Australian Society of
Exploration Geophysicists

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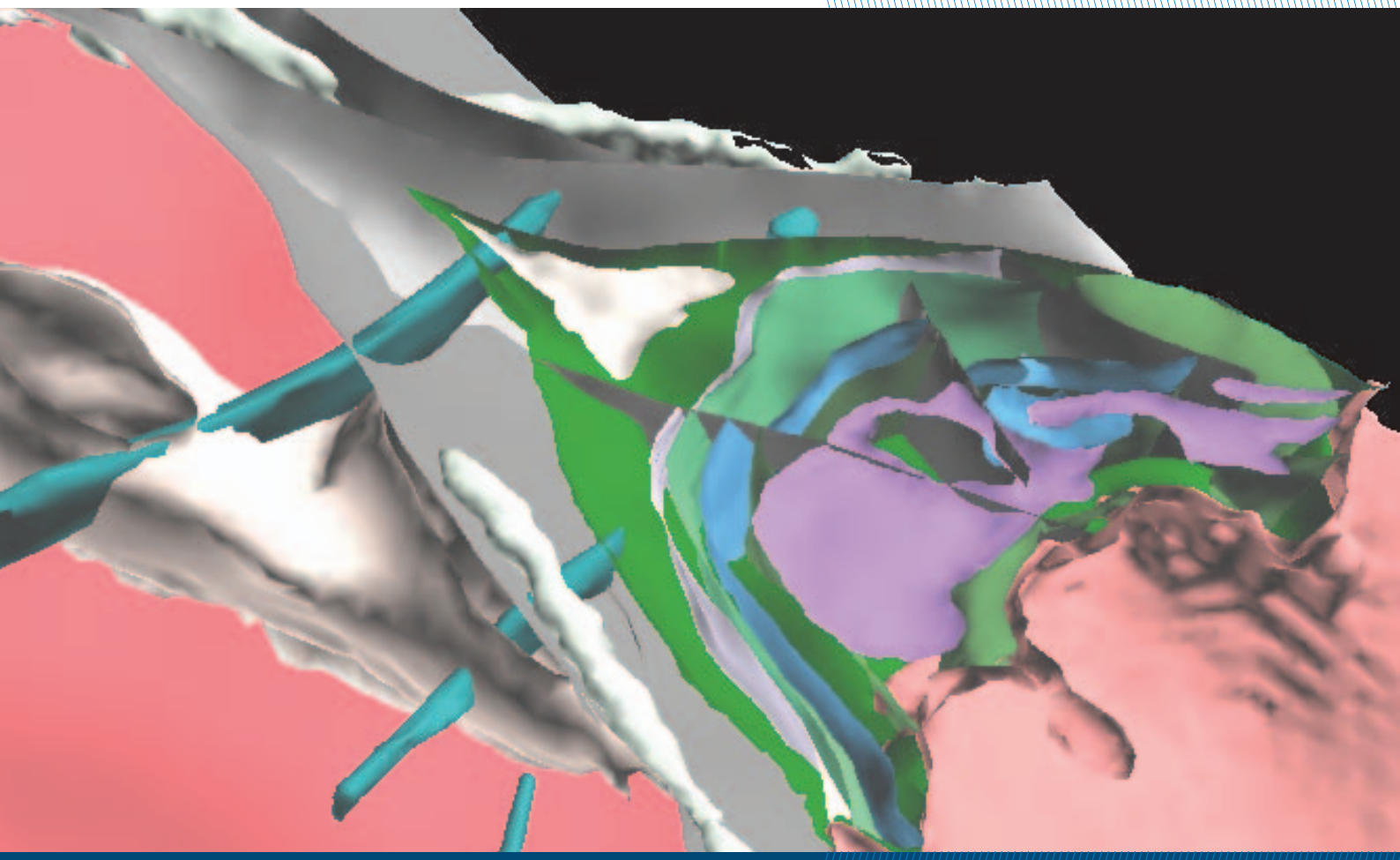
PREVIEW



NEWS AND COMMENTARY

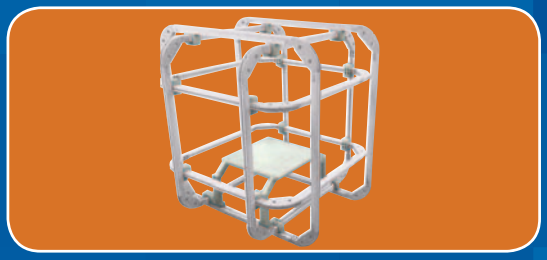
FEATURES

Magnetic Field Instrumentation

Three-Axis Magnetic Field Sensors

- For TDEM and airframe compensation
- Measuring ranges from ±60μT to ±1000μT
- Noise levels down to <4pTrms/√Hz at 1Hz
- Bandwidth to 3kHz; wide bandwidth version to 12kHz

Helmholtz Coil Systems



- For downhole tool and sensor calibration
- 500mm and 1m diameter coils
- Power Amplifier and Control Unit available

MS2/MS3 Magnetic Susceptibility Equipment

- Resolution to $2x10^{-6}$ SI
- Laboratory sensors with dual frequency facility
- Core logging and scanning sensors
- Field survey equipment

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PREVIEW

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CORPORATE MEMBERS

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Geotech Ltd
Papuan Oil Search Limited
Petrosys Pty Ltd
Quantec Geoscience Pty Ltd
Rio Tinto Exploration Pty Ltd
Santos Ltd
Seismic Asia Pacific Pty Ltd
Southern Geoscience Consultants Pty Ltd
Terrex Seismic
Wireline Services Group
Zonge Engineering

FRONT COVER

A screenshot of the Sandstone greenstone belt 3D model created by GSWA and taken from the feature article in this issue entitled 'End of the Flat Earth: a new era at GSWA'.

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We look backwards as well as forwards in this issue of *Preview*. David Denham reminds us that 2015 was a dismal year for commodity prices and that exploration spending is at very low levels. Noll Moriarty peers into the future and suggests that the end of this downturn is in sight. He is even brave enough to predict the timing of the next downturn! Mick Micenko reflects on the year that was and Guy Holmes imagines the year that will be. Roger Henderson tells us something about Australia's first lecturer in exploration geophysics, who was appointed in 1949 in a burst of post-war enthusiasm ('The first lecturer in exploration geophysics in Australia – later to become a world renowned seismologist'), and Ruth Murdie shows us where GSWA is heading over the next decade ('End of the Flat Earth – a new era at GSWA').

Roger Henderson's article on the first gravity meter, which was published in the last issue of *Preview*, sparked a lot of interest, as described in Roger's Letter to the Editor. It is clear from the nature of the feedback that *Preview* is being read internationally as well as nationally. In 2015 nearly 200 of 1000 plus ASEG Members were based overseas but, as the digital version of *Preview* is currently freely available online, our readership extends well beyond our membership. In 2015 over 1000 non-Members subscribed to the digital version of *Preview* and over 300 of these non-Member subscribers were based overseas; in the Americas, the Pacific, Asia, Africa, the Middle East and Europe. Many of these non-Member subscribers (in Australia and overseas) are not geophysicists but they are clearly interested in what is happening in the geophysical world. Non-Member subscribers include geologists, geochemists, hydrogeologists, agricultural and environmental scientists, science educators, policy makers and journalists. They also include future geoscientists. My hard copy of the December issue of *Preview* was prised from my grip, as I left the Millaa Millaa Post Office, by a 10-year-old boy; a passionate collector of rocks and minerals who was desperate to read Don Emerson's article on lapis lazuli!

So, it would seem that *Preview* is not just fostering and facilitating interaction between geophysicists in Australia and the Asia Pacific region. It is also fostering and facilitating the interaction between geophysicists and other earth scientists throughout the world. *Preview* contributors can make and shape opinions. So, keep those *Preview* contributions coming. *Preview* is your magazine and your chance to speak to the world. The world – those bits that count anyway – is listening!!

