian resident or former resident for the promotion of geophysics, (including but not necessarily limited to applications, technologies or education), within the non-geophysical community, including geologists, geochemists, engineers, managers, politicians, the media or the general public. The candidate need not be a geophysicist, or a member of the ASEG.
- ASEG Service Medal - In recognition of outstanding service (over and above normal) to the ASEG over many years, through involvement in and contribution to State Branch or Federal Committees, ASEG Publications or Conferences.
- ASEG Service Certificate - In recognition of outstanding service to the ASEG, through involvement in and contribution to State Branch or Federal Committees, ASEG Publications or Conferences.

Nominations are now called for the above awards. Any member of the society is eligible to nominate applicants. Nominations are to be supported by a seconder and include four copies of all relevant supporting documentation. For the Lindsay Ingall Memorial Award, the nomination should also be supported by letter by at least four other geoscientists who are members of an Australian geoscience body (e.g. GSA, AusIMM, AIG, IAH, ASEG or similar).

Nominations are to be sent to:

Bill Peters
Chairman ASEG Honours and Awards Committee,

8 Kearns Crescent
Ardross
WA 6153

Email: bill@sgc.com.au

Telephone contact:
08 9316 2814

Applications will close on May 5th, 2001.

New ASEG Award Honours Lindsay Ingall

The Federal Executive of the ASEG has approved the establishment of a new award, which carries the name of one of the Society's founding fathers and a leading figure in building strong and lasting links between geophysicists and other geoscientists. The Lindsay Ingall Memorial Award recognises individuals for the promotion of geophysics to the wider community.

Lindsay Ingall passed away at his home in the Blue Mountains of New South Wales on May 21st, 1999, whilst working on the affairs of the Australian Institute of Geoscientists (AIG) as he had done for 20 years. Among many scientific achievements, Lindsay's contribution to the completion of the gravity map of Australia is memorable. Lindsay always volunteered to help others. He helped found the Australian Society of Exploration Geophysicists (ASEG) in 1970, and was its President in 1971/72 and 1978/79. During this time, he worked with others from several institutions to establish the AIG as the professional institute representing geoscientists from all fields of practice. Lindsay was one of the founding AIG councillors in 1981, AIG President in 1989/90, long-term Honorary Treasurer and Chairman of the Membership Committee.

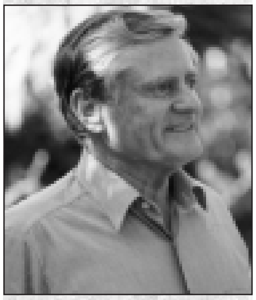
In 1988, Lindsay was made an Honorary Member of the ASEG and received a citation for the ASEG Service Medal for extraordinary service over many years. He had great communication skills, which contributed to his capacity to relate technically and effectively with other professionals, regardless of their own understanding of the principles of geophysics. The new award honours Lindsay Ingall for his capacity to comfortably cross geoscience boundaries and for his enduring commitment to assisting all geoscientists in Australia. Details of the award follow:

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

Number and Frequency of the Award
There will be a maximum of one award at each ASEG International Conference and Exhibition, if a suitable nomination is received. It will take the form of a framed certificate signed by the President and two officers of the ASEG.

Method of Nomination and Selection
Nominations may be submitted to the Chairman of the Honours and Awards Committee (Bill Peters) by any member of the ASEG, supported by letter by at least four other geoscientists who are members of an Australian geoscience body (eg GSA, AusIMM, AIG, IAH, ASEG or similar). The basis of the nomination will be documented in four hard copies files or a complete digital format copy of all relevant supporting documentation. The Honours and Awards Committee will consider any nomination(s) and make its recommendation to the Federal Executive for a final decision. Nominations must be received no later than two months before the Opening Ceremony of a Conference.

Bill Peters
(Chairman Honours & Awards Committee)
and Mike Smith *(ASEG Past President)*



Lindsay Ingall

A Corporate Life

Jon Sumner

Jon is currently Treasurer of the NT ASEG and full time geophysicist for Pod Geophysics.

Interested parties may contact Jon at anytime on 0500 578 277 or at jon@stellarexploration.com.au

A fractured work history highlighted by company downsizing and financial shortfalls is commonplace for the exploration geophysicist of the new millennium. This is the latest trend in an industry coping poorly with native title, oscillating commodity prices and beanies on the board squeezing every last drop from their parched exploration divisions.

Upon termination several opportunities present themselves to the jobless:

(1) ring all your industry mates about a job - if they're not unemployed or on the shortlist for the firing squad;
(2) change your career to something boring;
(3) do nothing;
(4) find an exploration backwater with no unemployed geophysicists and bum drinks off them.

I chose option 4, the backwater of choice being Darwin, Northern Territory - land of enormous tides, lush vegetation and backpackers. The geophysics industry in the N.T. is underpinned by the Government's Departments of Mines and Energy, and Lands, Planning and Environment, which harbour nearly one half of the Territory's geophysicists. The government up here is serious about attracting small business. Since my arrival in March 2000 I have completed a free certified small business course, registered a business name, also for free, and recently graduated from a free graphic design course during which I designed all my company stationery.

Not having work is no hindrance to being successful in the N.T. The Mines and Energy's Exploration Initiative means you can fill your CD racks with free airborne geophysics data and feel proud and important, without the hassles of survey planning and QC-ing data. The spanner in the works of my professional lifestyle choice came when the likes of Humphreys and Brescianini put my name forward to industry players who happened about their respective offices. Dragging yourself from the air-conditioned comfort of the Victoria Hotel to the woods of Batchelor in the mid-November build-up conditions was not appealing, but my commitment to exploration geophysics, and the need for at least a couple of dollars to pass through the company books, was stronger.

On the back of a seven-day job Stellar Exploration was seething with confidence and expansion was inevitable. Pod Geophysics was spawned and became the latest addition to the Stellar Group of Companies. The new sibling needed a corporate image, promo material, and of course, merchandise. T-shirts are currently in production soon to be followed by stubby holders, hats, mouse pads, 9V battery powered ultra strong electromagnetic fridge magnets, die cast POD Lambo's, glow in the dark yoyos, pocket knives, steak knives, and divining rods. Look for us at the next ASEG conference with our 48 seat internet-equipped Daytona network, free Grange for everyone and plenty of booth candy.

What's Next in Exploration Geophysics

The next issue of Exploration Geophysics (Volume 32, No.1) is scheduled for publication in March/April 2001. The papers listed are likely to be included in this Volume.

Airborne Electromagnetic Systems

• Choosing an AEM system to look for kimberlites - a modelling study	A. Raiche
• Tracking the transmitting-receiving offset in fixed-wing transient EM systems: methodology and applications	R. S. Smith
• Experience with SQUID magnetometers in airborne TEM Surveying	J. Lee, C.P. Foley, R. Binks, D.L. Dart & M. Asten

Potential Field Interpretation

• Wavelet based inversion of gravity data	F. Boschetti, P. Hornby F.G. Horowitz

Case Study: Lawlers, W.A.

• Electrical Structure of the Regolith in the Lawlers District, W.A.	J. Bishop, D. Sattel, J. Macnae & T. Munday
• Simplified electrical structure models at AEM scales, Lawlers, Western Australia	J. Macnae, J. Bishop & T. Munday
• A geological interpretation of observed electrical structures in the regolith: Lawlers, Western Australia	T. Munday, J. Macnae, J. Bishop and D. Sattel

In-Mine Geophysicsc

• Detailed orebody mapping using borehole radar	G. Turner, I. Mason, J. Hargreaves & A. Wellington

Electrical Methods

• Electric Potential arising from a point-source near a cylinder in layered earth structures: design criteria for a modified marine heat-flow probe	J. Yang & R.N. Edwards

Groundwater Geophysics

• Geophysical quantification of a moisture content profile in the near surface	P. Hahesy, G. Heinson & A. L. Endres

The Resources Professional and the Share Market

Laurence Kirk
Investment Advisor

Hartley Poynton

A Cautionary Tale

Perhaps this article should really be entitled Safety Matters - Financial Safety Matters. The author spent 17 years as a geologist in the mining and oil industries, watching friends and colleagues punt away the proceeds of their rather gruelling professions on speculative exploration shares. He then moved into stockbroking, to find out for himself what more rational investors actually did with their money. The results of this investigation are offered here as a gentle warning to the young professional caught up in the current on-line, day trading equivalent of the 1980s and 90s resources boom, and as a useful guide to those who wish to use the share market for wiser things.

The Lure of The Share Market

Our resources culture is a culture of risk and reward: the hot exploration dollar spent in search of riches, and the extremes of engineering needed to get them out. Our romance with the share market follows naturally from this. Speculative investors fund our exploits and our efforts in turn offer them the chance of sudden wealth. Our view of the share market is coloured by it. We often see it as a big casino, where people can make riches overnight or lose the lot. The young, well paid professional, sweating away at sea or in the bush, who should be building up assets and investments for the future, is often more tempted by the 'quick fix' of a high-risk punt on a speculative exploration stock. It's part of our culture. It's a sport.

The Pitfalls

Unfortunately, the chances of providing for the future this way aren't too good. The education and training that prepares us for our highly specialised professions, fails us badly when it comes to the investment and management of the rewards. The basic rules of prudent investing: diversification, quality and time, are widely ignored. Funds go into the shares of small, speculative companies, with little regard for liquidity or risk. People invest in their own industry, or worse still in their own employers, with no regard for diversification or the need to separate their source of income from their assets. This folly is made even worse for those in remote areas or overseas, who cannot even research or monitor the investments that they make.

The Consequences

The results of this are usually very poor returns. People's efforts to get ahead, get off the rigs or out of the bush and get on to a better life are marred by bad investments. Hard-earned money is wasted. The share market is misunderstood, misused and finally abandoned as a dead loss. Its potential to generate consistent good returns from wise investment and to compound these over time is never realised. The youthful advantages of good salary, low spending, spare money and the time to make that money work for you are thrown away.

A Safer and More Rational Approach

The key to avoiding these mistakes is to understand the simple rules of risk and return: the greater the return you seek, the greater the risk you must take. If you can't afford the risk, then you must go for lesser but more certain returns. Go for the returns of the quality stocks, of the All Ordinaries Index for instance, which has averaged 12.8% per annum over the past 20 years. Reduce your risk by using diversification, quality and time. Don't just buy resources exploration stocks: diversify across all the major sectors, so that if the explorers or the miners crash, the banks, telcos and retailers will still be powering ahead. Stick to quality: invest in real, well-managed businesses, with profits, dividends and growth. Be in for the long term: ignore the monthly fluctuations and such details as the 1987 boom and crash. Stay in for that average growth, compounded over time. By all means have your adviser spice your portfolio with a few percent of upstart companies to get an extra bit of growth, and let them make occasional switches, to take obvious profits or to avoid problems in individual stocks. But stick to the plot, and let time iron out the risk that others take when trading short-term highs and lows.

Some Financial Career Advice

The sum of this approach is portfolio share investment: invest your serious savings in a well-diversified portfolio of quality shares to get the long-term growth. Have it monitored and managed for you by a good adviser, with the backing and capabilities of a major firm. Have them report performance to you regularly and clearly, particularly when you do your tax return. Use the tax effective leverage of cautious margin lending where appropriate. Make the most of the concessionary tax advantages of superannuation. Take the time to sit down with your adviser and draw up a financial plan: where you are now, where you wish to end up, and how you are going to get there. Plot a course and stick to it, as you would with any other project. Don't just make it up as you go along. Have your financial future soundly engineered.

The Point of It All

A good career is not just the progression up through a demanding, fascinating, challenging profession, to responsibility and management or a company of your own. It is also the progression from being young and single, out there, doing it hard and rising to the challenge, to getting older, being married, having a family, and settling down somewhere pleasant, with a few well deserved comforts and bit more quality of life. To get that right, you need to follow a financial career as solid as your professional one. You don't do that just by trying your luck on the exploration stocks. You do it by prudent, rational, longer-term investment. This may not be as tempting as a punt on the latest drilling results, but the great thing about it is it actually works.

Written by:

Natasha Hendrick

n this edition of Preview, I introduce the Minerals and Energy Resource Departments from around Australia. All of the sites contain a wealth of information to help us in our roles as exploration geophysicists.

For those of you who haven't yet discovered the location of the AUSLIG satellite image included in the last Web Waves - it was Hobart. Congratulations to Ted Lilley for the first correct answer!

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.

Queensland Department of Mines and Energy
www.dme.qld.gov.au

At the Qld Department of Mines and Energy you can preview the latest Qld Government Mining and Energy Journal, learn more about the Geological Survey of Qld, or use the interactive, online maps to discover the mineral, coal and petroleum resources of Qld. Students can download information on fossils, gold, coal and silver-lead-zinc deposits. You can read the latest Mines Safety Alert, or download the question and answer guide to exploration tenure process and/or information on rights of landowners. You will also find information on major minerals projects, mineral commodities and coal publications.

Northern Territory Department of Mines and Energy
www.dme.nt.gov.au

This site introduces you to the key personnel in the NT Department of Mines and Energy. You can download Excel and PDF files covering facts and figures on petroleum reserves and production in the NT. You can also access PDF files providing an overview of mineral exploration; details on mines and projects, and related legislation are also available. The Geological Survey gives an overview of the regional geology, and details geoscience programs occurring in the different geological areas of the NT. Guidelines and application forms for licences, titles and permits are available online.

Minerals and Petroleum

(A Division of Department of Natural Resources and Environment, Victoria)
www.nre.vic.gov.au

An overview of the industry and the history of mining and petroleum exploration in Victoria are available on this site. You can also find out the latest on legislative amendments, keep up with weekly tenement reports or analyse the Minerals and Petroleum Statistical Review. Information on licences, permits and approvals is also available on this site, including details on Native Title and industry activity for petroleum acreage releases.

Minerals and Energy Resources

(A Division of Primary Industries and Resources, South Australia)
www.pir.sa.gov.au

The Mineral Resource Group's pages on this site will introduce you to the SA mineral initiatives as well as detailing major geological provinces and mineral resource potentials. A map of selected mines and deposits is available online. Information on available geophysical data, as well as mining legislation, can also be found. The petroleum group pages detail the prospectivity of SA and provide a geological overview of the basins of SA. You can read the latest industry-related media releases, find out more about Native Title, and look up details on products and services.

Department of Minerals and Energy, Western Australia
www.dme.wa.gov.au

Find out more about the role of the Department of Minerals and Energy and the Geological Survey of WA, read current media releases and the latest ministerial statements. This site also has a range of publications in PDF format, covering dangerous goods, mineral titles, land access and mining. You will also find information on safety and the environment for minerals and petroleum exploration, as well as details on tenements, licences and permits.

Mineral Resources Tasmania
www.mrt.tas.gov.au

Information on the mineral industry in Tasmania is available from this site, including an overview of the Western Tasmania Regional Minerals Program. Details on products and services, including current tenement maps and information for exploration tender areas are available. Read 'ProspecTas', the quarterly newsletter of Mineral Resources Tasmania, online.

Continued on page 15

Two new Cooperative Research Centres in Minerals Exploration Research

Two Mineral Exploration CRCs are included in the 19 new research centres the Commonwealth Government has agreed to support over a seven-year period, starting on July 1st, 2001. The $325M commitment does not represent additional money, but ensures that Commonwealth support is maintained at about $140M per year.

FASTS, the Australian Geoscience Council and the Batterham Report *The Chance to Change*, have argued for a larger public investment in this program, and we may find that the Prime Minister, in his forthcoming Science Statement, will come good with more government funds.

The CRC program is making an excellent contribution to Australia's applied research capacity. It encourages interaction between research teams from universities, industry and government, with funding contributions from each of the three partners. In the geoscience sector, the Geodynamics, Australian Mineral Exploration Technologies (AMET), and Landscape Environments and Mineral Exploration (LEME) CRCs have made very significant impacts to Australian Mineral Exploration.

The new CRCs are LEME2 and one on Predictive Mineral Discovery.

The Cooperative Research Centre for Landscape Environments And Mineral Exploration

This centre aims to provide a breakthrough in mineral exploration of areas characterised by substantial cover (>100m), a flow-on of airborne geophysical methods and regolith knowledge from mineral exploration to environmental studies, and a supply of skilled practitioners and researchers. The centre will also provide high quality, geoscience-based education for those entering the minerals industry, land care and environmental realms and provide continuing education for those already involved.

The core participants are:

Australian National University
Australian Geological Survey Organisation
Curtin University of Technology
Primary Industries and Resources, SA
University of Adelaide
Bureau of Rural Sciences, Land and Water Sciences Division
University of Canberra
NSW Department of Mineral Resources, Geological Survey
CSIRO (Divisions of Exploration and Mining, and Land and Water)
Minerals Council of Australia

The headquarters of the CRC will be in the new Australian Resources Research Centre at the Bentley Technology Park adjacent to Curtin University in Perth, with other nodes in Canberra, Adelaide and Sydney.