Lisa Worrall
Preview *Editor*
previeweditor@aseg.org.au

Letter to the Editor

Dear Lisa,

Readers of my paper on the first gravity meter (*Preview*, **179**, 53–61) might like to know that I have received not only very nice compliments from some ASEG Members and others in North America, but also some further information tending to verify my contention that the Threlfall and Pollock meter is the first in the world.

Richard Smith (Active ASEG Member since 1983) of Laurentian University in Canada thought my paper was worthy of being made known to those on the Grav Mag list server (grvmag-l@ldeo.columbia.edu) and kindly arranged it. Following that, Edgar Wright of Canada sent me a reference to Mr Boys and Lord Kelvin from *Astronomy and Astro-physics* **12** (1893), p. 366 by searching 'boys' and 'gravity meter' in Google Ngram. The result is; "It will be remembered that the 'differential' [equals 'relative'?] gravity meter devised by Lord Kelvin and described by him at the Birmingham meeting of the British Association (1886) was abandoned not only on account of elastic 'fatigue' in the flexed spring which he employed, but partly because Mr. Boys, then just out with his quartz fibres, proposed to use torsion in a horizontally stretched fibre, after the manner of a catapult whose arm is held back by gravity. It was hoped thus to obtain an instrument which would surpass Lord Kelvin's spring both in delicacy and precision. But if anything farther has come of Mr. Boys' torsion balance, it has escaped your reviewer."

Thus we learn that Lord Kelvin was unsuccessful because he wasn't using fused-quartz and that Boys proposed its use of which nothing was known by 1893. Threlfall and Pollock had a working unit by 1893 but did not announce it in London until 1899. Also, in my paper, I had expressed ignorance of the terms 'catapult' and 'bow and arrow' used to describe the drawing of the thread. However, the catapult method is partly explained in the above.

References to papers in the British Association Reports by both Lord Kelvin and Vernon Boys are given in the Bibliography of Threlfall and Pollock's paper.

Then, our own irrepressible Doug Morrison, who seems to have a bottomless source of historical documentation, provided me with a copy of a paper in *Geophysics* by E. A. Eckhardt 1940, (A Brief History of the Gravity Method of Prospecting for Oil: *Geophysics,* **5**, 231–242). On page 240, Eckhardt states, after discussing pendulums to 1932 that; "These considerations [such as pendulums being 'ponderous'] led geophysicists to turn their attention to the development of gravity meters, or gravimeters. The earliest instrument of this type seems to be that of Threllfall (sic) and Pollock". Then he gives the reference to their 1899/1900 paper as a footnote. He goes on to say; "In the United States gravimeter development appears to have been first undertaken by the Humble Oil and Refining Company. This development resulted in the Hartley, Truman and later models. The first Humble-Truman meter was sent to the field in June, 1930".

One other commentator of my paper (who I suspect hadn't read it) stated: "Fused quartz element meters was the invention of Gulf Oil but refined by many others starting the mid 1930s". This is clearly a 'USA perspective' of history.

Roger Henderson
rogah@tpg.com.au

Christmas reading, student projects, boom/bust and the future of UAV magnetometry

Phil Schmidt

The last issue of *Preview* was certainly good Christmas reading, especially with Don Emerson's erudite exposé on lapis lazuli and Roger Henderson's article on the first gravity meter built in Australia (perhaps a global first). The issue also contained interesting summaries of student projects in Australian universities in 2015 that suggest there is a healthy through-put of students in geophysics courses in Australia. Sadly there will probably be a decline in graduate numbers in the earth sciences for the next few years. Student through-put always lags the beginning and end of cycles in our boom-bust industry. Thus it ever was, which is a pity as now would probably be a good time to start to catch the wave of the next boom.

An article by Brendan Pearson, Chief Executive of the Minerals Council of Australia (MCA), also made for interesting reading over Christmas:

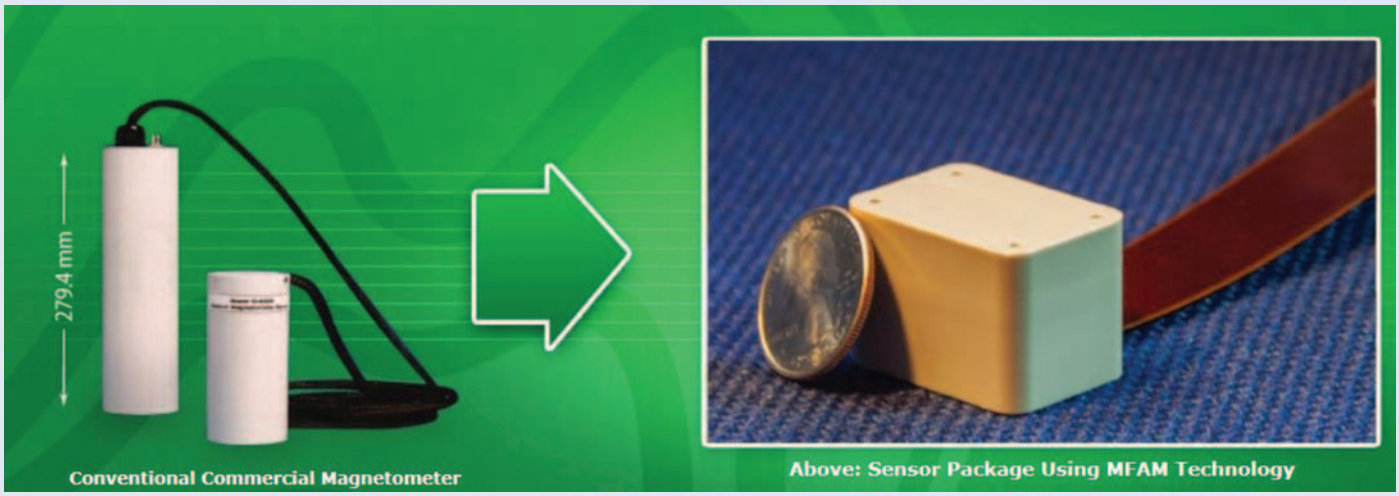
> 'The Turnbull Government's National Innovation and Science Agenda will help ensure that Australia's comparative advantage in mining is maintained and enhanced through continual innovation in the years to come.
>
> Innovation isn't about compensating for the end of the mining boom. It's about ensuring that Australia's long-term advantage in mining continues, notwithstanding cyclical activity.

I think that such statements, although repeating the obvious to people in the industry, need to be made periodically to counter relentless media articles speculating that mining in Australia has passed its use-by-date. For those looking for some facts go to: http://www.minerals.org.au/file_upload/files/publications/Innovation_The_Facts_Dec_2015.pdf

Until last year I was more or less an observer of the progress of the National Rock Garden (http://www.nationalrockgarden.org.au/). I have visited the garden and admired the Federation Rocks, some of which I have been challenged by during my career. Now, as ASEG President, I have been asked about ways in which the public can be shown how geophysics has contributed to Australia's mineral industry. These discussions are ongoing but I think that the best avenue is to prepare displays for the Education Pavilion that relate to the Federation Rocks. For instance, the Tasmanian dolerite played a pivotal role in the Continental Drift Debate of the 1950s and 60s. The interpretation of magnetic anomalies over WA's Hamersley Banded Iron Formations was important to understanding geological structures and, ultimately, to Australia's iron-ore prosperity. The near-surface geophysics of the Hawkesbury Sandstone and related strata has saved millions in rail and roadway tunnelling under Sydney. The Education Pavilion 'will seek to link with and complement, rather than to compete with, those at Questacon, the CSIRO Discovery Centre, the National Arboretum and Geoscience Australia's Education Centre'.