The Research and Education Programs are:

Program 1: Regolith geoscience,
Program 2: Mineral exploration in areas of cover,
Program 3: Environmental applications of regolith geoscience,
Program 4: Salinity Mapping, and
Program 5: Education and Training Program

The CRC expects to receive funding of $20.2M from the Commonwealth over a period of seven years. CSIRO's Raymond Smith will be the CRC CEO.

The Cooperative Research Centre for Predictive Mineral Discovery - pmd*CRC

This CRC aims to create a predictive environment for mineral discovery. The highest impact issue facing mineral exploration is: *prediction of the location and quality of ore deposits*. The associated scientific challenge is to develop a holistic view of the processes involved in ore formation. The objectives of this CRC are to:

(1) resolve key areas of uncertainty in existing exploration models;
(2) build 3D and 4D images of mineralising systems using the latest developments in airborne geophysics, seismic imaging, geoscience and isotope systematics;
(3) create a computational environment to simulate the 4D evolution of ore systems with the goal of making predictions concerning ore location, grade, and tonnage;
(4) create a computational environment to allow companies to interact with these computational simulations at a distance; and
(5) transfer these concepts, skills and technologies into the Australian educational scene and into Australian industry.

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Department of Mineral Resources, New South Wales www.minerals.nsw.gov.au

This site provides a good overview of the minerals industry in NSW, including a map of major resources. In addition, information is available for educators in the form of on-line fact sheets covering minerals, exploration and mining. The latest details on the Discovery 2000 initiative can be downloaded in PDF format. As well, you can download the annual report and find key contact details. Take time to enjoy the historic online photo gallery!

Continued from page 15

The core participants are:

Victorian Institute of Earth & Planetary Sciences
Department of Earth Sciences, James Cook University
Department of Earth Sciences, University of Western Australia
Australian Minerals Industry Research Association
CSIRO Exploration & Mining
Australian Geological Survey Organisation

The Research and Education Programs are:

Program 1: Interpreting and understanding mineralising systems and processes,
Program 2: Mineralising Systems Architecture,
Program 3: Mineralising Systems History,
Program 4: Sources, Transport and Deposition Processes,
Program 5: Computational and Interactive Visual Modelling of Mineralising Systems, and,
Program 6: Education and Training.

The CEO will be Robert Haydon from Pasminco.

Whole of Government IT Outsourcing to end: common sense prevails at last.

The Government has done a huge U-turn on IT outsourcing; and the 'whole of government' approach, which has been pushed by Finance Minister Fahey, will be scrapped.

As reported in the last *Preview*, following the Australian National Audit Office's findings on major problems in IT outsourcing, the government appointed Richard Humphry, the head of the ASX, to undertake an independent review of the situation.

Humphry's report was publicly released on Friday, January 12th and the government has accepted his recommendations.

Fortunately, he brought a good helping of common sense to the issue by recommending what many had been saying for several years; the responsibility for IT management within a government agency should rest with the CEO of that agency. It should not be subject to instructions from another part of government that does not have responsibility for the deliverables of that agency.

The original IT plan, adopted in 1997, was to outsource all the government's IT infrastructure by aggregating services within and across budget-funded agencies into 11 separate contracts. At present, 23 departments and agencies in five groups have outsourced their IT infrastructure. This represents around half of the agencies in the whole of government information technology outsourcing initiative and approximately $1.2 billion in contract value out of a total estimated $4 billion for the entire initiative. A further six groups were at different phases of outsourcing their IT infrastructure under the initiative. Cluster 9, which included AGSO, CSIRO and the other science agencies were part of this group.

Anyway, Humphry put a stop to all this and recommends that:

While it is the prerogative of the Government to set overall direction, the introduction of the FMA and CAC Acts places responsibility for implementation of policies with Chief Executives and Boards. Accordingly future responsibility for implementing the Initiative should be fully devolved to agency Chief Executives or Boards;

and,

The appropriateness of a particular outsourcing model will depend on individual agency requirements. The decision as to which model to adopt should be taken by the agency Chief Executive or Board in accordance with their responsibilities under the FMA and CAC Acts.

For the Science Agency Cluster he recommends that:

Group 9 should not proceed until the Chief Executives of each agency are satisfied that the implementation risks have been adequately addressed. Subject to that assessment, agencies should only proceed to outsource their IT infrastructure within the overall government policy to outsource, subject to careful decision on what, if any, elements should be outsourced.

It is difficult to argue with his logic.

Furthermore, it looks as though the Office of Assets Sales and Information Technology Outsourcing (OASITO), which was charged with the responsibility of implementing the IT outsourcing program, will soon cease to exist.

Mr Humphry recommended that: "*although OASITO has been an important and necessary catalyst for change and moving the Initiative from a point of inertia to realisation, it is no longer appropriate for them to continue with their centrally managed role. However, OASITO has significant experience in the formal process of government contracting for outsourcing and should continue to be available to agency heads as a reference point for procedural aspects.*"

In other words, thank you for your help but you are no longer needed.

The most unusual part of this whole fiasco is why it took so long for common sense to prevail. The complexity and sheer size of the implementation task introduced substantial risks and meant that only major multinationals would have the resources to bid for the tenders, let alone deliver the required outputs. Furthermore, all but two departments supported its implementation. It just shows the power of political correctness, when pursued to extremes.

The full report is available on the DOFA website: http://www.dofa.gov.au/humphryreview/index.html

***Eristicus*, 20 January 2001**

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

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Part 2 - Geotechnical evaluation in deep coal mining

Aims: The objectives of geophysical well logging for deep coal mining are the determination of:

1. Lithology of subsurface
2. Rock structural features
3. Elastic parameters of host rocks
4. Weakness zones
5. Stress field
6. Relationships between geophysical data and rock mechanical parameters

Well logs: Six different logging methods have been exploited in the lithological/geotechnical evaluation of coal deposits:

- Natural gamma ray (GR)
- Gamma-gamma density (Density)
- Full wave sonic to determine P- (dtvp) and S-wave transit times (dtvs)
- Focused electric tool to determine formation electrical resistivity (FEL)
- Borehole calliper (CAL) and Dipmeter to determine bedding (Dip1)
- Acoustic imaging of borehole wall (BHTV)

Lithology: The main lithology sandstone, silt-/mudstone and coal have been well recognised from well logs (loglith) and show good correspondence with the core record (Figure 3). The main log signatures of sandstone compared to silt-/mudstone are the low gamma ray activity, the high P- and S-wave velocity and the high electrical resistivity. The diagenetic high-consolidated sandstone shows also high acoustic BHTV-reflectivity. Depending on the available well logs from the silt/mudstone analysis, only a differentiation between sand-rich siltstone and clay-rich silt/mudstone can be achieved. The seismic velocity and the electrical resitivity increase with the increasing sand content. High-density values accompanied with high values of seismic velocity, electrical resistivity and acoustic reflectivity in the silt/mudstone lithology indicate carbonatisation of the formation. The transitions between fine grained, argillaceous sandstones and sandy siltstones from well logs are not always equivalent to those of the core record. Coal seams exceeding 20 cm thickness are well revealed from well logs, as coal has high electrical resistivity and acoustic travel-time and low density and gamma ray values.

Volumetric analysis shows the share of the individual rock constituents: sand (yellow), silt/mudstone (blue), coal (black) and porosity (white). The formation model used causes the observed low porosity, where carbonate minerals are not included. It is often the case that at the boundaries of coal seams high porosity has been calculated. This is caused by the observed caving at the roof and floor of the seams and by averaged log responses.

Elastic parameters: The elastic moduli E, M and m are calculated from formation density, P- and S-wave velocity (Figure 3). In contrast to P-wave, S-wave could not be always observed over the measured depth interval. In weak, heavyly fractured and low-velocity formations (such as coal), no S-wave can be observed and therefore the elastic moduli E and m cannot be calculated. The elastic parameters show in host rocks a clear positive correlation with sand content provided from the volumetric analysis and negative correlation with porosity and fracture score (Fscore) calculated from structural features extracted from BHTV images. The stiffness modulus has its lowest value of 10 GPa in coal seams.

Stress field: The determination of the mean azimuth of borehole breakouts and drilling induced fractures provides the direction of the maximum of the horizontal anisotropic compressive stress field (S_{Hmax}) (Barton et al., 1988, Blümling et al., 1983). The direction of S_{Hmax} is perpendicular to the direction of breakouts (Figure 4).

The breakouts can be seen in the images of acoustic borehole televiewers, as the acoustic borehole televiewer permits a high vertical and azimuthal resolution of the borehole wall. The breakouts appear as dark spots in amplitude images of the borehole

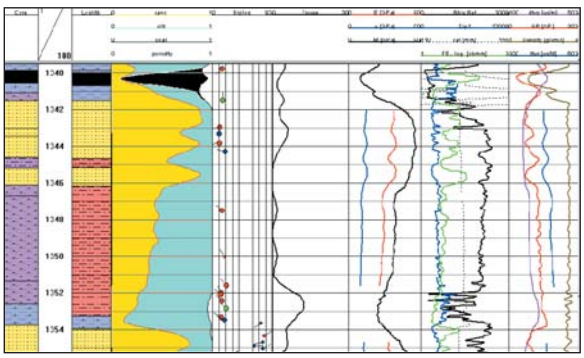

Fig. 3. (Below) Log derived elastic parameters and lithology as compared to core record.

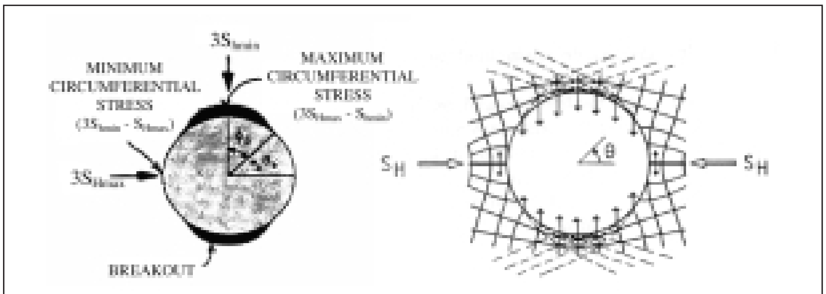

Fig. 4. (Bottom) Relationship between breakouts and stress field.

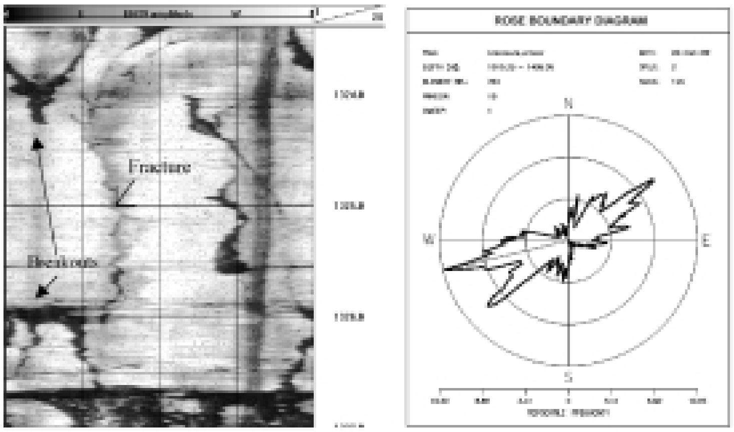

Fig. 5. Appearance of breakouts and drilling induced fractures in acoustic images (left), distribution of breakouts azimuths (right).

wall, causing a reduction in the reflected energy (Figure 5, left). The breakouts usually show a 180^0 azimuthal symmetry, however this symmetry is no assumption. The breakouts are observed over the whole depth interval. The main direction of extracted breakouts is N53^o± 4^o and shows symmetry of 180^o (Figure 5, right). Another group of breakouts appears at 23^o displacement at N104^{o}W±6^o. The S_{Hmax} direction should be then N37^{o}W, which coincides with data provided by stress measurements.

Drilling induced near vertical fractures occur, if a tensional stress exist in the S_{Hmax} direction (Figure 4). Their strike direction should be identical with the direction of S_{Hmax}. These fractures show a main strike direction of N130^{o}E (Figure 5, left), which is nearly vertical to the main direction of the borehole breakouts. The coincidence in the direction of natural fractures and borehole breakouts is of interest, as natural fractures usually do not relate to borehole breakouts (Teufel, 1985). However, one could suggest, that if natural fractures are vertically directed to S_{Hmax}, they will act as additional releases of breakouts.

Weakness zones: Weak and permeable zones are characterised in full-wave-sonic seismograms as late reflections, and depth-time distributions show V-form (tube waves). These reflections are caused at the borders of two contiguous media with a big contrast in acoustic impedance (such as compact/porous-brecciate rocks). In Figure 6 the log data, acoustic amplitude image, optical core image and the seismogram of the first receiver are shown. Discontinuities, clearly seen in the acoustic image, cause the characteristic V-form reflections in the sonic seismogram. Other well logs than the acoustic image log do not always have obvious features in respect to weakness zones. The curve overlaying the seismogram represents the summation of wave energy within one period length along two up- and down declined straight lines, with the slope corresponding to the velocity of the tube waves (White, 1983). The higher the reflection from weakness zones, the higher the value of the stacked reflection energy. Coal seams show similar behaviour as weakness zones, since they also show big contrast in acoustic impedance to the surrounding rocks.

Rock mechanical parameters: The knowledge of strength and deformation behaviour is important in rock engineering applications (Jaeger & Cook, 1984). Static, directly derived in laboratory loading tests, and dynamic, indirectly derived from destruction free measurements, methods exist to determine rock deformation parameters. The static methods are expensive and time consuming, where as dynamic methods are fast and relatively cheap. In the practice however, the static methods are preferred, as determination of rock mechanical parameters on core samples are made under similar stress conditions to those prevailing in underground. Therefore, the trial to characterise the relationships between static and dynamically derived parameters gains more importance.

Young's modulus: Rocks are deformed under stress action dependent on of their mechanical properties. Characteristic differences between static (1-axial compression test) and dynamic (elasticity theory, see section 2.2) derived elasticity modulus (Young's modulus), usually occur so that the relationship E_{dyn} / E_{stat} holds. The reasons for such differences are non-linear deformation and the high acting stress values by static methods. The influence of micro fractures on deformation behaviour of a stressed core sample is much higher than on the propagation of acoustic waves in dynamic measurements. The influence of water saturation is even more complicated. The static E-modulus decreases by increasing the water saturation of rocks, whereas the dynamic E-modulus increases in moist rocks (King, 1983). High correlation between static and dynamic E-modulus can be achieved only in highly consolidated rocks. The difference between the E-modulus will get bigger, the higher the fracturing degree and porosity are.

Linear and logarithmic relationships have been used as regression models (Schön, 1983, King, 1983). The best correlations achieved for logarithmic relationship (Figure 7) provide a regression coefficient of 0.33, which is small compared to the published data. In Figure 7 a cross plot the logarithms of the stiffness modulus M (calculated from borehole density and velocity measurements in axial direction of core samples) versus E_{stat} is shown. The scatter of M values is as high as E_{dyn}. However, M has higher correlation with Estat (r^2 = 0.443) than E_{dyn} with E_{stat} (r^2 =0.33). This can be explained by the high resolution of velocity measurements in the laboratory (frequency about 1 MHz in laboratory measurements as compared to 25 kHz in sonic measurements). The standard deviation of the error is 6.75 GPa in regards to the E_{stat} calculation from M and 7.77 GPa in regards to E_{stat} calculation from Edyn. The high scatter of E_{dyn} and E_{stat} in rocks of low competence is mainly caused by heterogeneity of rocks (thin beds) as can be seen from the optical core image in Figure 6 and by the limited resolution of the sonic log. The selected core samples for laboratory tests are not representative for the rock volume investigation by borehole sonic measurements.

Compressive strength: The often-used axial compressive strength σ_D in geotechnical evaluation is derived from 1-axial pressure tests in laboratory. The compressive strength depends on the material properties; stress kind, stress distribution and stress acting rate. It is well known from many experimental tests, that rock strength is smaller than the strength of the constituent minerals and is mainly affected by fractures, defects, porosity, cementation and rock texture. Water saturation also has influence, especially in clay rich formations. A higher porosity and fracturing degree causes low rock strength. Seismic velocity is also dependent on rock constituent minerals, consolidation of rock matrix, rock structure, porosity and fractures. The importance of correlation between seismic velocity and axial compressive strength has been early recognised by many researchers (in Schön, 1983). The most used regression models for correlation between σ_D and Vp are quadratic, logarithmic linear and exponential relationships. In Figure 7 the cross plots of the σ_D versus Vp, regression curve and regression parameters for an exponential relationship are shown. Generally the sandstone shows higher velocity and compressive strength than the silt/mudstone. The regression coefficient (r^2) of 0.3 differs slightly from the other investigated models. The high deviations are caused by intercalation of thin layers, which could not be resolved by sonic measurements.

With higher clay content in sand and siltstone a decrease of compressive strength, electrical resistivity and acoustic reflectivity, as well as an increase of natural gamma ray can be observed. The high gamma ray values however are not conclusive for silt-/mudstone with low compressive strength. A higher regression coefficient of 0.575 is achieved by multiple linear regressions between the logarithm of compressive strength and the logarithm of log data shown in Figure 3. Density values do not show clear correlation with compressive strength; the electrical resistivity, gamma ray, S-wave velocity and acoustic reflectivity however correlate with compressive strength.

Cohesion and friction angle: In Figure 7 a cross plot of cohesion c derived by a 3-axial pressure test in the laboratory and seismic velocity V_p is shown. As with compressive strength, an exponential relationship between cohesion c and seismic velocity V_p is well satisfied. The standard deviation of the error is 9.3 MPa. As with compressive strength, the high deviations are mainly caused by samples from intercalated thin beds.

Investigating an idealised rock model utilizing a sphere packing model of equal radius, relationships between friction angle and velocities of seismic waves with different polarisation and propagation directions have been derived (Schön, 1983). In Figure 7 a cross plot of friction angle, derived by 3-axial pressure tests in laboratory, and the ratio of axial (V_{ax}) to parallel P-wave velocity ($V_{||}$), determined in the laboratory from acoustic measurements in axial direction of core samples and parallel to bedding planes is given. Stratified rocks such as silt/mudstone show high acoustic anisotropy compared to relatively homogenous rocks such as sandstone. An increase of friction angle is accompanied by an increase of the ratio $V_{ax}/V_{||}$. Sandstone shows higher friction angle than silt/mudstone. A similar relationship between shear angle, derived form direct shearing test, and the ratio $V_{ax}/V_{||}$ can be seen. Neglecting core samples with a high $V_{ax}/V_{||}$ ratio and low shear angle, which are caused by inclusions of iron carbonate (e.g. Siderite), the quadratic relationship is well satisfied. The sideritic nodules in silt/mudstone have been transmitted by acoustic measurements in axial direction but not in the bedding parallel direction.

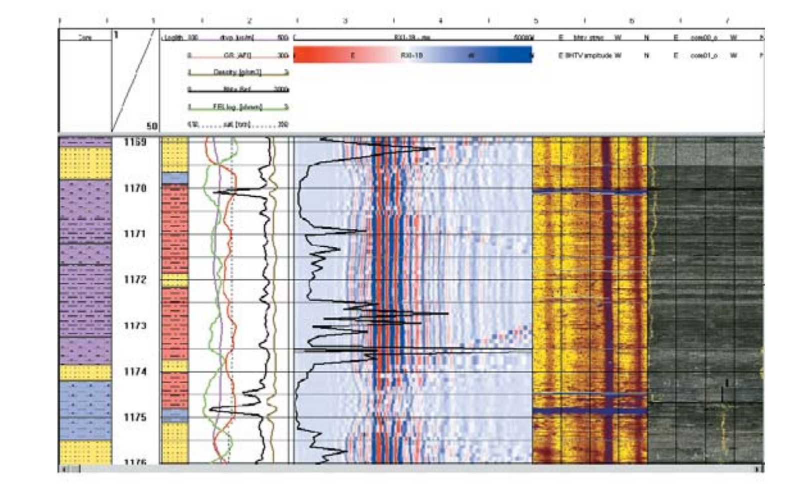

Fig. 6. The appearance of weakness zones (at 1170.05 m, 1174.6 m) in well logs.

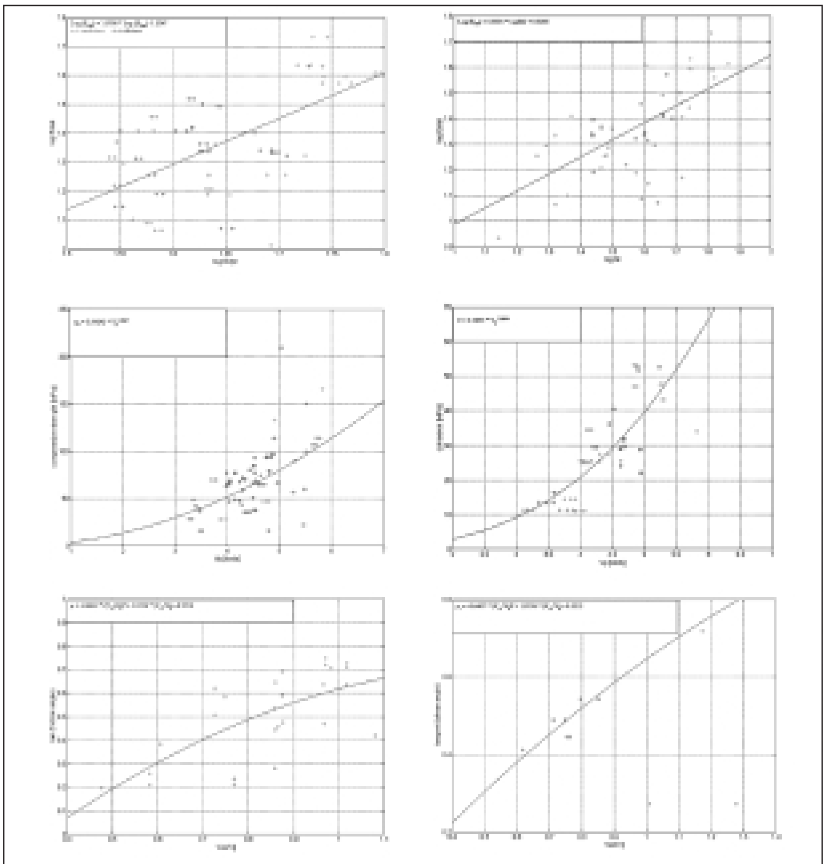

Fig. 7. Correlation between rock mechanic parameter and seismic velocities

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Q-Borehole: Borehole Seismic Acquisition and Processing

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Abstract

Q-Borehole represents a new approach to the borehole seismic business and is designed to effectively redefine the entire logging process. Significant improvements in acquisition efficiency, quality, health, safety and environment standards are targeted to remove some of the main obstacles when running a wireline seismic survey. Data processing developments are aimed at improving the relevance, quality, and turn-around time of the products that are used to finally solve clients' problems. Q-Borehole is a fully integrated borehole seismic system that optimises all aspects of borehole seismic from job planning, through acquisition, data transmission, processing interpretation and answer products to deliver sharp images of the subsurface.

Key features of Q-Borehole include:

(1) the acquisition array tool - VSI (versatile seismic imager),
(2) the wellsite QC and processing software - WAVE (wellsite acquisition validation and evaluation), and
(3) the 3D survey design and processing software - Gemini.

Q-Borehole paves the way towards efficient delivery of a total and complete solution for borehole seismic, in particular for 3D VSP surveys. It will improve the cost effectiveness of the borehole surveys by dramatically cutting the cost and reducing the turn-around time. Thus, the use of borehole seismic services is expected to expand.

Introduction

Borehole seismic (BHS) is an established and evolving technology for reservoir evaluation, development and management (Hardage, 1985). BHS is a catchall term for methods and technologies devoted to collecting seismic data from seismic sensors and sources deployed in boreholes. Figure 1 graphically illustrates the current BHS services at Schlumberger. BHS can be generally categorised into three groups:

- seismic-while-drilling,
- 'conventional' wireline, drillpipe and tubing-deployed surveys,
- downhole permanent seismic monitoring.

Conventional borehole seismic has a history as long as surface seismic. It is under continuous innovation and development just like the surface seismic. The key application at present is the calibration of surface seismic data. Checkshot or VSP surveys employ stationary sources on the surface, with receivers placed downhole via wireline, drillpipe or tubing in existing wells. BHS is the main link between logs and surface seismic data. The central problem in the interpretation of surface seismic is time-to-depth conversion, and borehole methods provide a whole suite of calibration information. Information from a BHS survey can also be invaluable for calibrating surface seismic data processing, enabling more objective parameter decision making and ultimately improving the tie between the seismic image and the well.

Stand alone BHS surveys, used for subsurface imaging, are a reservoir development tool. Offset and walkaway VSP surveys and 3D VSP provide high-resolution seismic imaging around wellbores (Dodds et al., 1998). The fine details are captured because BHS sensors are deployed below the near-surface weathering layer and in a quiet environment closer to the targets of interest. Imaging VSPs are helpful when surface seismic is not available or is of poor quality. Walkaway and 3D VSP surveys can also measure in-situ formation properties such as anisotropy and AVO effects and provide accurate calibration for surface seismic (Leaney, 1994).

Furthermore, borehole techniques usually record high-quality shear wave data, which are necessary for multicomponent work. Shear wave acquisition is well established in borehole seismic. Calibrating

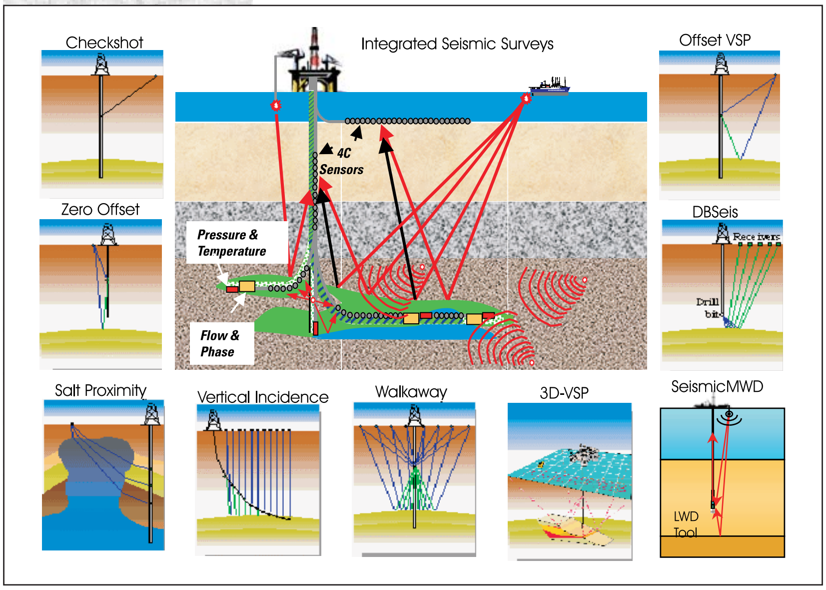


Fig. 1. Borehole seismic services at Schlumberger.

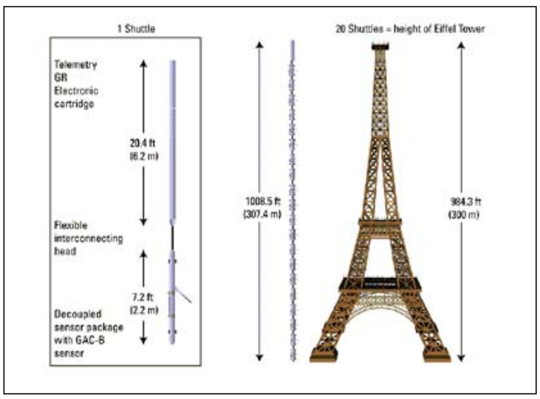


Fig. 2. Schematic diagram of a VSI Versatile Seismic Imager.

multicomponent surface seismic is evolving as a key role for borehole seismic.

Evolving areas in borehole seismic in existing wells are cross-well and single-well surveys. The allure of cross-well seismic data lies in its ability to image beds and faults with resolutions of a few feet. Cross-well seismic can deliver down to 1.5 m of resolution and supply excellent information about horizontal velocity structure, which is important in interpreting anisotropy. Single-well seismic imaging to a depth of 6 to 15 m is possible today using sonic logging technology.

Seismic-while-drilling (SWD) is a generic term for all types of seismic measurements made while drilling. SWD can be used for the optimisation of a drilling program by providing time/depth information in real time at the wellsite. SWD data can be acquired in two different configurations. The first one, called Drill Bit Seismic (DBSeis), uses the acoustic energy radiated by a working drill bit to determine the seismic time-to-depth relation as the well is drilled (Schlumberger, 1995). The other, called Seismic Measurement While Drilling (SeismicMWD), deploys seismic sensors as a logging-while-drilling tool and the seismic source is fired at the surface.

Permanent downhole seismic installations represent part of the future for borehole seismic. They are targeted toward reservoir monitoring, and aim to address problems such as the identification of bypassed reservoir compartments. Passive monitoring methods have already been developed, such as listening for acoustic emissions when a well is fractured. The information is then used to map in real time a 3D image of how the fractures develop. Permanent monitoring technology would remove a huge stumbling block to greater use of borehole seismic for reservoir monitoring.

BHS is a small segment of the overall geophysical industry, but it offers some of the sector's strongest potential for innovation and growth. Schlumberger has played a key role in the advancement of borehole seismic and has recently launched the Q-Borehole technology. Q-Borehole is a fully integrated borehole seismic system that optimises all aspects of borehole seismic from job planning, through acquisition, data transmission, processing interpretation and answer products to deliver sharp images of the subsurface. In this review, I will concentrate on the key components in Q-Borehole and the potential of expanding the borehole seismic services.

VSI Versatile Seismic Imager

For Q-Borehole, the showpiece feature is a new array tool, VSI versatile seismic imager as shown in Figure 2, that equals the height of the Eiffel Tower when fully deployed. The downhole tool can be configured with up to 20 sensor sections, with three-component geophones in each. As a simple wireline is used between shuttles, the number of levels and the spacing between the levels are adjustable in the field. This flexibility will allow the simultaneous acquisition of multiple walkaway VSP surveys thereby reducing the acquisition cost and further adding value to the borehole seismic service.

VSI is equipped with superior acoustic isolated sensor package whose elastic performance is not matched by any alternative sensor available in the industry today. The sensor module contains three orthogonal sensor GACs, their preamplifiers and a shaker. The module housing and contact surfaces are designed to minimize distortion from modal and coupling resonances. While the tool is being moved, the module is retracted inside the main body of the sonde by an actuator. To record data, the sensor module is decoupled from the tool body. The sensor response to excitation by the shaker is used to verify that optimum sensor-to-formation coupling has been achieved.

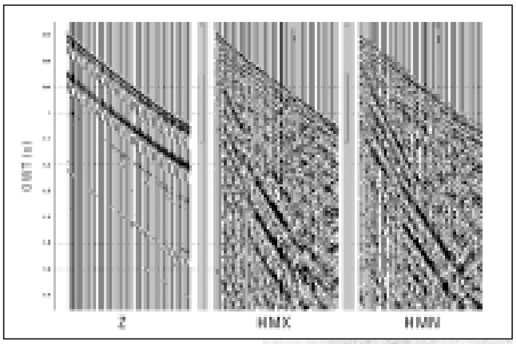


Fig. 3. Rotated zero-offset VSP data acquired using VSI from North Sea.

Figure 3 shows a zero-offset VSP data acquired using VSI in the North Sea. In comparison to a conventional dual downhole toolstring, the total acquisition time was almost halved. As expected, the data quality was excellent and results from this survey exceeded most expectations.

The superior acquisition system makes it possible to image targets that are undetectable on surface seismic and will pave the way towards efficient acquisition of complex BHS surveys which up to now have been either uneconomical or impractical. Its central attraction is its potential to dramatically expand the use of BHS services.

Survey design and evaluation

With Q-Borehole, the surveys can be acquired much more economically, reducing non-productive rig time by more than half. This is made possible by proper evaluation of customer needs for BHS surveys (and the existing problem) with an objective to deliver solutions. This approach allows proper planning and design of the survey using the Schlumberger common modeling environment - Gemini.

The optimum number of receivers can be determined from the survey design. For example, Table 1 lists the time breakdowns in hours for all the options of a VSP job. Note that the number of downhole tool levels for a single shot is indicated in the first row. The bottom VSP level is at 3560 m and the top VSP level is at 1500 m. The VSP level spacing is 15 m and the total number of VSP levels is 136. It is clear from the table that the best choice for the VSP job is either a 8-level or 12-level VSI in terms of time. Taking other acquisition factors (such as logistics, downhole coupling and etc) into consideration, the option of an 8-level VSI would be the optimum downhole toolstring.

The fundamental importance of the survey design and evaluation is the feasibility of the proposed borehole seismic survey. This investigates the applicability of

Table 1. Acquisition time breakdowns in hours of various tool options for a VSP.

	1xCSI	2xCSI	3xCSI	ASI(5)	VSI(4)	VSI(8)	VSI(12)	VSI(16)	VSI(20)
Rig up	0.25	0.50	0.75	0.75	0.75	1.00	1.25	1.50	1.75
Tool check	0.25	0.30	0.30	0.25	0.25	0.25	0.25	0.25	0.25
Run in hole	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17
Check shots	0.08	0.10	0.14	0.10	0.10	0.13	0.17	0.20	0.23
Correlation	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
VSP acquisition	10.81	7.83	6.84	3.55	3.93	2.53	2.06	1.83	1.69
Pull out of hole	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Rig down	0.25	0.50	0.75	0.75	0.75	1.00	1.25	1.50	1.75
Total	13.8	11.4	10.9	7.6	7.9	7.1	7.1	7.4	7.8

borehole seismic technique in a given situation and to recommend a set of optimal acquisition and processing parameters. The methodology of a feasibility study is to use a suite of seismic modeling packages, from 1D to 3D methods, to test various hypotheses.