Discussions amongst a few UAV hopefuls (I include myself here) suggest that the time is right for us to hold a workshop. Unfortunately we may have missed the boat for the next ASEG meeting in Adelaide, but I think there is now enough activity for ASEG to consider forming a special interest group. While I and others have been mucking around with fluxgates, which is instructive if not frustrating, ultimately I think we have been wasting our time. Sometime this year Geometrics should have their MFAM (MicroFabricated AtomicMagnetometer) on sale. Geometrics recently announced a miniaturised atomic clock magnetometer allowing a 10-fold reduction in size and power consumption without sacrificing performance (15 cc in size and 2 W power). This picture from the Geometrics website shows the reduction in size they have achieved. I don't think the coin is indicative of the price, which initially will be pretty steep, but, with mass production, the price will inevitably decline and even hobbyists will be able to afford one.

Phil Schmidt
ASEG President
president@aseg.org.au



EAGE

See you in Barcelona!

4-8 September 2016

22nd EUROPEAN MEETING OF ENVIRONMENTAL AND ENGINEERING GEOPHYSICS

SECOND APPLIED SHALLOW MARINE GEOPHYSICS CONFERENCE

FIRST CONFERENCE ON GEOPHYSICS FOR MINERAL EXPLORATION AND MINING

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CONFERENCE & EXHIBITION

www.eage.org/event/environmental-engineering-2016
www.eage.org/event/mineral-exploration-2016
www.eage.org/event/shallow-marine-2016

4-8 September 2016, Barcelona, Spain

Welcome to new Members

The ASEG extends a warm welcome to 21 new Members approved by the Federal Executive at its December and January meetings (see table).

First name	Last name	Organisation	State	Country	Membership type
Hassan	Abbas	Shell Australia	WA	Australia	Associate
Emma	Brand	Origin Energy	QLD	Australia	Active
Tongjun	Chen	China University of Mining and Technology		China	Associate
Craig	Covich	Mosman Council	NSW	Australia	Associate
Feri	Ferdianto	Independent Consultant		Malaysia	Active
Jose	Gomez Martinez	Universidad Industrial de Santander		Columbia	Student
Thomas	Harris	Merlin Geophysics	SA	Australia	Active
Mahmood ul	Hassan	Royal Institute of Technology, Stockholm		Sweden	Student
Rhys	Hawkins	ANU	ACT	Australia	Student
David	Inkster	Geoplus Pty Ltd	SA	Australia	Active
Mosayeb	Khademi Zahedi	Independent Consultant	WA	Australia	Active
Yoshua	Kwizera	Curtin University	WA	Australia	Student
Bill	Mansfield	Adelaide University	SA	Australia	Student
Tim	Marshall	Rio Tinto Exploration	QLD	Australia	Associate
Andrew	Pearson	The University of Melbourne	VIC	Australia	Student
Dmitry	Poik	Curtin University	WA	Australia	Student
David	Rowe		SA	Australia	Active
Matthew	Sisson	Monash University	VIC	Australia	Student
Ashley	Uren	UWA	WA	Australia	Student
Carmine	Wainman	University of Adelaide	SA	Australia	Student
Alexey	Yurikov	Curtin University	WA	Australia	Student

ASEG Federal Executive 2014–15

Phil Schmidt: President (Honours and Awards Committee)
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Email: president@aseg.org.au

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Barry Drummond: Secretary
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Theo Aravanis: Treasurer (Finance Committee Chair)
Tel: (03) 9242 3327
Email: treasurer@aseg.org.au

Greg Street: Past President (Publications and History Committees)
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Email: pastpresident@aseg.org.au

Koya Suto: Vice President (International Affairs Committee Chair, Research Foundation)
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Email: vicepresident@aseg.org.au

Kim Frankcombe: Past President (AGC Representative, Conference Advisory Committee and Technical Standards Committee)
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Wendy Watkins (Education Committee Chair)
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David Annetts (Web Committee Chair)
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Marina Costelloe
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Danny Burns
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Email: branch-rep@aseg.org.au

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Email: cac@aseg.org.au

Honours and Awards Committee Chair:
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Research Foundation – Donations: Peter Priest
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Secretary: Michael Dello
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Secretary: Anya Reading
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Secretary: Seda Rouxel
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Notice of Annual General Meeting (AGM)

The 2016 AGM of the Australian Society of Exploration Geophysicists (ASEG) will be held in Perth on 13 April 2016. The meeting will be hosted by the WA Branch at Minespace, 1292 Hay Street, West Perth (www.minespace.com.au). Drinks will be available from 17:30 and the meeting will begin at 18:00.

The business of the Annual General Meeting will include:

- To confirm the minutes of the 2015 Annual General Meeting;
- To receive from the Federal Executive reports on the activities of the Society during the last preceding financial year;
- To receive and consider the financial accounts and audit reports that are required to be submitted to Members pursuant to the Society's Constitution and to law;
- To consider and if agreed approve any amendments to the Constitution of the Society that the Federal Executive may bring to the meeting;
- To report the ballot results for the election of the new office holders for the Federal Executive;
- To confirm the appointment of auditors for the 2016 financial year.

The AGM will be followed by a scientific presentation. The speaker and title will be advised closer to the event.

Invitation for candidates for the Federal Executive

Members of the Federal Executive serve in an honorary capacity. They are all volunteers and Members are encouraged to consider volunteering for a position on the Executive or on one of its committees. Current members are listed in *Preview;* please contact one of them if you wish to know more about volunteering for your society.

The Federal Executive comprises up to 12 members, and includes the following four elected members:

(i) President,
(ii) President Elect,
(iii) Secretary, and
(iv) Treasurer.

These officers are elected annually by a general ballot of Members. Katherine McKenna was elected as President-Elect in 2015 and as such will stand for the position of President in 2016. Members wishing to nominate for one of these positions should note that in accordance with Article 8.2 of the ASEG Constitution '…The elected members of the Federal Executive are designated as Directors of the Society for the purposes of the [Corporations] Act.'

The following officers are also recognised in the Society's Constitution and serve on the Federal Executive:

(i) Vice President,
(ii) the Immediate Past President (unless otherwise a member of the Federal Executive),
(iii) the Chairman of the Publications Committee,
(iv) the Chairman of the Membership Committee,
(v) the Chairman of the State Branch Committees, and
(vi) up to three others to be determined by the Federal Executive.

These officers are appointed by the Federal Executive from the volunteers wishing to serve the Society.

Nominations for all positions (except Past President) are very welcome. Please forward the name of the nominated candidate and the position nominating for, along with the names of two Members who are eligible to vote (as Proposers), to the Secretary:

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ASEG Secretary
Care of the ASEG Secretariat
PO Box 576
Crows Nest
NSW, 1585
Tel: (02) 9431 8622
Fax: (02) 9431 8677
Email: fedsec@aseg.org.au

Nominations for the elected positions must be received via post, fax or email **no later than COB Wednesday 16 March 2016**. Positions for which there are multiple nominations will then be determined by ballot of Members and results declared at the Annual General Meeting.

Proxy forms and further details of the meeting will be sent to Members prior to the meeting by email and made available to Members on the Society's website.

Executive Brief

Since the last report from the Federal Executive in *Preview* 179 (December 2015) the Federal Executive has met on two occasions: 19 November and 17 December. The following brief summary outlines key issues dealt with by the Federal Executive on those occasions.

Society finances

The Society will finish the year in a sound financial position. Unaudited figures before final payments were made in December were:

Total Assets $1,438,310.86
Total Liabilities $19,038.56
Net Assets $1,419,272.30

Audited accounts for the 2015 financial year will be available early in 2016.