The feasibility study serves three main purposes. The first is to establish whether the objectives are likely to be achieved, given the nature of the subsurface and the recommended acquisition parameters. It needs to determine if the targets (direct, reflected and/or diffracted arrivals) that may be present are large enough to overcome the various noises in the system. It needs to determine if there are sufficient differences between geological conditions and their seismic expressions to distinguish the response. For subsurface imaging, it also needs to determine the optimal source-receiver configuration to obtain a best image.

Figure 4 shows the determination of optimal source/receiver locations for a borehole seismic survey. In this case, 3D surface seismic and its interpretation were available. A 3D model was built from the 3D surface seismic interpretation. A well trajectory was also proposed and displayed both in the 2D seismic section and in the 3D model. The prime objective of the borehole seismic survey was to accurately define the faults at the target horizon. The optimal source positions were determined by the target-oriented survey design. By shooting a cone of rays from a set of receiver positions to the region of interest, the rays were reflected back to the surface at different potential source positions. The receiver positions are constrained by the proposed well trajectory. The distribution pattern of the potential source positions at the surface was used for the determination of optimal source positions.

The second is to assess the reliability of results obtained on real data. There are many cases where seismic anomalies are observed which are not indicative of hydrocarbons. Modelling is carried out to assess the likelihood of such anomalies occurring in the dataset under investigation.

The third is to extract the seismic characteristics/attributes (e.g. AVO, anisotropy) from the modelling results of a known model. These characteristics can then be used to calibrate their counterparts from the surface seismic data in an integrated interpretation project.

Data processing and interpretation

Most borehole seismic surveys, like any other well measurements, are of a decreasing value/use with time after acquisition as shown in Figure 5. Therefore, the timely delivery of processed result is paramount.

Data processing services include data transmission, data preparation, transit time and velocity determination, synthetic seismograms, wavefield separation, deconvolution, corridor stacking, wavefield migration, acoustic impedance inversion, Q estimation, overburden transfer function estimation, AVO analysis, anisotropy determination and tomographic velocity reconstruction.
Data interpretation services make full use of high-quality

downhole seismic data for the provision of high resolution formation evaluation and reservoir characterisation. For example, by match-filtering between surface and borehole seismic data and integrated interpretation of surface and well data, surface seismic volumes can be interpreted into spatial volumes of different reservoir parameters, e.g. fluid content, porosity and pore pressure.

For Q-Borehole, one key feature in data processing is that most data processing tasks can be carried out using the WAVE wellsite acquisition validation and evaluation software at the wellsite. For most BHS surveys, data processing is split into two components: wellsite and computing center. At the wellsite, the most important data processing steps include the quality control and preliminary processing. Quality control is carried out in real time and it makes sure that the data acquisition geometry (source, hydrophone and receiver positions) follows the recommended acquisition geometry, and acquisition environment and tool coupling are consistent so that seismic data are of the best quality. Preliminary processing ranges from transit time determination, geometry correction, interval velocity calculation, wavefield separation, corridor stacking and acoustic impedance inversion.

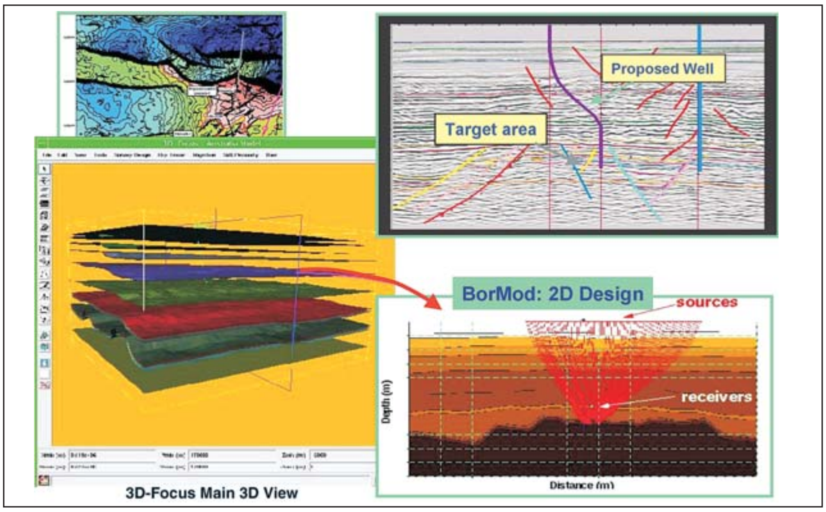
At a computing centre, a suite of BHS processing packages are available and major processing tasks include:

- Geometry correction and header editing
- Trace editing, time picking and stacking
- 1 and 2D frequency analysis
- Hodogram analysis
- Data rotations
- Parametric wavefield decomposition
- AVO extraction
- Anisotropy determination
- Median filters, f/k filters, tau-p filters, Hilbert transform techniques
- Waveshaping, predictive and semblance weighted deconvolutions
- Arbitrary corridor stacking
- Acoustic impedance inversion
- 1, 2 and 3D Kirchhoff migration

For Q-Borehole, another key feature in data processing is the ability to model and understand the subsurface in 3D. This is achieved with the new software package called Gemini. It has the capabilities for common model building, visualisation and evaluation. Gemini provides a common platform for unified 3D model building and other major model-based seismic processing, such as survey design, ray-based synthetic generation, tomography and migration. It allows the user to use the same model to design both borehole and surface seismic surveys and to use the model to process the acquired data.

Benefits of Q-Borehole

The development of Q-Borehole will create tremendous benefits to the borehole seismic services. For most zero-offset VSPs, the acquisition time can be substantially reduced thereby generating significant savings to operating companies. With conventional borehole seismic technology, many potential borehole seismic projects would fail the vigorous value-and-cost analysis (project screening). With Q-Borehole, a significant portion of these projects will pass the test due to the cost reduction and therefore the use of the borehole seismic services will expand. This is particularly true for high-end borehole seismic services, e.g. walkaway and 3D VSP.



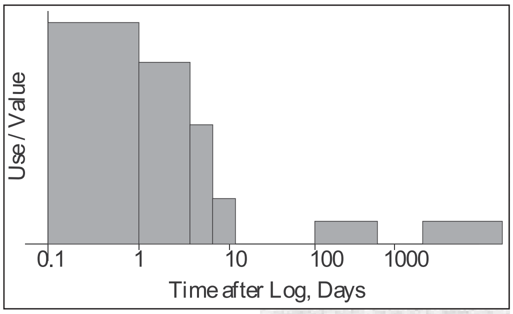


Fig. 4. (Top) Determination of optimal source/receiver locations by survey design.

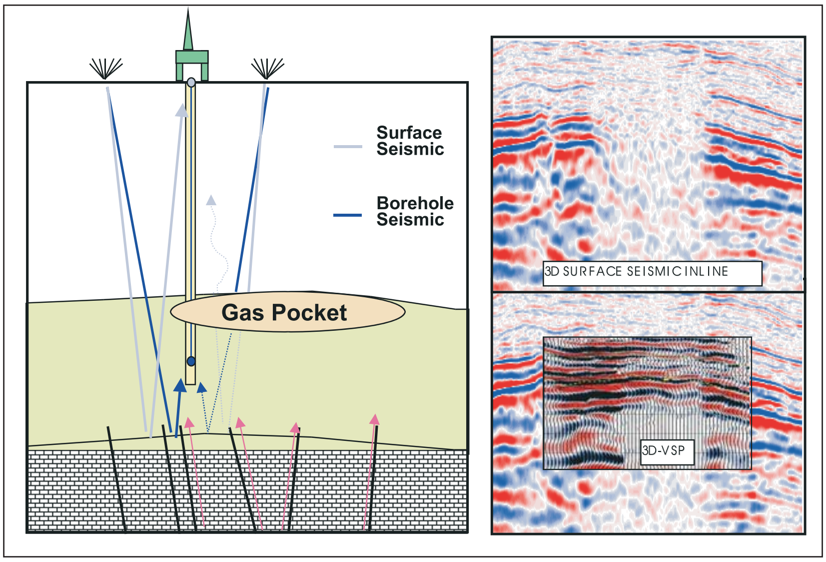
Fig. 5 (Above) The use/value of well measurements vs the time after acquisition.

For example, a common problem encountered with conventional compressional surface seismic imaging occurs when the presence of gas causes severe attenuation of the compressional wavefield. Several remedies such as undershooting 3D VSP, 4C-OBC (4-component Ocean Bottom Cable) or their combination have been successfully applied, but their use has so far been limited. Two 3D VSP surveys are included here to illustrate their values in solving imaging problems.

In the Ekofisk field of North Sea, the gas cloud severely attenuated the 3D surface seismic and the target was poorly imaged (a gap) as shown in the upper right panel of Figure 6. As shown in the left panel of Figure 6, the gas cloud was well separated from the target and a highly deviated well was drilled below the gas cloud. With a purposely-designed 3D VSP, the gap in the surface seismic was successfully filled as shown in the lower right panel of Figure 6, and the reservoir was much better delineated for further development planning.

In the Attaka field of Kalimantan, compressional waves are affected by gas and compressional seismic does not adequately image the reservoir (Cao et al., 2000). As Attaka is a mature field, a large number of wells already exist. This allowed the possibility of simultaneously acquiring the OBC and borehole seismic data. One well was selected near the centre of the 3D survey to deploy an array of five magnetically clamped 3-component sensors in the borehole, and simultaneously record shots with the OBC cable recording providing a 3D walkaway using the same shots at the OBC recording (Figure 7).

A joint tomographic inversion of the surface and borehole seismic traveltimes was performed to build an accurate velocity model. The results of the 3D walkaway data provided a detailed compressional and shear model to be



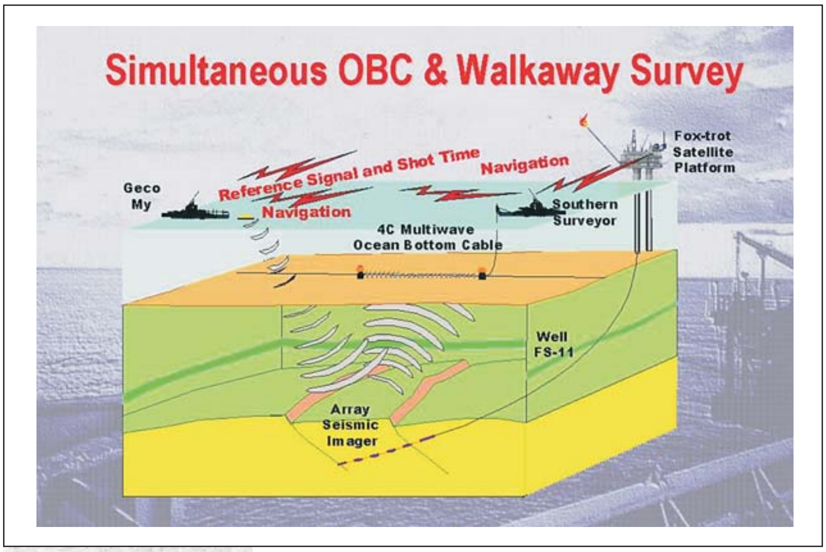


Fig. 6. (Top) Undershoot a gas cloud with a fit-for-purpose 3D VSP.

Fig. 7. (Above) Schematic diagram for a simultaneous acquisition of OBC and 3D-VSP.

applied to the OBC common conversion point mapping and migration. Converted wave reflections are now correlatable between the walkaway and the OBC shear section. It is also worth noting that shear waves have provided more coherent information than compressional waves because shear waves are essentially unaffected by pore fluids and are mainly influenced by the rock matrix. The walkaways also allowed derivation of Qp and Qs information, which indicated a very low Qp in the near surface. This low Qp is thought to be responsible for the poor quality compressional seismic.

These two examples clearly demonstrate the value of 3D VSP subsurface imaging. They were achieved with conventional borehole seismic technology. With Q-Borehole, the cost of a 3D VSP will be significantly reduced. For example, if Q-Borehole is used, the costs for the two 3D VSPs mentioned above would be less than 30% of their original costs. Thus, more 3D VSP projects will pass the screening process.

The simultaneous acquisition of borehole and surface seismic would also become easier with the development of Q-Technology, which comprises of Q-Borehole, Q-Land and Q-Marine. Q is a methodology for acquiring and processing seismic wavefields by optimally combining the digital waveforms recorded on sensors. Q delivers an optimally sampled 3D wavefield ready for imaging, analysis and interpretation into reservoir model. Q-Technology will bring improvement in data quality and savings in operation logistics for simultaneous acquisition. The result is a survey fully optimized to eliminate non productive time and to solve the problems faster.

Q-Borehole has significant relevance to the oil and gas industry in Australia, in particular the North West Shelf and Timor Sea where gas clouds are known to cause severe deterioration of compressional surface seismic. 3D VSP, as an imaging tool, will soon find its way into the gas and oil exploration industry in Australia.

Concluding Remarks

Q-Borehole represents a new approach to the borehole seismic business and is designed to effectively redefine the entire job process. Q-Borehole is an effective reengineering of borehole seismic. It is a fully integrated borehole seismic system that optimizes all aspects of borehole seismic from job planning, through acquisition, data transmission, processing interpretation and answer products. Q-Borehole is to deliver a total and complete solution for borehole seismic surveys.

Q-Borehole paves the way towards efficient delivery of borehole seismic services. It will change the net present values of many potential projects from negative to positive by dramatically cutting the cost and reducing the turn-around time. Thus, the use of borehole seismic services is expected to expand.

Acknowledgements

I would like to thank my colleagues throughout Schlumberger whose hard work and dedication over the years have resulted in the development of the Q-Technology. This paper is the result of contributions from numerous people which includes, but is not limited to, the following persons. Apologies to all those omitted from this list, all errors are my own.

Les Nutt, Di Cao, Ikem Okafor, Kenzo Hara, David Mathison, Tatsuki Endo, Phil Armstrong, John Tulett, Scott Leaney, and Joerg Meyer

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Advanced Borehole Seismic Geometries

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The development of seismic applications of geophysics in a borehole has been one of applying sources and receivers in a variety of geometries. Where there has been flexibility in arranging these sources and receivers there have been new ways of looking at the subsurface. This article intends to illustrate this premise by reference to a variety of applications. The first part reviews the standard configurations, while the latter part of the article describes some more exotic examples from my experience. The details are left to the References.

The traditional application of check-shot surveys still remains the most widely used borehole seismic technique. It provides the time-depth tie that will reduce the drilling uncertainty in an exploration campaign. This type of survey needs only a limited number of receivers to achieve the information required. However, improving the sampling rate by increasing the number of receivers in the borehole makes it possible to extract the reflected information present in the seismic trace at each receiver. This means time and depth information can be supplemented by an independent estimate of reflectivity at the borehole. This reflectivity can then in turn be compared with a synthetic estimate of reflectivity generated from the density and sonic logs.

The economics of deployment of single receivers against the benefits of the information have driven the development of array receivers that can accomplish the increased sample rate with a reduced acquisition time. This change in source receiver geometry has enabled new geometrical possibilities. In exploration scenarios, where the cost of suspending drilling operations for borehole seismic is expensive and there is a need for immediate results, the noise generated by the bit has been used as a source and the receivers deployed on the surface in an inversed geometry. This technique is called seismic while drilling.

Where the well is vertical, borehole seismic surveys provide a one dimensional earth response. More information can be extracted by varying the position of the source, i.e. offset with respect to the receivers. This means that the imaging becomes 2D. Where the source is at a fixed offset from the receivers, the energy reflected from the imaged horizon moves out and away from the borehole as the borehole receiver effectively moves up the borehole and away from the imaged horizon. The coverage of the horizon depends on the source offset distance and the formation dip. This can also be achieved by keeping the receiver fixed at some depth and moving the source in a line centred on the surface projection of the receiver. In practice, separation of the downgoing energy from the reflected energy requires a minimum number of receiver positions for the same source line. Efficiency is gained when the downhole tool is an array of triaxial receivers, then one surface pass of the source provides sufficient data for imaging. This is called a walkaway survey. Increasing the number of lines parallel to each other can provide a three dimensional image of the reservoir around the well (see Fig. 1, Dodds et al., 1992, and Van der Pal et al., 1996)

Another way of increasing the geometrical sampling of the Earth is to utilise the geometry imposed by the well itself. Offshore deviated wells of increasing deviation through to horizontal have improved the economics of exploitation. In these wells the sources can be deployed above the receivers and trace out a 2D image beneath the well track, in what is called a vertically incident survey. A variety of other source geometries can also be used in such a borehole geometry.

The following provides four case histories that follow a path from these conventional geometries to unconventional arrangements of sources and receivers. The first demonstrates how a Vertical Seismic Profile (VSP) can drive the well design options, the second describes how a walkaway VSP can probe the elastic properties of the Earth through Amplitude Versus Offset (AVO) techniques, the third explores the utilisation of crosswell and the fourth adapts these principles to single well imaging in horizontal well applications.

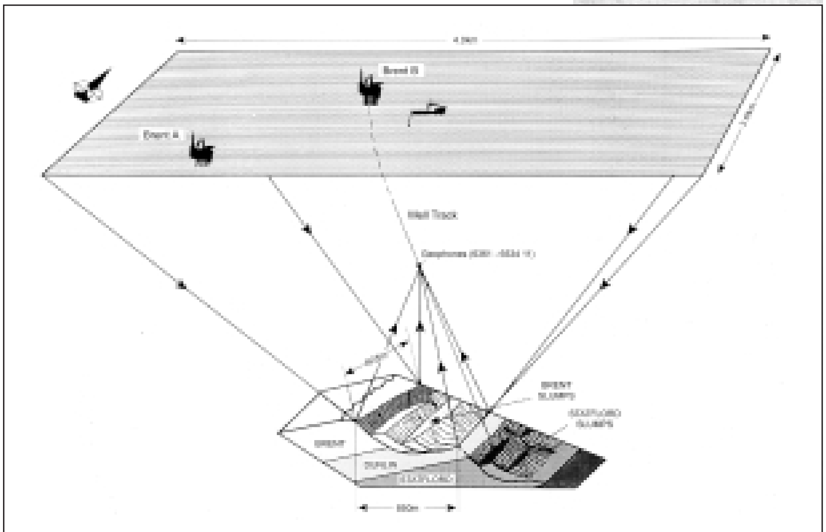


Fig. 1. The illumination of a 3D VSP survey in the slump structure in the Brent Field, The North Sea. Positioning of the receiver and the line lengths critically determine the target resolution and coverage.

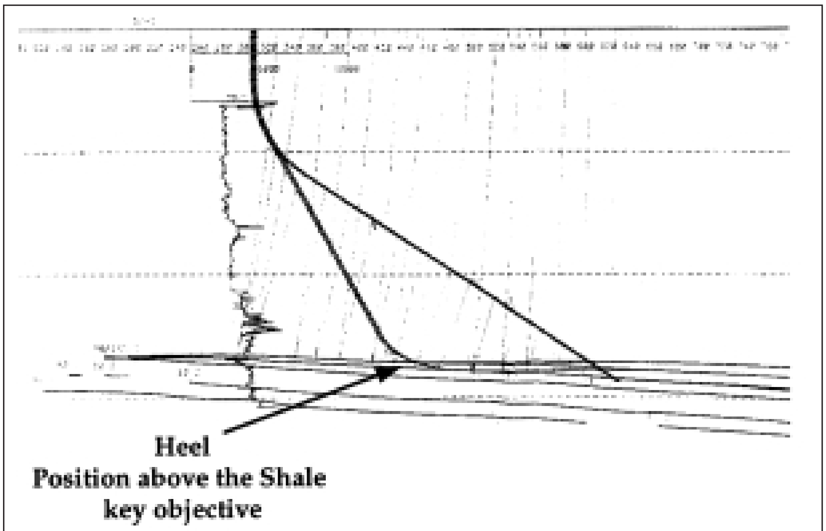
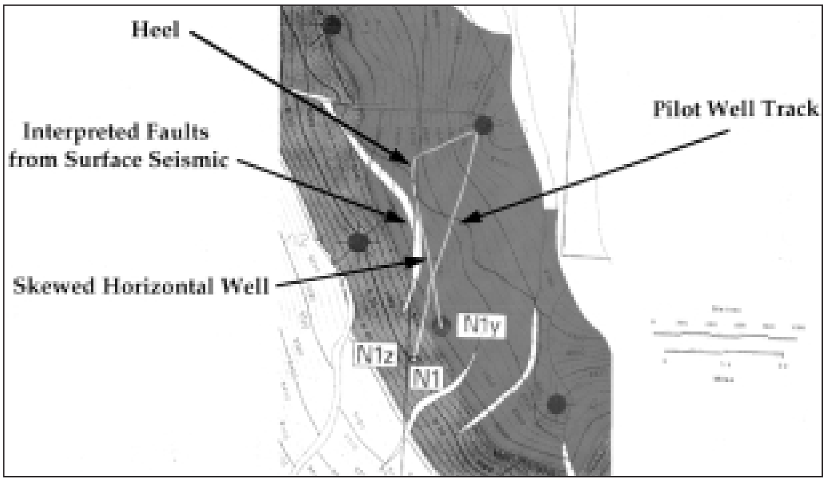


Fig. 2. Model of the pilot well and the horizontal well showing the underlying horizons and the relationship to the heel of the well.



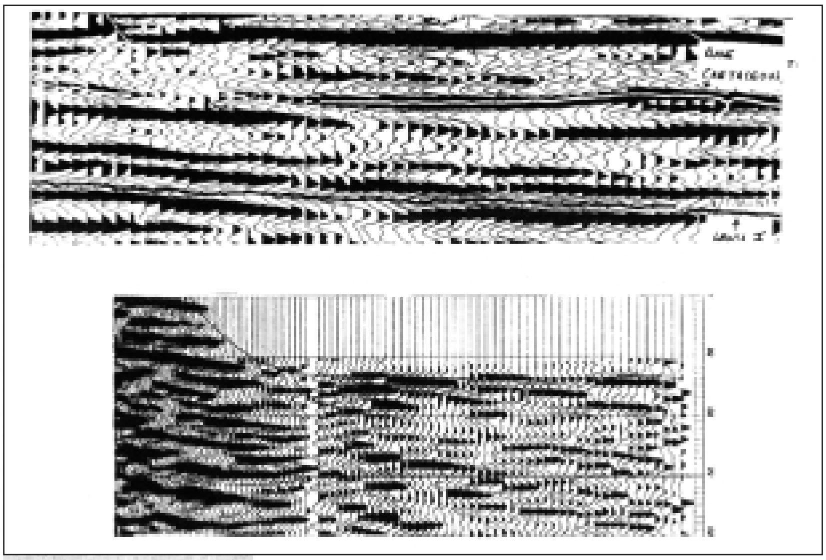


Fig. 3 (Top) Plan view of the target horizon showing the pilot well track and the skewed track of the horizontal well. The azimuth of the horizontal well was optimised within the error margins of the structural map, with reference to the information gained from the pilot well VSP.

Fig. 4 (Above) Horizontal well VSP compared with the resolution of the surface seismic. The breaks in continuity correlated exactly with fractures imaged by the borehole scanner and sonic Stoneley reflections. These fractures were sub-seismic however, they can critically affect the flow characteristics of the reservoir.

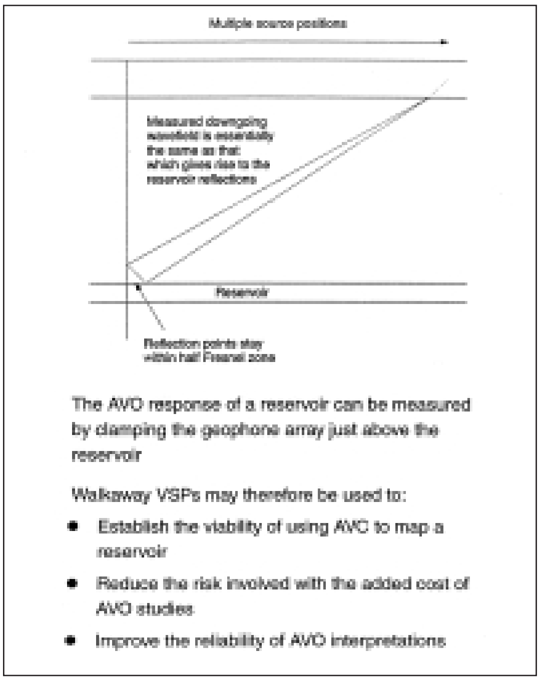


Fig. 5. Geometry of a walkaway as applied to its application to AVO calibration. The AVO aperture is twice the offset of the furthest source.

VSPs for well design optimisation

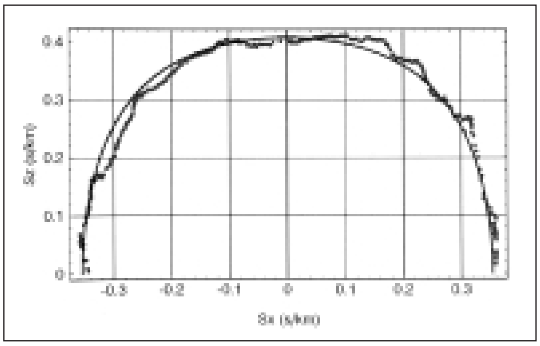
This case history traces the interaction of the imaging potential of VSPs in an active process of steering a horizontal well. The drilling challenge required positioning a horizontal well to maximise the exposure to the producing section of the reservoir. It was important that the horizontal well steered clear of faults interpreted from the surface seismic and more importantly, it should avoid potential intersection of sub-seismic fracturing associated with these faults. Furthermore, the horizontal well had to be positioned as close as possible to an underlying shale without piercing it; this would provide the optimal potential production length. This was a three dimensional problem requiring a strong cross-disciplinary interaction and experience with the strengths of the imaging with borehole seismic.

The operational plan consisted of an initial deviated pilot well with the primary purpose of VSP imaging. This would then be immediately followed by the horizontal well with the heel of the well and its azimuth being dictated by the rapid interpretation of the pilot well borehole seismic (Figure 2). The pilot well imaging goals were to identify precisely the shale interface by calibrating the lower resolution surface seismic and at the same time the improved resolution would improve the detectability of fractures along the potential path of the horizontal well. All this information would drive the decision on how to skew the azimuth of the horizontal well within the predetermined error margins (Figure 3). Preparation included synthetic modelling and mapping out scenario options based on three dimensional reconstruction of the potential range of dips and thicknesses, so that decisions could be made rapidly once the second well was started.

The acquisition, using a five level receiver array in a 70^0 well, was rapid and the subsequent image precisely defined the heel point above the shale. This was confirmed subsequently by the horizontal well briefly touching the shale top. The decision was taken to follow-up the vertically incident pilot well survey with a VSP in the horizontal well. The processed image which overcame limitations of an horizontal well imaging (see Smith et al., 1995) showed that breaks in continuity in the horizons precisely correlated with fractures detected by imaging and shear sonic logging (Figure 4). The production from the well was well above projected estimates.

VSP applications in AVO calibration

The walkaway geometry discussed at the start reproduces the same geometry as a surface seismic Common Depth Point (CDP) gather. There is an important difference; the buried receivers are intercepting the direct and reflected energy very close to the reservoir, whereas the surface seismic gather has sources and receivers remote from the horizon. This has many advantages. The receivers are close to the reflection point to be studied for the full range of the offset source positions, while the direct and reflected travel paths are nearly coincident and hence traverse similar geology (Figure 5). The fact that the receivers intercept the energy halfway along the path means that the VSP geometry samples twice the effective offset of the surface gather. Think about it. Access to a broad angular range and proximity to the horizon of interest means that



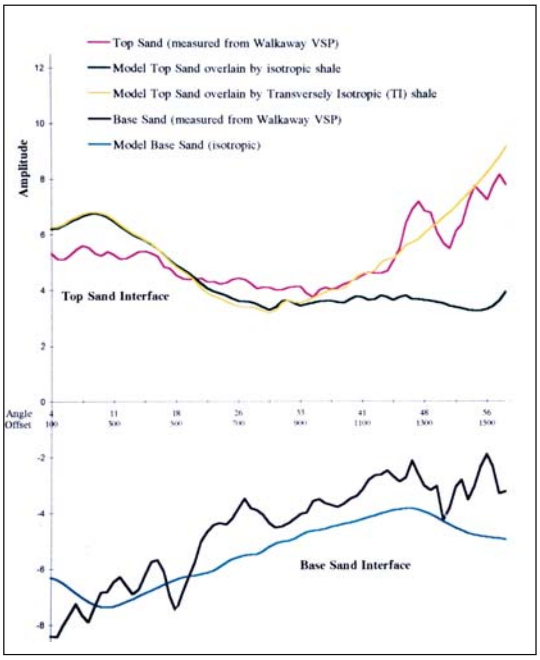


Fig. 6. (Top) Plot of the horizontal and vertical velocities, corrected for minimum time arrival envelope and dip. Each point represents a source receiver pair, and the axes are horizontal and vertical slowness in seconds per kilometre.

Fig. 7. (Above) Predicted and measured AVO amplitudes for the top and bottom of the reservoir. The wriggly line, whose slope is predicted at the base of the reservoir (sandstone), represents the measured values, however, the measured amplitude trend follows the anisotropic model prediction at the top of the reservoir (due to shale velocity anisotropy).

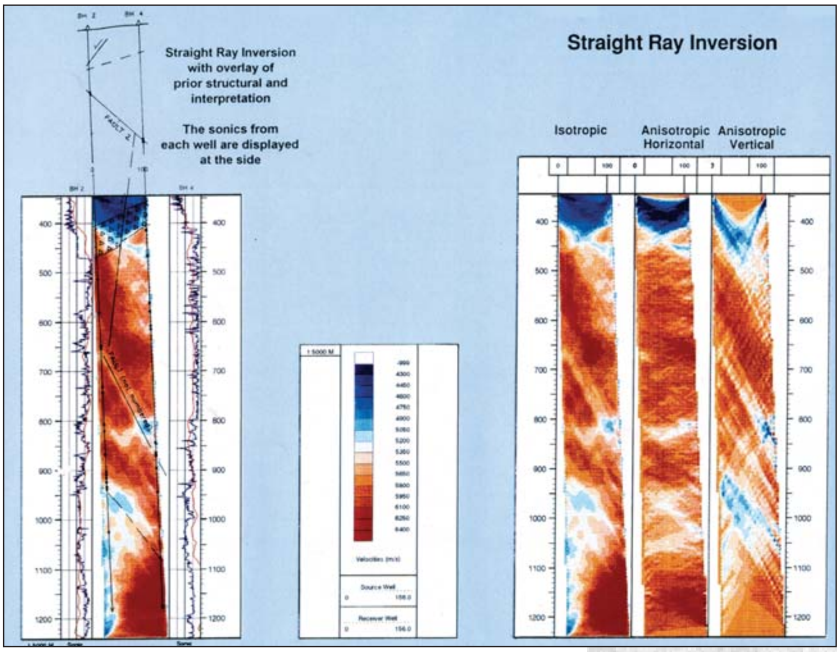


Fig. 8 Crosswell tomographic inversion where the variation in colour corresponds to the velocity anomalies associated with the fluid weakened rock and fractures. The fractures were correlated by a number of other measurements in the borehole.

we know the properties of that point through a range of other measurements available in the well. So we have precise knowledge of one point in the reservoir and its angular/offset amplitude response, which can be used to calibrate AVO anomalies that are imaged remotely by surface seismic.

There is an additional set of properties that can also be obtained by this type of geometry. We can determine the angular variation of velocity at the receiver array, from vertically to horizontally propagating energy. This characterises the anisotropic velocity response. (Figure 6). If we then carried out additional walkaways in different azimuthal orientations, we could evaluate whether this anisotropic response varied azimuthally and hence be related to local fracturing.

A case history that neatly encompasses all these properties was carried out to assess an AVO anomaly observed in a field that was going into decline (see, Armstrong, 1995). It was important to determine whether this anomaly could be used to map the extent of the in-place hydrocarbon or was related to the old oil-water contact in a depleted field. In other words was the anomaly related to the in-place oil or altered rock properties? The reservoir was capped by a shale, and consequently it was important to determine the anisotropic properties of this shale and how this affected the observed amplitude anomaly. Previous analysis had only assumed isotropic properties. The array was placed in the shale directly above the reservoir, hence one geometry suited both purposes; the AVO investigation and the anisotropic velocity measurement.

The analysis was essentially one that compared what you could predict with what was observed. The first step was to predict the AVO synthetically, assuming an isotropic shale, and then again assuming an anisotropic shale interface with the reservoir. The anisotropic parameters were derived from the walkaway VSP and were included in the modelling using equivalent medium theory. Then a comparison was made of the observed VSP AVO with the two predicted responses. Finally the process would be to calibrate the surface seismic derived AVO and then map away from the well.

The results were quite surprising. There was a substantial difference of gradient between the anisotropically derived anomaly compared with the isotropically derived response, with departure occurring at higher angles (Figure 7). The amplitude variation of the VSP with angle, showed variations associated with overburden effects. However, it was clear its trend matched the anisotropic synthetic data. The conclusion was that the anomaly was due to the anisotropy of the shale and not the reservoir fluids, and hence it could not be used to map the current reservoir contact.