The Federal Executive spent some time at the November meeting discussing the poor financial information that was provided by some Branches, which led to both time (and therefore money) being spent by the Secretariat chasing up valid tax invoices so that payments could be made to suppliers and, consequently, delays in payments to the suppliers. The Executive resolved to revise the purchasing guidelines for the Society. A revised version of the guidelines will be circulated to Branches for comment early in 2016.

Most of the activities of the Society that are visible to Members are conducted by our Branches. The Branches develop draft annual budgets in the December/January period, and the Federal Executive then considers state Branch financial situations on a case by case basis. Most Branches finished 2015 in a sound financial position but, since 2014, the WA Branch has been striving to reduce a considerable deficit, accumulated over a number of years and principally caused by high administration expenses associated with monthly technical events, seminars, and meetings. Under the existing policy for dealing with conference surpluses, WA is eligible to receive $25k of the surplus from the 2015 Perth conference. It will also receive some of the surplus from a workshop in Perth on water management for shale and tight gas that was co-sponsored with several other societies. Even with this additional funding, the WA Branch would have started 2016 with a debit of ~$15k, limiting its ability to provide services to its Members. Given the healthy financial state of the Society, the Federal Executive agreed unanimously to make a one off contribution to the Branch's accounts. This contribution will allow the Branch to wipe out its deficit when capitation fees are transferred to the Branch in 2016. Thus, all Branches will be in a healthy financial position in 2016.

The 2016 Annual General Meeting

The Federal Executive reviewed arrangements being made to hold the 2016 Annual General Meeting in Perth in April. A notice of the AGM appears elsewhere in this issue of *Preview* and will be posted on the Society's website.

Membership

Membership numbers at the end of November 2015 were up 5% on those for the same time in 2014, although the growth in numbers was not uniform across the Branches. The numbers are shown in Table 1.

At the meeting in December, the Executive approved 8 additional new memberships not included in Table 1. The Membership Committee has an additional 16 applications for new membership that are being finalised before being presented to the Executive for approval.

The Federal Executive finds that the arrangements set out in the Society's Constitution for approving new members are inadequate for some grades of membership and ambiguous for student membership. The Constitution also allows for memberships to be cancelled by the Federal Executive under certain conditions but provides guidance to the Executive that is at best subjective.

The Executive therefore resolved to look at the wording of the Constitution with a view to bringing changes to the AGM in April for approval. The changes would clarify the arrangements for appointing Members, codify some guidelines for cancelling membership and, to the extent possible, remove administrative arrangements from the Constitution and place them in a By Law or By Laws where they can be managed and amended more flexibly by the Federal Executive.

The Federal Executive spent some time during its December meeting discussing a case in which a Member used the Membership Directory to send advertising material to all Members of the Society who were listed in the Directory. This action was in contravention of the

Table 1. ASEG Membership in November 2015

	2015 Members								
Branch	Active/Associate	Student	Retired	Honorary	Corporate	Journal exchange	TOTAL	Same time in 2014	Change (%)
ACT	46	10	7	3	0	1	67	62	8%
NSW	93	30	11	7	1	0	142	151	–6%
QLD	94	25	3	1	4	0	127	124	2%
SA/NT	91	27	2	2	4	0	126	156	–19%
TAS	13	3	1	0	0	0	17	13	31%
VIC	56	8	5	5	1	0	75	66	14%
WA	362	45	3	1	2	0	413	387	7%
International	164	24	5	1	1	3	198	150	32%
TOTAL	919	172	37	20	13	4	1165	1109	5%

copyright statement in the Directory. The Executive subsequently received a number of complaints from Members, including from one Member who said he would resign from the Society as a consequence. The Member who sent out the advertising material was approached by both the President and the Editor of the Membership Directory and subsequently apologised to the President. The Executive resolved at its meeting in December that this column is the appropriate vehicle for passing on that apology to all Members.

Membership renewals were sent out in late 2015. The Membership Committee received requests from 6 Members seeking assistance due to hardship during the current downturn in industry. They were considered in confidence by the Committee. The Chair asked the Federal Executive to consider all of the requests while keeping them anonymous. The case made by the Committee was based on the duration of memberships, periods of unemployment, and previous volunteer work for the Society. Payment of the fees for these Members was suspended for 2016. Each case will be reviewed after 6 months and if the Members have found work they may be charged fees for the remainder of the year.

This situation occurs from time to time because of the cyclic nature of the resources sector and successive Federal Executives have striven to be sympathetic. However, to ensure that each case is taken equally on merit, the Executive will develop a set of guidelines that can be applied from now on.

We were recently informed by the AIG that a number of non-scientific individuals and societies have been implying membership of the ASEG (e.g. see 'Associations' in http://creation.com/andrew-a-snelling) and other learned and professional societies in order to gain acceptance of their non-scientific agendas. Please ask the ASEG (secretary@aseg.org.au) for confirmation of membership before giving credence to such claims.

Publications

Our Journal *Exploration Geophysics* is now published jointly with the Japanese and Korean geophysical societies. The Memorandum of Understanding (MOU) with these societies is due for renewal and negotiations are underway on the wording and cost sharing arrangements in a new MOU. The Federal Executive discussed ways to leave open the expansion of the arrangements to other societies during the term of the new MOU.

2016 and 2018 geophysical conferences and exhibitions

The Federal Executive discussed progress with the planning of the 2016 ASEG-PESA-AIG 25th Geophysical Conference and Exhibition. The downturn in the resources sector is causing some concerns and the Executive noted that the conference organising committee is constantly revising its budget to minimise the risk that the conference will make a loss due to low attendance.

The Executive agreed that the NSW Branch is to be offered the 2018 conference to be held in the first quarter of the year in conjunction with PESA and AIG.

Barry Drummond
Honorary Secretary
fedsec@aseg.org.au

ASEG Branch News

Queensland

The Queensland ASEG Branch hopes that everyone has enjoyed their Christmas and New Year's break and we would like to remind all our Members to re-new their memberships in 2016.

The Queensland Branch will host its first meeting of the year in February – the details are still being organized so please keep checking the ASEG website for information. The Annual General Meeting is scheduled for March and all positions will be up for nomination. Please contact qldsecretary@aseg.org.au if you require further information regarding Branch position nominations.

Megan Nightingale
(QLD Branch Secretary)

South Australia & Northern Territory

The SA/NT Branch had a great end to the year with two fantastic events held in November and December. We were fortunate enough to be joined by the SEG Near Surface Honorary Lecturer, **Dr Hansruedi Maurer**, who presented on 'the curse of dimensionality in exploring the subsurface.' A great turnout ensured some lively discussion into the evening following this very captivating presentation.

Our final event for the year was a combination of two of our most popular events, the Annual Student Night and our Christmas Party. This event also saw a very encouraging turnout from the local Branch membership who helped support local students give presentations on their recently completed honours projects. We thank **Matthew Musolino, Brad Cox** and **Matthew McIntyre** for their willingness to take part and their great presentations, but congratulations must go to **Max Fry,** who won the prize for best presentation on the night. After the official business of the evening was complete all the attendees were invited to stay and celebrate the festive season.

The local Branch held a number of successful technical talks and courses as well as other industry events in 2015 with numerous local, interstate and overseas guest speakers, as well as a healthy social calendar. We would like to thank all of our sponsors for 2015, including Beach Energy, the Department of State Development, Geokinetics, Minotaur Exploration, Petrosys, Santos, Schlumberger, Borehole Wireline and Zonge. We hope all of our 2015 sponsors will lend their support again for 2016 and, of course, if you or your company are not in that list and would like to give your support, please get in touch at the email below.