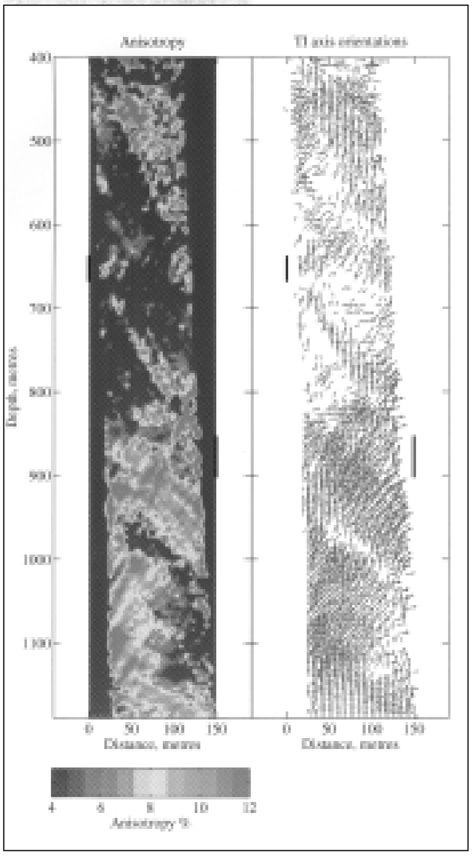
Crosswell Surveys

The availability and use of crosswell surveys, with their benefits in terms of a resolution step change compared with VSP and ability to image between wells, remains elusive. The evolution of the systems i.e. receivers and downhole sources, the physics of transmission in differing lithological environments, the rendering of the data into interpretable images (straight ray, curved ray inversion, reflection imaging), not to mention the many practical problems in acquiring data, means that the technology has not been broadly used.

This case history illustrates aspects of these issues, and also the benefits. The survey and a subsequent five more were commissioned to provide a high-resolution structural characterisation between wells to supplement other VSP and borehole data. It was a layered volcanic environment multiply fractured, characterisation of the latter being the goal. Despite being a hard rock environment, the Q inferred from the acquired data was quite low, of the order of 30, making it typical of a soft rock environment. This meant that the transmission range was limited, although transmission distances of up to 1 km were achieved. This also meant that stacking was the key to transmission distance given the type of source and receivers used. The survey was over a 900 m interval to a total depth of 1500 m requiring 16 scans each consisting of 176 source positions into a 16 level hydrophone array, each scan taking 8 hours to complete. Each source position was occupied for 2.5 min and the entire survey took 7 days of continuous operation. The data set consisted of 50 000 traces, with each trace consisting of a downhole stack of 32 shots, (see Dodds et al., 1994). These statistics show the effort required to get sufficient coverage for a reasonable tomographic image. It also illustrates the logistical and economics issues.

The data were processed using both straight ray and curved ray inversion schemes. The velocity image provided the first real picture of the fracture propagation between the wells and the structure around these fractures weakened by the interaction of fluids (see Figure 8). Prior to these surveys, the fractures could only be extrapolated between wells from borehole measurements (see Parker et al., 1994). The standard VSPs were of too low resolution to image any of the fractures. Further enhancement of the image was obtained by inverting for the anisotropic parameters at each pixel and imaging as a series of arrows representing the axis of symmetry (see Figure 9 and Kragh et al., 1994). This image was correlated with the varying properties of fractures and lithology. This survey was carried out in wells separated by 120 m, the survey with the maximum separation had a much-reduced resolution due to the distances involved. It also required 15 days of continuous (24 hr) acquisition.

Fig. 9. (Below) The result of the anisotropic inversion of the crosswell data with the arrows indicating the direction of the axis of symmetry. The sensitivity of the measurement to anisotropy is related to the aperture length of the individual shot scans.



Single well imaging

Given the logistics of tying up two wells for a crosswell survey, it makes more sense to adapt these techniques to a single borehole acquisition, where both source and receivers are in the same well and the same tool string. A sonic array consisting of a single source and multiple receivers is used conventionally to monitor wave propagation along the borehole. However, the geometry is in fact equivalent to a marine seismic streamer. Modification of the source-receiver geometry to suit reflection rather than refraction imaging, means that this conventional sonic system can be used in an unconventional way. These concepts were developed by Elf during the late 1980's.

An experimental system consisting of a sonic acquisition system, adapted so that varying spaces could be set between source and receivers, was used to acquire data in a common borehole to the cross-well campaign described above. The spacing of the source and the receivers was varied to optimise the timing of the reflected signals without being swamped by the high amplitude borehole-guided shear and Stoneley modes. The data were then processed using common receiver and common source gathers and conventional seismic techniques. The outputs were migrated using the velocities observed in the well. As the well was vertical and the volcanic layering had minimal contrast and was orthogonal to the borehole there were no reflected events from these interfaces. However, the highly dipping (relative to the borehole) fracture planes acted as efficient P-wave to S-wave converters, scattering the energy back to the receivers. When both compressional and shear velocities were part of the migration scheme these events were migrated coherently, aligning with the maximum fracture dip (there was no orientation information in the received wavefield), and confirmed by correlation with other measurements. Hence three images were produced. The first for compressional converted to shear events in one direction; the second for shear converted to compressional events in the opposite direction in the same plane (This plane is perpendicular to the fracture planes); and the third consisted of far-field

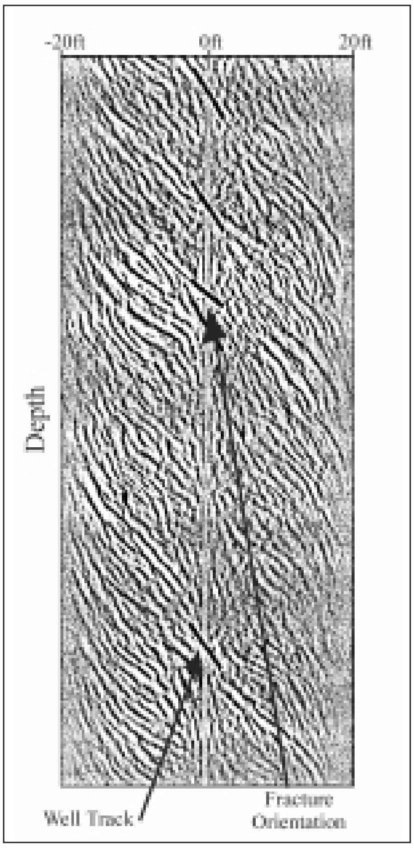


Fig. 10. A composite stack of the individual migrations corresponding to compressional and shear travel paths. Compressional to shear conversions occur on one side of the well, while shear to compressional conversion occurs on the other side of the well. The black lines correspond to independently measured fracture orientations.

compressional to compressional reflected events, where the geometry was appropriate. All three could then be effectively stacked together. The fracture imaging extended out to 1.5 to 3 m from the borehole on each side (see Figure 10 and Dodds et al., 1998).

The concept of a downhole streamer has potential in a horizontal well, where the layering is sub-parallel to the well deviation. This is the conventional earth geometry suitable for surface seismic imaging techniques. This suggests applications where the top or bottom of a reservoir can be imaged, or the presence of impermeable stringers, which could act as baffles to fluid flow, could be imaged. Knowledge of this would help to optimise the perforation strategy to reduce coning or gas pull-down. The last example is an example where the same experimental sonic system was deployed using drill-pipe conveyed logging techniques and successfully imaged the top reservoir as it dipped towards the well (see Figure 11 and Esmersoy et al., 1997). These applications have illustrated the potential of these techniques, however, the optimisation of this system requires a radical sonic redesign optimised for these types of measurements.

We have travelled full circle, from an application of conventional borehole seismic in an horizontal well, to a novel geometry in the same environment. This review has attempted to show, with reference to these case histories, that the borehole offers a variety of ways of focussing acoustic energy on reservoir properties. This is achieved when we can vary the source receiver geometries, the frequency content of the source and use the well geometry to suit the target application.

I hope that this general review will stimulate ideas and innovative thinking. This is relevant not only to the petroleum community, from which the examples are drawn, but also to the mineral exploration community who have their own experience in a different exploration environment.

Acknowledgements

The case histories and techniques above were drawn from my experience during my career with Schlumberger in Europe. I would like to acknowledge all the people with whom I collaborated in accomplishing this work. I would like to acknowledge Mobil North Sea for the first case history which was not published. I would also like to acknowledge Nirex and Texaco North Sea for the crosswell and the single well imaging. The references are not all comprehensive but contain brief published details of the case histories outlined above.

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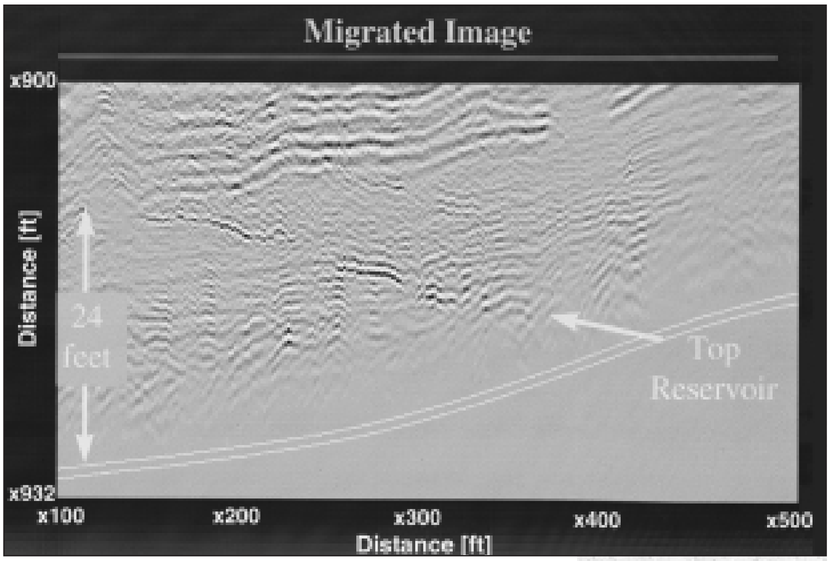

Fig. 11. (Above) Migrated single-well sonic streamer data in a horizontal well. The horizontal well is shown dipping at the bottom. The event angling up the section corresponds to the shale at the top of the reservoir. The geometry of the reservoir section and the position of the well within this is important to optimise the perforation strategy and hence production from the well.

Geophysical Grade Estimation in Mines

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Introduction

Geophysical logging is well established at producing coalmines for seam boundary definition and litho-stratigraphic mapping, and is employed at some metalliferous mines as an ore boundary definition tool. The cost-benefit of borehole logging at mines is usually couched in terms of 'diamond drilling saved', since wireline logs deliver accurate lithology and ore boundaries in uncored holes. However, to regard logging solely as a substitute for coring is to ignore potentially more significant impacts:

1. Increased revenue flowing from improved ore recovery and/or reduced dilution via logging of blast holes (King et al., 1994).
2. Enhanced geotechnical modelling, from more detailed and complete rockmass characterisation (Guo et al., 2000).
3. Fast, cost-effective grade estimation, in both uncored and cored holes.

The third of these potential benefits is explored in this paper. Grade estimation is attractive in its own right, and it also expands the scope for substitution of core drilling.

Grade estimates based on borehole logging will normally be less accurate, in a strictly analytical sense, than geochemical assays. However, the geophysical estimate has three potential advantages.

Firstly, the borehole probe measurement relates to a volume of rock, which is hundreds of times larger than the volume of core from the same depth interval. The geophysical data are therefore more volumetrically representative, and could be more representative of the bulk grade than the core assay.

Secondly, the geophysical estimate could carry information about ore mineralogy and texture, as well as grade. Mineralogical and textural cues could enhance predictions of the metallurgical behaviour and hence improve metal recovery.

Thirdly, the geophysical grade estimate can be obtained in real-time, avoiding the delays and costs associated with sample handling and assaying.

There are arguably three styles of petrophysical grade estimation: direct, indirect, and deterministic.

- Direct measurement of elemental abundance can be achieved via techniques such as natural gamma, neutron activation, and XRF.
- Indirect grade estimation relies on inference from measurements of one or more physical properties of the ore mineral assemblage or alteration assemblage.
- Deterministic methods predict mineral abundance from petrophysical measurements via inversion, on the basis of mixing laws. Grade is derived subsequently via stoichiometry.

If geophysical logs are to be used for grade estimation it is essential that the measurement procedures are rigorous, like the procedures enforced for geochemical assays. Grade estimation is quantitative, demanding a higher level of quality control than qualitative ore boundary definition. Repeatability is crucial: ideally, repeated measurements at the same location over time should yield the same physical property value, independent of the specifics of the probe (physical design, operating parameters, temperature stability, signal strength, etc.) or the condition of the borehole (fluid type, hole diameter, hole rugosity). The hardware and software already exist for acquisition and reduction of repeatable wireline logging data, but measurement procedures are not always adequate.

Examples of Geophysical Grade Prediction

Direct prediction

Natural gamma activity is routinely logged at uranium deposits for ore delineation and grade control (Conaway and Killeen, 1978). Nuclear logging techniques such as spectral gamma-gamma (Killeen and Schock, 1991) and neutron activation (Borsaru et al., 1994) can provide a direct indication of elemental abundance. Safety and logistical factors associated with the deployment of radioactive sources have restricted application of these techniques. A wide range of downhole analysers has been developed for petroleum wells, including XRF and neutron activation. Inco has trialled the Schlumberger prompt gamma neutron probe, with an electronic neutron source, to assess its efficacy as a means for *in-situ* Ni grade determination (McDowell et al., 1998). Results were technically encouraging, determining the nickel abundance to 0.23 weight% uncertainty over a range from 0 to 6 %.

Indirect prediction

In underground metalliferous mines, practicalities strongly favour the radioactive and the inductive (conductivity and magnetic susceptibility) techniques, which are effective in both wet and dry holes. Magnetic susceptibility provides an accurate indication of grade at the Malmberget iron mine in Sweden (Virkkunen and Hattula, 1992). Conductivity correlates closely with grade for some base metal sulphide ores, e.g. at the Enonkoski nickel deposit in Finland (Hattula and Rekola, 1997; Figure 1). At Outokumpu's Kemi chromite mine, gamma-gamma logging provides the basis for grade control (Talvisto, 1997). Similarly, coal quality can often be inferred from geophysical logs. Ash content has been estimated using a variety of tools, including gamma-gamma and resistivity (Edwards and Banks, 1978; Campbell, 1994) and neutron-gamma (Borsaru et al., 1986; Nichols, 2000).

The mineral(s) dominating the petrophysical responses are not necessarily the ore mineral(s). For virtually all gold deposits and many base metal deposits, the abundance of the economic commodity, or its petrophysical contrast with respect to its host rock, is insufficient to produce a detectable physical response. However, in some cases a strong mineralogical association exists between ore and a mineral, which is readily detectable. In some

Witwatersrand mines, for example, a correlation between uranium content and gold grade permits prediction of gold grades using natural gamma logging or face scanning (Campbell, 1994). In other cases multi-parameter grade estimates have been derived. Nelson and Johnston (1994), for example, estimated copper grade at an oxide deposit in Arizona from a linear combination of density, natural gamma, neutron capture, and neutron activation log responses.

The chemical accuracy and spatial resolution of petrophysical grade estima-tion need not be high in order to be useful. For example, within the ore intervals it may be possible to reliably distinguish high grade from low-grade zones on the basis of logs, without necessarily providing accu-rate geochemical abundance estimates. At the Pasminco polymetallic Rosebery depo-sit, Tasmania, the ratio of natural gamma to density correlates with zinc-equivalent grade (Fallon and Fullagar, 1997; Figure 2). This correlation provided a basis for automated prediction of ore categories.

Orebody Modelling with Geophysical Assays

Mine operators are generally uneasy about 'geophysical assays'. In some cases the reluctance to accept geo-physical grade estimates has more to do with mine culture, or regulatory cons-traints, than technical considerations. At the Laisvall Pb-Zn Mine (Sweden), for example, density-based grade estimates are accurate to $\pm$0.2% Pb, but are not accepted for ore reserve calculations (Fallon and Fullagar, 1995). Sometimes there is good reason for caution. At Outokumpu's Tara lead-zinc mine in Ireland, for example, gamma-gamma logging of in-fill percussion delineation holes is used not only to refine contact geometry, but also to rank the grade of ore blocks within individual stopes (J. Ashton, pers. comm.). The combined zinc+lead grade estimates at Tara are fairly reliable, but the presence of barite (dense) in some sections of the mine can compromise grade estimation based on density alone.

If petrophysical properties correlate with grade, automatic grade estimation is achievable using a variety of techniques, including multi-variate statistics (e.g. Urbanic and Bailey, 1988; Emilsson, 1993; Fullagar et al., 1999; Fallon et al., 2000) and neural networks (e.g. McCreary and Wanstedt, 1995). The assumption underlying automated interpretation is that the relationships between petrophysics and grade established in control holes are valid for other holes some distance away. It may be necessary to invoke different control data sets in different sections of a mine.

Even if geophysical grade prediction *per se* is not always feasible, there is scope to constrain geostatistical metalliferous ore reserve models using geophysical logs; wireline logging data are a vital input for petroleum reservoir modelling, e.g. Xu et al. (1992), McCarthy (1993). Differences in support volume and sampling interval constitute the principal complications in joint modelling of logs and assays. Geophysical logging data are typically recorded at a regular 10 cm interval, whereas geochemical assays usually relate to core lengths of 1-2 m. These issues are the focus of current research at the WH Bryan Mining Geology Research Centre at the University of Queensland.

Conclusions

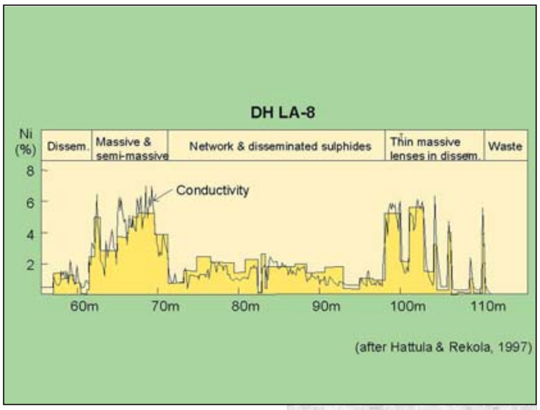

Fig. 1. Correlation between nickel grade and conductivity (Enonkoski Mine, Finland)

Currently, the cost benefit of geophysical logging at metalliferous mines is derived from substitution of core drilling with percussion drilling and logging. The benefit calculated in this way is usually a lower limit, as it takes no account of intangibles such as 'time saved' or 'waste rock not mined'. Much more substantial benefits have flowed from borehole logging at Stobie (King et al., 1994) and Laisvall, where it has generated significant new revenue.

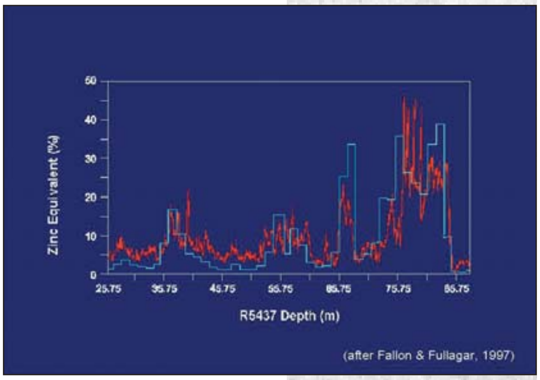

Fig. 2. Correlation between reciprocal gamma product (red) and zinc equivalent grade (cyan).

Grade estimation from borehole geophysical logging is not novel: Rautaruukki Oy has used magnetic susceptibility logging for grade control in its iron ore mines for more than 40 years (Hattula, 1984). However, research into geophysical grade prediction has not been vigorous, except for radioactive methods. Indeed, mining companies have been generally slow to exploit the potential for *any* quantitative interpretation of wireline logs, notwith-standing the high level of sophistication applied to petroleum well log interpretation. Automated inter-pretation, or any quantitative analysis, pre-supposes a high standard of instrumental precision, if not absolute calibration. Ensuring quality control during data acquisition is therefore essential if the full potential of borehole logging for grade prediction is to be realised.

Overall, the application of borehole logging in mines to date has been cost-effective but somewhat limited in scope. The twin drivers of increasing commercial incentive and advancing technical capability are likely to prompt more quantitative analysis of borehole logs at mines in the future, and more grade prediction in particular.

Acknowledgements

This article has drawn heavily on the findings of CMTE/AMIRA Project P436. We gratefully acknowledge the industry sponsors of that project, some of which are no longer with us: Aberfoyle Resources, Acacia Resources, CRA, MIM, Normandy-Poseidon, Outokumpu, and Pasminco.

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Petroleum Exploration Increases, and Minerals still in Decline

Petroleum up

Figures released last month by the Australian Bureau of Statistics showed that expenditure on petroleum exploration in the September quarter 2000 was $220M, 33% ($55M) higher than the June quarter 2000, and 6% ($13M) higher than the September quarter 1999. These numbers indicate the highest level of activity since the March quarter 1999.

The increase was dominated by the offshore drilling figures, which increased by 64% ($50M).

The other good news was that between the June and September quarters 2000, expenditure for petroleum exploration on both 'production leases' and 'all other areas' rose 113% ($22M) and 22% ($32M) respectively. In other words, the search for new reserves away from known fields is increasing.

Once more Western Australia dominated the scene with a total reported expenditure for the quarter of $149M (a 31% increase) out of a national figure of $220M. The Northern Territory was next with $31M. Unfortunately the figures from NSW, South Australia and Tasmania are not available for publication.

Figure 1 shows the recent trends over the last two years.

Mineral Expenditure still Declines

The trend estimate for mineral exploration expenditure was relatively stable in the September quarter 2000 but still indicated a small decline. This followed the levelling off of the trend estimate in the June quarter 2000 after 12 quarters of decreasing expenditure levels.

The September quarter 2000 trend estimate of $167M was only 3% lower than the trend estimate of $172M for the September quarter 1999.

Figure 2 shows the trends in the last eight years.

In the September quarter 2000, the largest increase in the trend estimate occurred in Victoria (up 8%), while in New South Wales, Queensland and South Australia the estimates increased only marginally. Western Australia, Tasmania and the Northern Territory showed small decreases. However, Western Australia is by far and away the largest contributor. Out of the total of $167M, $101M was spent in WA with Queensland a distant second at $22M.

Between the June quarter 2000 and the September quarter 2000 the trend estimate for metres drilled increased by 39 km (3%) to 1500 km. This was only 0.4% lower than the September quarter 1999.

The bad news is that the fall in total mineral exploration expenditure in the September quarter 2000 was due to a 13% ($19M) fall in expenditure reported in 'all other areas'. Although this was offset partially by a 16% ($6M) increase in exploration expenditure on 'production leases', it means that 'green field' exploration declined significantly.

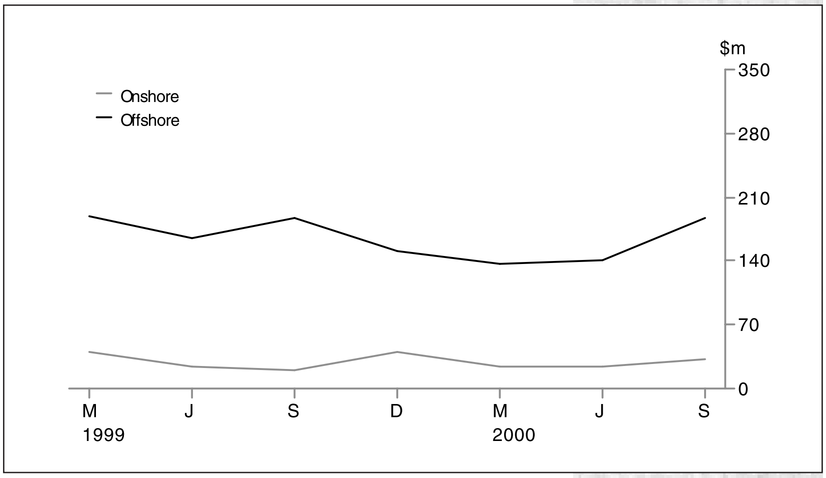
Exploration expenditure for gold decreased by 16% ($17M) in the September quarter 2000. The majority of the decrease for gold occurred in Western Australia, down 16% ($12M).

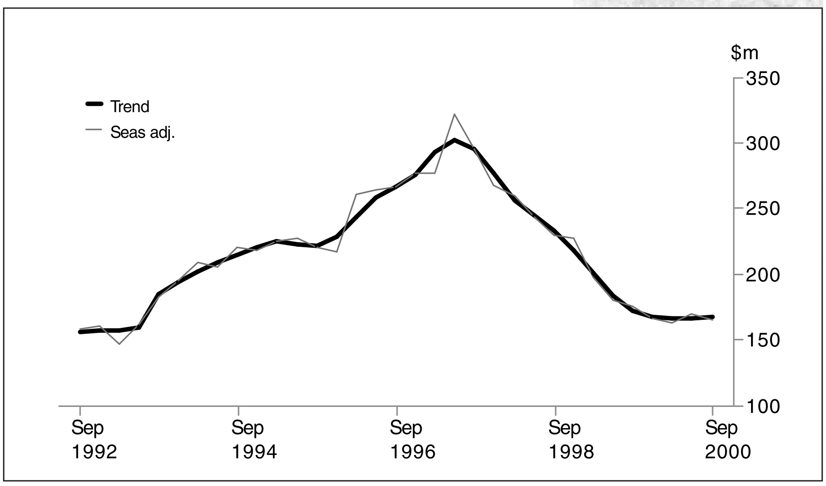
Between the June and September quarters 2000, exploration expenditure for basemetals (copper, silver-lead-zinc, nickel and cobalt) decreased 3% to $39M. We are not yet out of the slump, but the decline has been halted.

Charts provided with permission of the Australian Bureau of Statistics.

Fig. 1. (Below) Petroleum exploration expenditure March 1999 to September 2000

Fig. 2. (Bottom) Mineral exploration expenditure September 1992 to September 2000





New Software Release from Encom Technology

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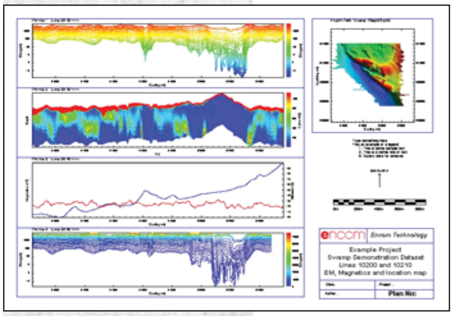
Encom will show its first release of Profile Analyst in March at the PDAC Convention in Toronto, Canada. This software takes a fresh look at an old method of data analysis that has been overlooked in today's era of image analysis. The majority of geophysical data is collected along lines and quickly converted to grids for subsequent image analysis. Encom's Managing Director, Dr. David Pratt, believes that subtle targets may go undetected when we rely on imagery alone.

Profile analysis allows an interpreter to derive additional information that cannot be resolved in images. Examples include simultaneous visualisation of more than three channels of data, subtle shape information in curves, comparison of unrelated data types, and fine detail that may be lost during gridding. Until the arrival of Profile Analyst, the detailed analysis of profile data from large surveys was slow and image analysis provided the only practical method for analysing large quantities of survey data.



Profile Analyst is designed to address many of the inefficient workflow processes in routine project analysis. It connects directly with Oasis montaj and Intrepid databases thereby eliminating data import inefficiencies. Application templates provide a fast way for experts to present data in a way that is optimised for specific exploration objectives. Specialised templates can be reused by operational staff on interpretation projects that have similar specifications.

Application templates have been developed for base metal exploration with EM and magnetic data, diamond exploration with magnetic and radiometric data and uranium exploration with radiometric and magnetic data. Templates can be customised to suit other applications such as salinity surveys with EM data, coal mining hazard detection with magnetic and radiometric data and multi-element geochemical profile analysis for base metal exploration.

As the interpreter identifies features of interest, the points are identified graphically, tagged, described and stored in a database. In this way cumulative knowledge is captured for redisplay in Profile Analyst or directly linked to MapInfo and ArcView.

Visit Encom at the PDAC Convention (booth 708) for a demonstration of the software. Please visit www.encom.com.au or contact info@encom.com.au for further information.

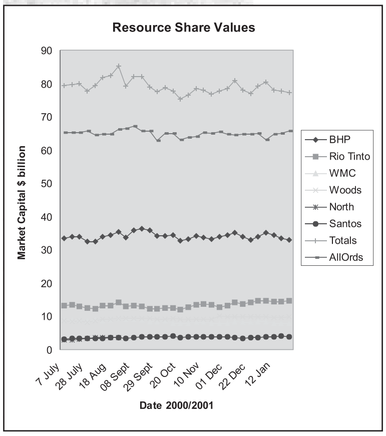
How did Resource Shares Fare in 2nd half of 2000?

David Denham

The market capital of mineral and petroleum resource companies is a useful indicator of the health of the resource sector. I have therefore made a simple analysis of the major resource industries listed on the ASX during the second half of 2000, using this parameter.

The diagram shows how the total market value of those companies listed in the top 150 companies (currently 13 companies), the 'All Ords' index, and the value of the largest six resource companies have changed during that period. The other nine companies are much smaller and are not plotted.

Fig.1. The 'Totals' represent the total market capital of the 15 top resource companies on the ASX. Only the top 6 companies are plotted individually. 'All Ords' represents the (All Ords index)/50.'



The totals represent the total market capital of the 15 top resource companies on the ASX. Only the top six companies are plotted individually. 'All Ords' represents the (All Ords index)/50.

Essentially, while the All Ords index remained approximately constant during the second half of 2000, the total value of the resource stocks declined by about 1.5%. Most of the decline was caused by the takeover of North in August (valued at ~$3.5 billion when the acquisition took place) by Rio Tinto. In comparison, Ashton, which was taken over in December (also by Rio Tinto) only had a market value of ~$0.7 billion.

The big five winners over the period were:

1. Rio Tinto, from $13.4 to $14.7 billion (~10%)
2. Woodside, from $8.7 to $ 9.8 billion (~13%)
3. Santos, from $3.0 to $3.7 billion (~20%)
4. MIM, from $1.7 to $2.0 billion (~20%), and,
5. Sons of Gwalia $0.59 to $0.73 billion (~24%).

For the most part, it appears the best way to increase the share price is to attract a takeover bid.

The big three losers (apart from those taken over) were:

1. Pasminco, from $1.0 to $0.7 billion (~28%)
2. Anaconda, from $1.0 to $0.8 billion (~20%), and
3. Lihr, from $0.86 to $0.70 billion (~20%).

The values for the other companies (BHP, WMC, Normandy, Newcrest, and Oil Search) changed by less than 5%.

Overall, the resource industries held their own reasonably well in the market place, but takeovers are of concern in a sector that does not seem to be expanding.

Shell Persisting with its Hostile Takeover of Woodside Petroleum

The Federal Government is now involved in the battle for Woodside Petroleum Ltd., after it decided to give the Foreign Investment Review Board (FIRB) up to 90 days to consider the take over bid.

Shell needs FIRB clearance to raise its stake in Woodside from 34.7% to a controlling 56%, which it hopes to do by offering shareholders $14.80 in cash and a call option.

In late December 2000, the independent directors of Woodside Petroleum Ltd. issued a statement reiterating their earlier recommendation that the bid should be rejected. The Shell-nominated directors of Woodside did not make a recommendation.

The statement gave three key reasons why Shell's offer should be rejected; the offer is neither fair nor reasonable, it does not contain an adequate premium for control of Woodside, and it does not fully reflect the growth initiatives of Woodside.

Based on a report by an independent expert, Woodside's Managing Director, John Akehurst, stated that, "the fair market value of Woodside should be $16 to $18 a share. This compares with Shell's offer of $14.80 and a conditional call option, which the independent expert has valued at between $0.20 and $0.42."

Mr Akehurst said, "Woodside had the asset base, financial capability and the people to deliver substantial growth over the next decade."

Woodside has the potential for significant growth through the company's developments, in particular from:

(i) acceleration of North West Shelf production through earlier commitment to LNG train 5;
(ii) higher planned production and reserves for the Legendre oil field development;
(iii) higher levels of reserves and scope for recovery and the earlier start-up of production from new discoveries in the WA-271-P permit area; and
(iv) lower cost and earlier commercialisation of Greater Sunrise resources via a Darwin-based LNG project, as a result of the co-operation principles agreed in November 2000 with Phillips Petroleum Company Australia, the operator of the Bayu-Undan joint venture.

Mr Akehurst also pointed out that Woodside had one of the world's lowest finding costs per barrel of oil equivalent with finding costs between 1998 and 2000 having been US$0.51 a barrel.

No wonder Shell is going for a takeover.

BHP's Falcon Team Wins CSIRO Medal

CSIRO awards four medals each year for outstanding research performance. One of these is given to a research team or individual outside CSIRO for significant research achievement. The 2000 CSIRO Medal was awarded to BHP's Team Falcon. The citation reads:

BHP's Project Falcon has succeeded in turning the exploration geophysicists' vision of airborne gravity into reality with two fully operational airborne gravity gradiometer (AGG) systems. These AGG systems provide sensitive, high-resolution detection of small variations in the earth's gravity at the level required in exploration for mineral and hydrocarbon resources. Airborne geophysics allows rapid, low cost surveying of large areas without the variety of access problems that can make ground surveys slow, difficult and expensive.

The project was the result of a strategic vision of a small group of research and exploration staff in the period 1991-3. The goal of the team was to determine whether BHP could achieve an international competitive advantage in mineral exploration and also address hydrocarbon opportunities. Starting in 1991, BHP surveyed all the known gravitational technologies in the world to assess the practicability of development of an operational airborne system with the sensitivity, reliability, and operating costs required by the minerals industry. It was decided that a sensor technology originally developed by the US Navy in the 1970s, at a cost of USD$400m, and installed in their Trident submarines held the greatest promise.

The Falcon team is shown above. They are from the left: Graeme O'Keefe, Mark Dransfield, Xiong Li, Bob Turner, Edwin van Leeuwen, Jim Lee, Ken McCracken, Marion Rose, Maurice Craig, Mike Asten, and Peter Stone.

Absent were: Clive Affleck, Peter Diorio, Nick Fitton, Giles Hofmeyer, Gary Hooper, Tim Monks (deceased), and Ken Witherley.