I would also like to thank the 2015 Branch Committee, with special mentions to **Adam Davey** our Treasurer for all his hard work and the three Members who will be stepping down this year. They are **Luke Gardiner**, who has previously been both President and Treasurer in his near decade on the committee, **Jenni Clifford**, who has served as Treasurer and has been instrumental in organising the ever popular Melbourne Cup Luncheon for more years than I can remember, and **Michael Dello**, one of our most recent Committee Members, who quickly volunteered to be the local Branch Secretary for 2015. All your efforts are much appreciated by all of the Committee and the local Branch alike. As for those sticking around, we look forward to a great 2016. We also welcome any interested Members to the local Committee and any commitment, large or small, would be appreciated.

The first event for 2016 will be the AGM, to be held in early March, with our Annual Student BBQ to follow later that month. Please keep an eye out for more details.

Also, please remember that the Australian Society of Exploration Geophysicists 25th Geophysical Conference and Exhibition, to be co-hosted by PESA and AIG, will be held at the Adelaide Convention Centre from 21-24 August, 2016. Having grown from a relatively low-key event, first held in the AMF Centre in Adelaide in 1979, to the premiere exploration geophysical conference in the southern hemisphere, it is appropriate that the theme: Interpreting the Past, Discovering the Future is reflective of our Society's Members' ability to change, innovate and grow through time. We hope you can all make it.

As ever, new Members and other interested persons are always welcome to attend local events. For further details, please contact Josh at joshua.sage@beachenergy.com.au or 8338 2833.

Josh Sage
(SA/NT Branch President)

Tasmania

An invitation to attend Tasmanian Branch meetings is extended to all ASEG Members and interested parties. Meetings are usually held in the CODES Conference Room, University of Tasmania, Hobart. Meeting notices, details about venues and relevant contact details can be found on the Tasmanian Branch page on the ASEG website.

Interested Members and other parties should also keep an eye on the seminar program of the University of Tasmania's School of Earth Sciences, which regularly delivers presentations of geophysical as well as general earth science interest. Contact Mark Duffett taspresident@aseg.org.au for further details.

Mark Duffett
(Tasmanian Branch President)

Victoria

The approaching holidays and the end of 2015 were celebrated in style at the Annual Joint PESA-ASEG-SPE Christmas Luncheon on 9 December at the Victoria Hotel in Melbourne. This year **John Hughes** and **Bruce Holland** of The Norwood Resource presented 'The Norwood Resource: Dismantling Myths!' along with games, quizzes, excellent food and drink and even better company!

On Thursday 10 December the ASEG Victoria Branch hosted a technical meeting with **Dr Hansruedi Maurer**, ETH Zürich and SEG Honorary Lecturer, presenting 'The curse of dimensionality in exploring the subsurface'. The meeting was held at the Kelvin Club for a disappointingly small crowd. Despite the marginal turn-out Hansruedi delivered an excellent presentation, which sparked a lot of comments and questions from the audience.

Now for the **upcoming events**:

Following the summer break, the 'Joint ASEG/PESA/SPE Mid-Summer Social' will be the place for some serious networking to get 2016 going. The event will be held on Wednesday 10 February from 5pm at Henry & the Fox, 525 Little Collins Street in Melbourne's CBD. This event is limited to current ASEG Members only – so make sure you are up-to-date on your membership. Please note that this is a paid event – charged at

SEG HL Hansruedi Maurer presenting for a small, but attentive, audience in Melbourne's Kelvin Club.

only $10 per person. Drinks and Canapés will be provided.

On Thursday 18 February the ASEG Victoria Branch will host the Annual General Meeting (AGM) along with the technical meeting with **Dr Phil Schmidt**, owner of Magnetic Earth and ASEG President, presenting 'Magnetic Exploration Projects in CSIRO from 1978 to Now'. The meeting will be held at the Kelvin Club, starting at 6pm (drinks and nibbles) for a 6:30pm presentation.

Pre-meeting registration for any of the upcoming events is mandatory, and can be made via the ASEG Events web-page. We look forward to seeing many ASEG Victoria Branch Members at the meetings in the coming months.

Asbjorn Norlund Christensen
(Victorian Branch President)

Western Australia

The WA Branch held two technical sessions towards the end of 2015:

- 18 November – **Hansreudi Maurer** as part of the SEG Honorary Lecturer Tour presented 'The Curse of Dimensionality in Exploring the Subsurface.' His talk provoked a lengthy and interesting discussion.
- 2 December – The student presentation night resulted in four awards from a total of eleven submissions from students from University of WA and Curtin University. Awards were presented to **Jacob Jackson**, **Tom Horrocks**, **Lee Tasker** and **Dane Padely** (all pictured below).

The Christmas wind-up was held combined with the AGM on 24 November at Willong Pavilion, Kings Park and up to 40 patrons attended a self-catered Greek BBQ with

ASEG WA Branch student award winners from left Tom Horrocks, Jacob Jackson, Lee Tasker and Dane Padely.

refreshments. The AGM duly re-elected the principal office bearers from 2015 and the Committee for WA will continue through the 2016 year as it stands.

Thanks go to all who assisted with the BBQ and to GPX for donating cool boxes and a refrigerator.

Prue Leeming
(WA Branch Preview correspondent)

Australian Capital Territory

2016 is shaping up to be another exciting year for the ASEG's ACT Members. The ACT Branch AGM will be held in March, **Serge Shapiro** will present a one day course in March, the Adelaide conference preparations, abstracts and presentations are already underway and a DISC course by **James Gaiser** is planned for August.

2015 was a busy year for our local Branch as, with the help of the Federal Executive and **Wendy Watkins** in particular, we were able to offer many world class short courses and lectures.

Some of the highlights from last year include: February's Perth Conference, **Peter Milligan**'s talk at our March AGM, the award of two scholarships to two amazing students, a UAV talk by **Adam Kroll** and **Andrew Tridgell**, an out-of-this-world space geophysics talk by **Jon Clarke** and a fun Geo-Societies Quiz night in August. September saw **Josef Holzschuh** present his near surface seismic talk and **Phillip Wynne** present on gravity, October brought two OzStep courses to Canberra – **David Lumley**

Members enjoying the WA Branch Christmas wind-up at Willong Pavilion, Kings Park.

and Bob Musgrave, in November the ACT Branch held one of the largest EAGE InSAR courses in the world presented by **Alessandro Feretti**, and December saw **Hansruedi Maurer** deliver his near surface talk on 'the curse of dimensionality'.

A big thank you to **Millie Crowe** in her role as Secretary and **Ross Costelloe** in his role as Treasurer. Thank you to the current Branch Committee Members: **Phill Wynne, Bill Jones, Ned Stolz, Eva Papp** and **Ray Tracey** for their input and support.

A special thank you to those who signed up to Facebook just to help us reach 500 likes – we did it!

Marina Costelloe
(ACT Branch President)

New South Wales

In November **Roger Henderson** (Chair of ASEG History Committee) gave a talk about the gravity meter built at University of Sydney (Physics Department) in the 1890s and his belief that it is the first in the world of the modern type using a fused-quartz beam (Roger published a paper on this in the last issue of *Preview*). Roger described the plans of the meter and how it was constructed and the trials and tribulations that the physicists went through to achieve their goals. Roger also presented the data that the scientists acquired using it. Much discussion and reminiscing of times past followed.

In December **Kyle Blay** (CSIRO – Manufacturing), gave us a talk on a remote, rapid and accurate three-dimensional ore waste boundary tracking system. Kyle explained that understanding the final location of the various grades is vital to ensure valuable gold is not unnecessarily discarded (ore loss), or uneconomic waste rock is put through the processing plant (ore dilution). Kyle explained how recently developed technology leverages magnetic positioning techniques and through-rock communications to determine the locations of markers that are embedded within the rock bench both before and after the blast. This technology means the grade boundaries can be more accurately known and so ore loss and dilution can be reduced. Plenty of discussion finished off the last meeting for the year

First up this year, the NSW Branches of AIG, GSA and ASEG are presenting a two day short course by **Professor Mike Dentith**, 'Geophysics for the Mineral Exploration Geoscientist' based on his 2014 book of same name and co-authored with Steve Mudge.