As tests of the instrument in an aeroplane would have been too expensive and technically unreliable, BHP conducted a detailed feasibility study to determine whether the technology could meet the requirements of airborne mineral exploration. It became evident that the gravity sensor, although based upon the Navy's concepts, was going to be an entirely new instrument and had to be designed from scratch using modern components. In

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addition to the development of the instrument itself, even greater effort was required to develop the software that would allow the flight data to be fully processed, corrected for topography and displayed as a gravity map all within 12 hours. This required applied mathematics, statistics and signal and image processing of the highest order.

To achieve the strategic vision, BHP assembled a small group of high calibre technology-development people from its corporate technology laboratories. This team operated under intense pressure, in a manner similar to the ' Skunk Works' operation used by several companies to achieve exceptional breakthroughs in technology. The relentless pace of the work continued for four years until, in October 1999, the Einstein system was declared operational following exhaustive tests over regions of well-known gravitational properties.

The Falcon instrument represents a major contribution to Australia's industrial development. By reducing exploration costs and providing a competitive edge worldwide, it contributes strongly to the continuance of the Australian mining and downstream processing industries. It is an excellent example of technology transfer and demonstrates a new paradigm for industrial research wherein key elements are sourced outside the company while being managed internally.

Congratulations to Team Falcon.

Advances in Interpretation: from Poststack Reflection Data to Multi-Volume Rock Property Data

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Jason Geosystems

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Throughout the 1990s seismic technology was recognised as the technology providing the highest impact on the Exploration and Production (E&P) business. If we want to maintain that momentum, we must continue to add value to the E&P business process. Arguably the largest gains in this new decade are to be expected in seismic data analysis and interpretation. This will be achieved by moving from seismic poststack reflection interpre-tation, to integrated quantitative rock property analysis and interpretation.

The first step into the rock property domain is to move from seismic poststack reflection interpretation to acoustic impedance layer based interpretation. With modern inversion techniques, high fidelity acoustic impedance (AI) cubes are readily produced from poststack seismic data. Combining high-end inversion with impedance interpretation adds considerable value to the interpretation process:

- Good inversion reduces interference from closely spaced reflectors (or tuning) and incorporates geological model information. The resultant AI volume integrates information from the seismic amplitude data, seismic velocities, well logs and sequence stratigraphy.
- AI is the common currency for multi-disciplinary teams: It links to well logs as it is the product of density and velocity; it links to seismic data as seismic reflectivity relates to changes in AI contrast; it links to engineering reservoir models as often strong relationships exist between AI, lithology, porosity and pore fill; and it links to sequence stratigraphic interpretation, as it shows layers with the same AI values.
- AI data shows layers and seismic reflectivity data show layer boundaries. Therefore, AI data, as opposed to seismic reflectivity data, support faster and more accurate volume based interpretation. One to two orders of magnitude in interpretation efficiency can be achieved.

Figure 1 provides an example of the benefits of moving interpretation into the AI domain. The top section shows the seismic data with several interpreted events. Due to structural interference in the seismic data it is not straightforward to interpret the yellow event. The lower section shows the corresponding AI data, here the interpretation of the yellow event can now be made with much more confidence and a channel feature is better visible.

The many advantages of working in the AI domain have led to a spectacular growth in its use. Many of the leading oil companies now use AI as the preferred basis for interpretation. Our expectation is that the next few years will see AI replace poststack seismic data as the favoured basis for interpretation.

The development of interpretation technology will not end with the introduction of AI. One exciting new development is in using AVO information in seismic data and turning this into rock property information. It is now possible to simultaneously invert multiple partial stacks to recover both acoustic and shear impedance (SI). Having these two fundamental rock properties available greatly enhances our power for lithology and fluid discrimination.

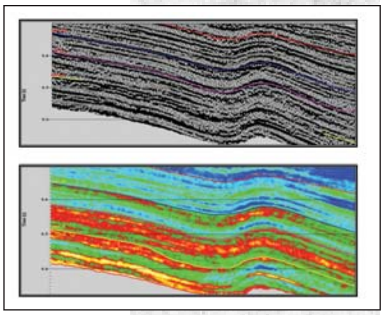

Fig. 1. The top section shows the seismic data with several interpreted events. The lower section shows the corres-ponding AI data, here the interpretation of the Yellow event can now be made with much more confidence and a channel feature is becoming visible.

The second development is in the area of combining geostatistical modeling, in the context of a sequence stratigraphic framework, with inversion. This allows us to produce quantitative lithology and porosity probability models of reservoir rocks far below seismic resolution. Figure 2 shows a section through a sand probability cube derived through stochastic inversion. The red colours indicate high sand probability, the blue colours indicate low sand probability, and the well tracks show the sands in yellow.

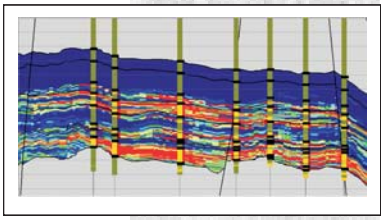

Fig. 2. Section through a sand probability cube derived through stochastic inversion. The red colours indicate high sand probability, the blue colours indicate low sand probability. The well tracks show the sands in yellow.

New tools to analyze and interpret the multiple volumes generated by these new methods are being developed in parallel. Figure 3 shows an example where the acoustic and shear impedance cubes were generated by the simul-taneous inversion of multiple partial stacks, calibrated to well control. Figure 3a shows a well log AI/SI crossplot that shows that both AI and SI are required to resolve the reservoir lithology and fluid content. In the crossplot domain, polygons can be drawn to capture the sand points, and within the sands the oil points. Figure 3b shows how in a multi-volume inter-pretation tool all 'geobodies' of spatially connected points corres-ponding to sands are automatically captured from the inverted AI and SI cubes. Figure 3c shows the auto-matic capture of the oil sand bodies within the reservoir sands.

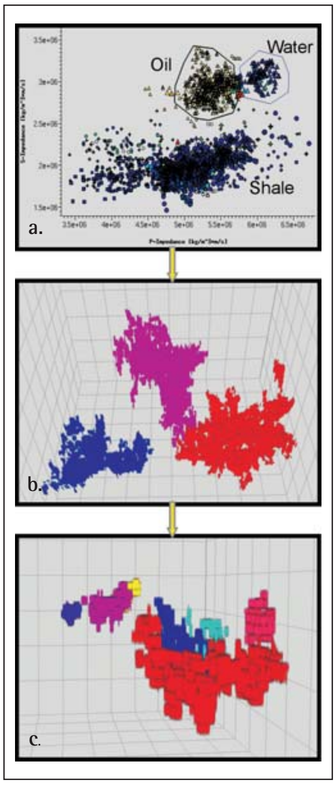

Fig. 3a. Well derived crossplot showing polygons for oil and water sands in the P, S Impedance space.

Fig. 3b. 3D view of the 'sand' geobodies captured from the P and S impedance volumes based on the above crossplots

Fig. 3c. 3D view of the 'oil charged sand' geobodies captured from the P and S impedance volumes based on the above crossplots. Note the difference in OWC for the different geobodies.

SEG Publishes Special Issue on Mining Geophysics

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The SEG has just published in *Geophysics* (Vol 65, No. 6), a special issue of 16 papers, which describe a series of recent developments in mineral exploration and mining geophysics. The papers were selected from material presented (but otherwise unpublished) at The Exploration '97' Conference held in Toronto in 1997. Of the 56 contributing authors, Australia is strongly represented with 18.

One of the most dramatic changes illustrated by five of these papers is the successful cross-fertilisation between petroleum and mining geophysics, whereby advances in seismic methods, in particular 3D data acquisition and processing, have been brought into routine application in the structurally-complex environments associated with mineral provinces and ore-deposit geometry. A further three papers describe developments in underground/cross-hole seismic, radar and radio wave imaging methods. It is the hope of the editors that, just as these examples have extended traditionally 'petroleum' technologies into mineral related problems, so the high-resolution techniques and the integration of electromagnetic methods with seismic methods, will prove of benefit to petroleum geophysicists.

Four papers review the state-of-art in acquiring and imaging airborne EM and spectrometric gamma-ray data. The quality of the data and images now achievable show why these techniques are becoming essential tools for geological mapping and reconnaissance, as well as for their former and traditional role of direct ore-body target location.

One paper on 3D inversion of induced polarisation data introduces a new advance (from 2D into 3D geometry) of one of the most significant break throughs of the last generation in surface mineral geophysics - that of stable inversion of resistivity-IP data.

Finally, we have three papers, which discuss the application of geophysics and borehole logging to mine planning and ore body evaluation. Acceptance of geophysical technology in these areas has been slow, and it is notable that these case histories demonstrate how its correct use brings savings of the order $millions to the field of mineral extraction.

Seismic, EM and Physical Property Studies

Drummond, Goleby et al. use three case studies to demonstrate how seismic techniques could be applied during mineral exploration. Their paper addresses each within a mineral systems framework in the pre-competitive area selection stage of exploration, and at the orebody scale, where the seismic survey can be designed to target structures and alteration halos around the orebodies, rather than orebodies themselves.

Pretorius et al. describe how a 3D seismic survey has accurately delineated the structure at a gold bearing orebody at depths ranging from 1000 m to 3500 m, imaging faults with throws ranging from 20 m to 1200 m. The resultant structure plans have been merged with drillhole, underground survey and sampling data into an integrated mine modelling, gold reserve estimation and mine scheduling package.

White et al. describe an attempt to map the subsurface extent of Ni ore bearing rocks in a complex geological environment using seismic reflection and electromagnetic techniques. The results of this study demonstrate how these techniques might be effectively employed as regional exploration tools.

Salisbury et al. show that laboratory and logging measurements of the acoustic impedances of ores and host rocks from the Bathurst mining camp suggest that it should be possible to detect massive sulfides in many geological settings using high-resolution seismic reflection techniques. This has been confirmed by the detection of an ore deposit at Bathurst using VSP and 2D seismic reflection profiling.

Milkereit et al. report a 3D seismic survey in the Sudbury basin, conducted over a deep nickel-copper deposit. Results indicate that high frequency reflection surveys can detect and delineate massive sulfide deposits in the crystalline crust.

Cross-Hole Seismic and EM Methods

Wong reports a case history in which a piezoelectric vibrator source was used with hydrophone detectors to acquire crosshole seismic data for ore body delineation. A color-coded P-velocity tomogram created from first arrival times successfully imaged a massive sulfide ore zone residing in crystalline host rock.

Greenhalgh, Mason, and Sinadinovski present results from an underground seismic experiment conducted in a nickel mine in which both tomography and reflection imaging procedures were used to successfully map rock structure and stope geometry.

Fullagar et al. demonstrate the potential of radio tomography, and simple 'radio shadowing', for near-mine exploration and orebody delineation in the Sudbury area. Radio signals were successfully propagated through the Sudbury Breccia host rock, McConnell Mine, over ranges of at least 150 m at frequencies between 500 kHz and 5 MHz.

Induced Polarization

Li and Oldenburg present an algorithm for inverting induced polarisation data in 3D and examine the practical issues associated with its application. They also demonstrate that good chargeability models can be obtained efficiently by using approximate conductivity models in the inversion, and that joint inversion of surface and borehole data significantly improves the result.

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In-Mine and Grade-Control Geophysics

Mutton uses some examples of results obtained during the evaluation of the Century zinc deposit in northern Australia, and describes the opportunities available, and the rationale for applying geophysical methods beyond the exploration stage of mineral development. The results demonstrate some of the potential benefits that could flow from the routine use of geophysics during resource evaluation, or integrated with mining, when used to address such problems as orebody delineation, grade control or hazard detection and monitoring.

Hattula and Rekola demonstrate the importance of geophysical techniques in site-specific and deposit-scale exploration with investigations on sulfide ore deposits of the VMS type in the Pyhasalmi area. Applications are also presented to illustrate the successful extension of geophysics into mine production using borehole logging for grade control at mines operated by the Outokumpu Group.

Charbucinski, Borsaru and Gladwin describe the prototype of a fully spectrometric gamma-gamma probe, which uses an ultra-low activity gamma-ray source, and give results of tests at a Zn-Pb deposit in Queensland. The probe showed an excellent capability for ore-body delineation and good potential for quantitative determination of Pb and Zn content in ore.

Airborne Geophysics

Leggatt et al. describe the SPECTREM airborne EM system, the signal processing challenges and data transformation methodology to obtain conductivity-depth parasections. The system has proved successful in finding two massive-sulfide mines in Canada, and in mapping the regolith in Africa.

Sengpiel and Siemon have developed new AEM sounding curves of apparent resistivity versus centroid depth values aiming to enhance the sensitivity of the curves to vertical resistivity changes. These curves can be used either to provide an initial step model for a 1D Marquardt type inversion of EM data or for a direct representation of complex resistivity structures.

Jayawardhana and Sheard describe how airborne radiometrics have been used in geographic information systems to identify alteration zones and aid mineral exploration. The case study for this paper focuses on the Mount Isa airborne survey undertaken from 1990-92.

Shives et al. describe how modern airborne and ground gamma ray spectrometry provide quantitative geochemical information applicable to geological mapping, mineral exploration, environmental studies and land use planning. In this paper, case histories illustrate the use of gamma ray spectrometry to measure and map potassium enrichment related to volcanic hosted massive sulfide, polymetallic and porphyry mineralisation, leading to new discoveries in Canada.

AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS

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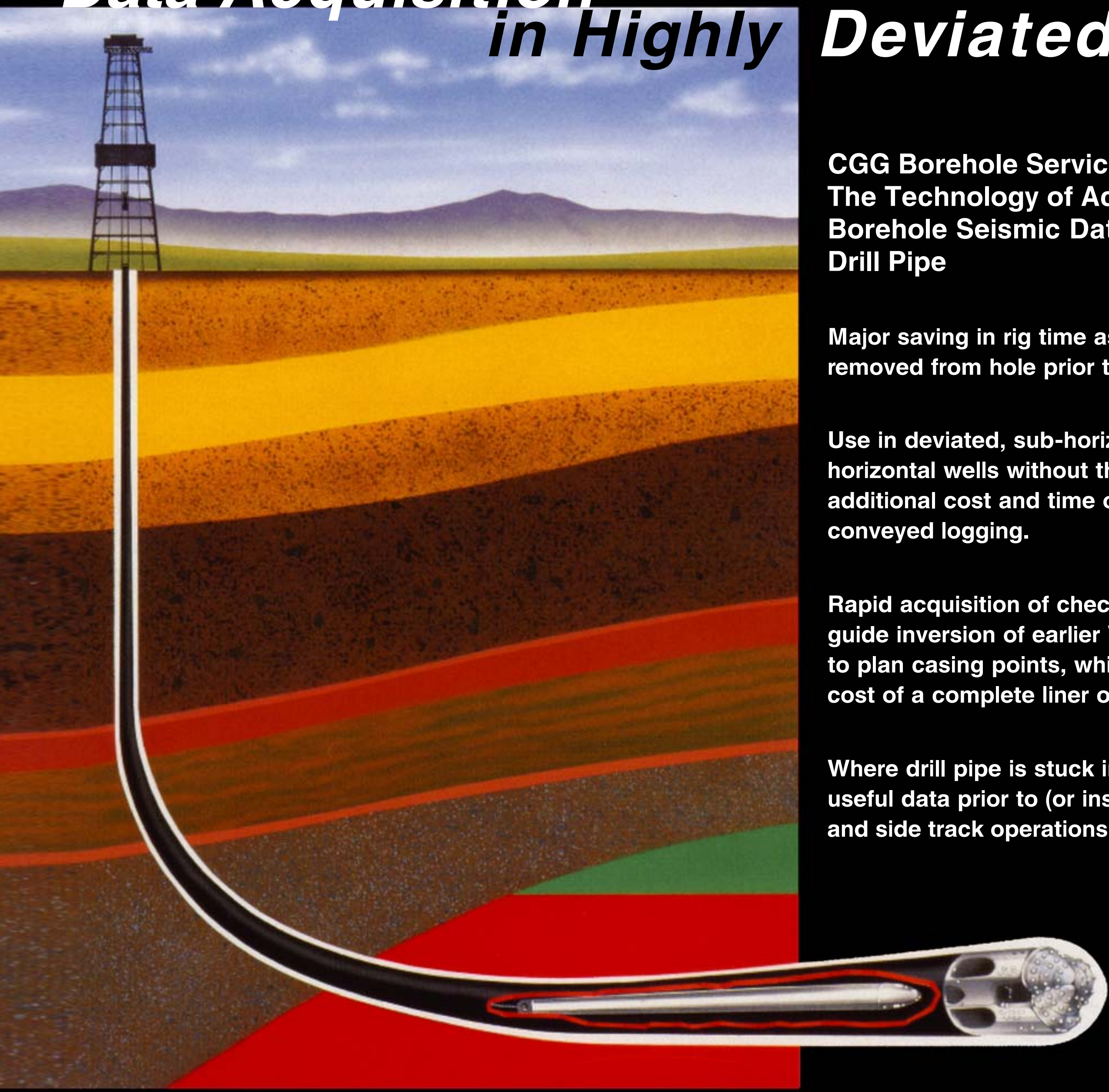

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