The course will be held in The Barbarian Room, Level 3, The Rugby Club, Rugby Place, off 31 Pitt Street, Sydney, 16–17 February, 2016. The scheduled monthly Branch meeting will follow (17:30 for 18:00) to be addressed by Mike after suitable refreshment.

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

Mark Lackie
(NSW Branch President)

ASEG calendar

ASEG calendar: technical meetings, courses and events

Date	Branch	Event	Presenter	Time	Venue
2016					
10 Feb	VIC	Annual Joint PESA-ASEG-SPE Mid-Summer Social	TBA	1700–2000	Henry & the Fox, 525 Little Collins Street, Melbourne
16–17 Feb	NSW	Geophysics for the Mineral Exploration Geoscientist	Mike Dentith	TBA	The Barbarian Room, Level 3, The Rugby Club, Rugby Place, off 31 Pitt Street, Sydney
17 Feb	NSW	Technical meeting	Mike Dentith	1730–2000	The Rugby Club, Rugby Place, off 31 Pitt Street, Sydney
18 Feb	VIC	AGM & Technical Night: Magnetic exploration projects in CSIRO from 1978 to now	Phil Schmidt	1800–2000	The Kelvin Club, 14–30 Melbourne Place (off Russell Street), Melbourne
Early Mar	ACT	ASEG ACT Branch AGM	TBA	TBA	TBA
Early Mar	SA&NT	ASEG SA&NT Branch AGM	TBA	TBA	TBA
Early Mar	QLD	ASEG QLD Branch AGM	TBA	TBA	TBA
15 Mar	WA	Rock physics and geomechanics of fluid-induced seismicity: hydraulic fracturing, stimulation of geothermal systems and hazard assessment	Serge A. Shapiro	TBA	Minespace, Level 1, 1292 Hay Street, West Perth
21 Mar	ACT	Rock physics and geomechanics of fluid-induced seismicity: hydraulic fracturing, stimulation of geothermal systems and hazard assessment	Serge A. Shapiro	TBA	Geoscience Australia, Room 1.024, Corner of Jerrabomberra Avenue and Hindmarsh Drive, Symonston, ACT
13 Apr	WA	2016 ASEG AGM	TBA	1730–2000	Minespace, 1292 Hay Street, West Perth
21 Aug	SA	SEG DISC: 3C Seismic and VSP: Converted Waves and Vector Wavefield Applications	James Gaiser	TBA	TBA
26 Aug	ACT	SEG DISC: 3C Seismic and VSP: Converted Waves and Vector Wavefield Applications	James Gaiser	TBA	TBA
29 Aug	WA	SEG DISC: 3C Seismic and VSP: Converted Waves and Vector Wavefield Applications	James Gaiser	TBA	TBA

TBA, to be advised (please contact your state Branch Secretary for more information).

ASEG-PESA-AIG 2016: News from the Conference Organising Committee

Happy new year to everyone! At the time of writing there are only 7 months until the conference and still a lot to do. The Conference Organising Committee is gearing up for a busy few months.

Early bird registration is now open. It will close on 31 March 2016, so get in quickly!

The exhibition hall is filling up fast so if your company would like a booth, please get in contact with us ASAP. The prospectus is available for download on the conference website: www.conference.aseg.org.au. The Conference Organising Committee has endeavoured to contact as many companies as possible – if your company hasn't been contacted please let us know ASAP!

There are still sponsorship opportunities available if your company is looking for exciting promotion opportunities. Again, please don't hesitate to contact us if you are interested and would like further information.

The call for abstracts is still open. Extended abstracts must be submitted by the end of March. The programme committee will review all papers in April and we anticipate the final programme will be complete shortly afterwards.

The programme subcommittee have invited several more keynote speakers. All keynote speakers are listed in Table 1 and the conference website contains photos and links to their websites.

The workshop committee have constructed an exciting programme of 18 workshops. They are listed in Table 2.

Table 1. Keynote speakers

Assoc Prof Juan Carlos Afonso	Macquarie University
Prof Esben Auken	Aarhus University
Dr Graeme Beardsmore	Hot Dry Rocks Ltd
Peter Boult	Santos
Andrew Bull	INOVA Geophysical
Dennis Cook	ZDAC Geophysical
Dr Karol Czarnota	Geoscience Australia
Prof Mike Dentith	University of Western Australia
Mark Dransfield	CGG
James Gaiser	Gaiser Geophysical Consulting
Prof Graham Heinson	University of Adelaide
Creties Jenkins	Rose and Associates
Rob Kirk	Rob Kirk Consultants
Andrew Long	PGS Geoscience and Engineering
Prof Dave Lumley	University of Western Australia
Bill Peters	Southern Geoscience Consultants
Assoc Prof Anya Reading	University of Tasmania
Prof Klaus Regenauer-Lieb	University of New South Wales
Prof Malcolm Sambridge	Australian National University
Dr Nick Smith	PassiveX
Dr Stephan Thiel	Geological Survey of South Australia
Dr Nick Williams	High Power Exploration, Canada
Assoc Prof Yingjie Yang	Macquarie University

Please stay tuned to the website for any updates to this programme.

We're also constructing an exciting schools programme. Local high schools will be invited to participate in an information day to learn about the geophysical industries, and be given the opportunity to visit the trade exhibition.

Finally, a reminder that childcare will be available at the conference. Simply tick the box on the registration form and we'll be in contact closer to the time with the available options.

Philip Heath
Co-chair Minerals
philip.heath@sa.gov.au

Luke Gardiner
Co-chair Petroleum
luke.gardiner@beachenergy.com.au

Table 2. Workshops

Workshop ASEG-PESA-AIG 2016 Delegates [Non-Delegates]	Earlybird	Standard	Late
Saturday 20 August 2016			
Workshop 1 (two day) – Remote sensing and field spectroscopy for geoscientists – part 1 and 2	$550 [$625]	$550 [$625]	$550 [$625]
Workshop 2 – Exploring with Airborne Gravity Gradiometry	$225 [$300]	$225 [$300]	$225 [$300]
Workshop 3 – IP processing and QC – from amps in the ground to an Inversion input	$225 [$300]	$225 [$300]	$225 [$300]
Workshop 4 – Full Waveform Tomography	To be advised	To be advised	To be advised
Workshop 5 – Terrain Scale Assessment of Major Metallogenic Provinces	$225 [$300]	$225 [$300]	$225 [$300]
Sunday 21 August 2016			
Workshop 1 – Remote sensing and field spectroscopy for geoscientists – part 2	See above	See above	See above
Workshop 6 – Geophysics through the Regolith: UNCOVER Australia	$225 [$300]	$225 [$300]	$225 [$300]
Workshop 7 – Operational sequence stratigraphy-deep water fans	$225 [$300]	$225 [$300]	$225 [$300]
Workshop 8 – Near surface passive seismic surveying for mineral exploration, environmental and engineering applications	$225 [$300]	$225 [$300]	$225 [$300]
Workshop 9 (afternoon) – Cooperative and Joint Inversions of Seismic and Magnetotelluric data	$195 [$270]	$195 [$270]	$195 [$270]
Workshop 10 – Airborne Gravity 2016	$150 [$225]	$150 [$225]	$150 [$225]
Workshop 11- 3C Seismic and VSP: Converted Waves and Vector Wavefield Applications	To be advised	To be advised	To be advised
Thursday 25 August 2016			
Workshop 12 – Prospect, Trap and Fault Seal Analysis Key Uncertainties	$225 [$300]	$225 [$300]	$225 [$300]
Workshop 13 – Gravity and Magnetic Methods for Oil & Gas and Mineral Exploration and Production	$225 [$300]	$225 [$300]	$225 [$300]
Workshop 14 (morning) – Effective community engagement- more than risk management	$195 [$270]	$195 [$270]	$195 [$270]
Workshop 15 – Effective structural geology and data management in exploration and mining	To be advised	To be advised	To be advised
Workshop 16 (morning) – Tectonic and structural controls to gold and copper mineralization in the circum-Pacific region	$195 [$270]	$195 [$270]	$195 [$270]
Workshop 16 (afternoon) – The geological setting, geochemical signature and geophysical expression of porphyry copper-(gold) systems on the district-scale: global examples	$195 [$270]	$195 [$270]	$195 [$270]
Workshop 16 (full day) – Tectonic and structural controls to gold.../The geological setting, geochemical signature…	$300 [$375]	$300 [$375]	$300 [$375]
Workshop 17 – Young Professionals Development Day	To be advised	To be advised	To be advised
Workshop 18 – Magnetotellurics from terrane- to camp-scale – insights and case studies	To be advised	To be advised	To be advised

Nominations open for 2016 ASEG Honours or Awards

A reminder to all Members that nominations are open for the next series of ASEG Awards which are scheduled to be presented at ASEG-PESA 2016: 25th Geophysical Conference & Exhibition, 21–24 August 2016 – Adelaide, South Australia. All ASEG Members as well as State and Federal executives are invited to nominate those they consider deserving of these awards. The available awards are:

ASEG Gold Medal – for exceptional and highly significant distinguished contributions to the science and practice of geophysics, resulting in wide recognition within the geoscientific community.

Honorary Membership – for distinguished contributions by a Member to the profession of exploration geophysics and to the ASEG over many years.

Grahame Sands Award – for innovation in applied geophysics through a significant practical development of benefit to Australian exploration geophysics in the field of instrumentation, data acquisition, interpretation or theory. The nominee does not need to be a Member of the ASEG.

Lindsay Ingall Memorial Award – for the promotion of geophysics to the wider community, including geologists, geochemists, engineers, managers, politicians, the media or the general public. The nominee does not need to be a geophysicist or a Member of the ASEG.

Early Achievement Award – for significant contributions to the profession by a Member under 36 years of age. Prior to 2016, the award was determined solely on publications in Exploration Geophysics or similar reputable journals by the nominee, but has now been expanded to include overall contributions to geophysics, ASEG Branch activities, committees, or events.

ASEG Service Awards – for distinguished service by a Member to the ASEG, through involvement in and contribution to State Branch committees, Federal Committees, Publications, or Conferences over many years.

Nomination procedure

Any Member of the Society may nominate suitable candidates. Details of all award criteria and nomination guidelines can be found on the ASEG website at: https://aseg.org.au/honours-and-awards. Proforma nomination forms are available from the website or by contacting the Committee Chair. Nominations including digital copies of all relevant supporting documentation are to be sent electronically to:

Andrew Mutton
ASEG Honours and Awards Committee Chair
awards@aseg.org.au

ASEG-PESA-AIG 2016
25TH GEOPHYSICAL CONFERENCE & EXHIBITION

Interpreting the Past, Discovering the Future

Early Registrations Open 11 January 2016
Call For Abstracts Open
Last Chance for Presenting Workshops

August 21-24 Adelaide, South Australia

Web:http://conference.aseg.org.au

2016 Conference Manager: Plevin and Associates Pty Ltd PO Box 54, Burnside 5066 South Australia
Tel +61 8 8379 8222 Fax +61 8 8379 8177 / Email asegpesa2016@plevin.com.au

Convened by The Australian Society of Exploration Geophysicists, Petroleum Exploration Society of Australia and Australian Institute of Geoscientists

PESA Petroleum Exploration Society of Australia

Australian Society of Exploration Geophysicists

AUSTRALIAN INSTITUTE OF GEOSCIENTISTS

GA: update on geophysical survey progress from the Geological Surveys of Western Australia, South Australia, Northern Territory, Queensland and Victoria (information current on 15 January 2016)

Further information on these surveys is available from Murray Richardson at GA via email at Murray.Richardson@ga.gov.au or telephone on (02) 6249 9229.

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Coompana	GSSA	GA	GPX Surveys	7 Feb 2015	255 265	400 m 80 m E–W	85 910	8 Nov 2015	Dec 2015 for magnetic and elevation data	173: Dec 2014 p. 24	The magnetic and elevation data were released via GADDS on 10 Dec 2015. The radiometric data is expected to be released in Feb 2016
Delamere/ Spirit Hills	NTGS	GA	Thomson Aviation	20 Jul 2015	96 500 est.	400 m 80 m N–S	33 690	7 Nov 2015	Expected to be supplied to GA in Jan or Feb 2016	176: Jun 2015 p. 22	TBA
Yalgoo	GSWA	GA	MAGSPEC Surveys	30 May 2015	110 516 est.	100/200 m 50 m E–W	11 200	27 Sep 2015	Nov 2015	176: Jun 2015 p. 23	10 Dec 2015

TBA, to be advised.

Table 2. Gravity surveys

Survey name	Client	Project management	Contractor	Start survey	No. of stations	Station spacing (km)	Area (km²)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Gippsland	GSV	GA	Atlas	30 Jun 2014	1440	12 traverses at 500 m station spacing	8358	21 Jul 2015	2015	170: Jun 2014 p. 25	10 Dec 2015
Northern Wiso Basin	NTGS	GA	Atlas	18 Jun 2015	5020	4 km regular grid with areas of 2 km and 1 km infill	83 240	9 Aug 2015	Preliminary final data supplied to GA in Sep 2015	176: Jun 2015 p. 24	14 Oct 2015
SW Yilgarn	GSWA	GA	Atlas	12 Jun 2015	27 678	2 km along public roads and tracks	175 000	100% complete to 3 Dec 2015	TBA	176: Jun 2015 p. 24	Proposed release on 11 Feb 2016
Victoria Basin	NTGS	GA	Atlas	14 Aug 2015	6300	4 km regular grid	99 170	17 Sep 2015	Preliminary final data supplied to GA on 13 Nov 2015	177: Aug 2015 p. 17	10 Dec 2015
Stavely	GSV	GA	TBA	Survey Quotation Request in preparation	Approx. 8000 in 9 separate areas	500 m regular grid in 8 areas and 500 m station interval along one traverse	TBA	TBA	TBA	177: Aug 2015 p. 18	TBA
Wiluna	GSWA	GA	TBA	The Survey Quotation Request was released on 28 Jan and closes on 23 Feb	Approx 17 000 in 2 separate areas	2500 m regular grid	103 000	TBA	TBA	The proposed survey covers parts of the Bullen, Trainor,Nabberu, Wiluna, Sir Samuel, Madley, Herbert, Robert Standard 1:250 000 map sheets	TBA

TBA, to be advised.

Table 3. AEM surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Musgrave Region	GSSA	GA	TBA	Mar 2016	16 000 est.	2 km; E-W lines	30 691	TBA	TBA	179: Dec 2015 p. 23	The Quotation Request was released on 12 Oct 2015 and closed on 30 Oct 2015. The proposed survey covers parts of the Mann, Woodroffe, Alberga, Birksgate, Lindsay and Everard Standard 1:250 000 map sheets
West Kimberley and Ord-Bonaparte	WA Government: Departments of Water, Agriculture and Food	GA	SkyTEM Australia	26 Sep 2015	7837	Various + traverses	TBA	3 Nov 2015	TBA	178: Oct 2015 pp. 30–31	TBA
Isa Region	GSQ	GA	TBA	Winter 2016. Centred on Cloncurry	TBA	TBA	TBA	TBA	TBA	The Technical Specifications of the survey are being planned between GSQ and GA	The National Collaboration Framework Agreement was executed between GA and GSQ on 16 Dec 2015

TBA, to be advised.

GSSA: Coompana magnetic and radiometric survey and future initiatives

The largest airborne magnetic and radiometric survey ever conducted in South Australia was completed in late 2015. The survey covers the Coompana Province and parts of the Officer, Eucla and Bight Basins, representing under-explored frontier areas in the State's far west. The survey collected over 250 000 line kilometres of pre-competitive geophysical data at 400 m line spacing, with 200 m infill over the Coompana Anomaly, at 60 m flight height.

The Coompana magnetic survey (2015SA0001) (Figures 1–3) is available for download from SARIG using the Geophysical Data Downloads tool. Some simple instructions for using the tool can be found at: http://minerals.statedevelopment.sa.gov.au/online_tools/free_data_delivery_and_publication_downloads/sarig/geophysical_data.

At the time of writing the radiometric data is being processed and should be available on SARIG by late January.

The SA Government has committed $20M to exploration in South Australia as part of the PACE Copper Strategy. At the time of writing we are in the early planning stages of several major geophysical activities in South Australia. As well as re-flying some key areas of the Gawler Province at 200 m resolution, we're hoping to undertake gravity infill in areas with sparse coverage. The details of these exciting programmes will become available over coming months, so stay tuned!

Phillip Heath
Senior Geophysicist, Geological Survey of South Australia
Philip.Heath@sa.gov.au

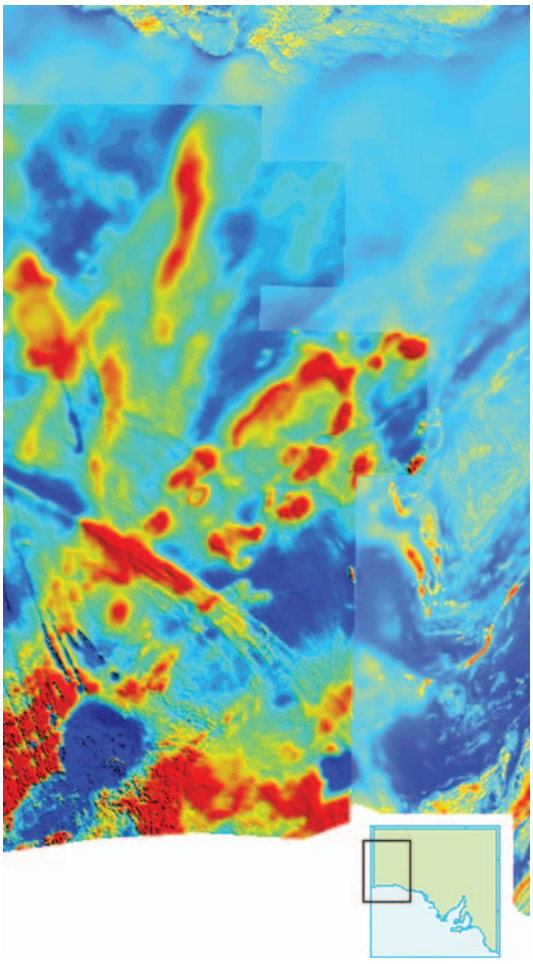

Figure 1. *Coompana Total Magnetic Intensity image.*

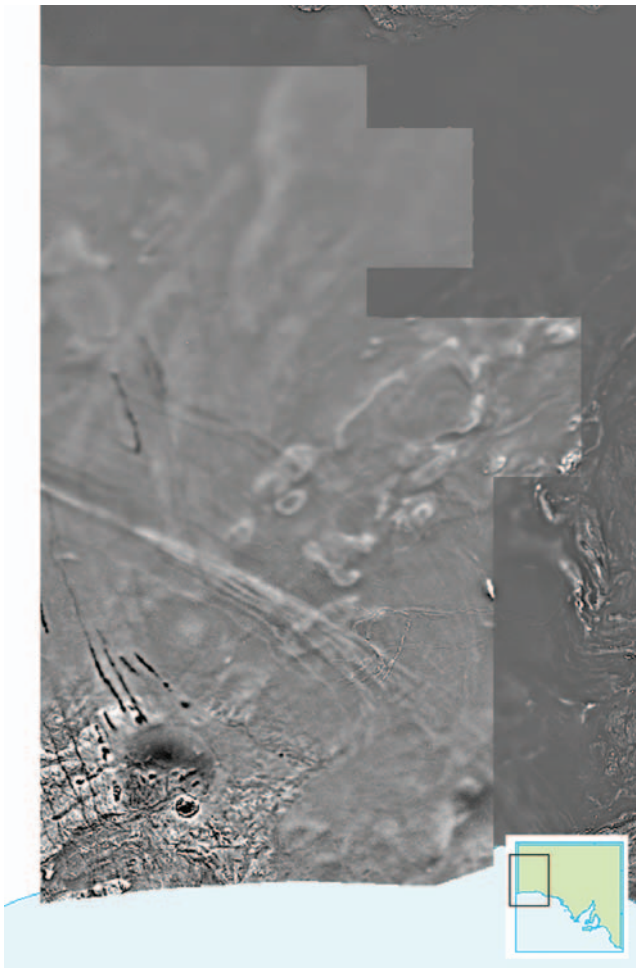

Figure 2. *Coompana First Vertical Derivative of TMI image.*

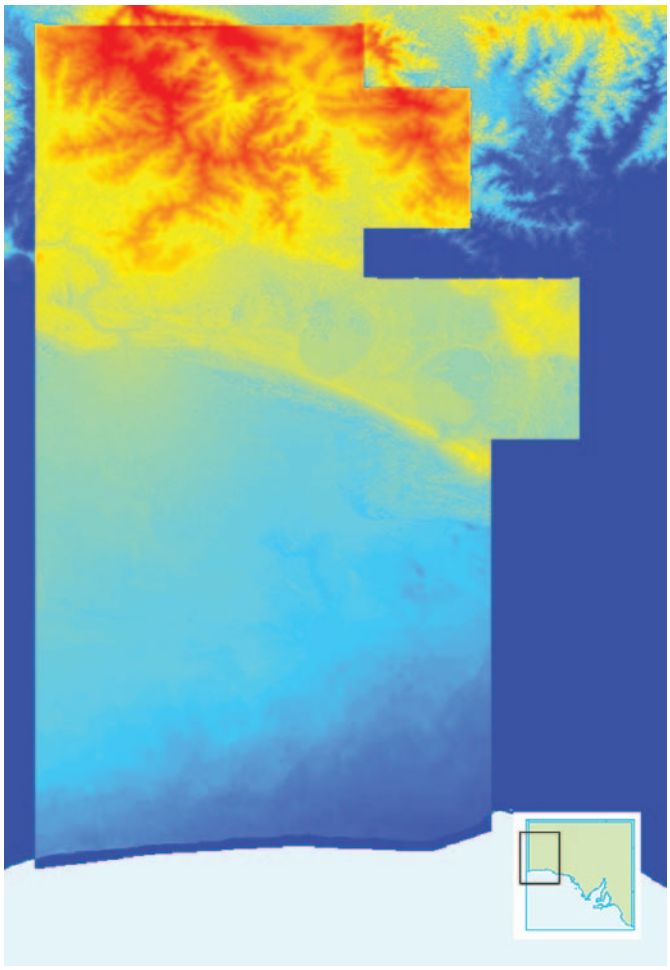

Figure 3. *Coompana Digital Elevation Model.*

Canberra Observed

David Denham AM
Associate Editor for Government
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Turnbull launches National Innovation and Science Agenda

It was refreshing to hear the Minister for Industry, Innovation and Science; Christopher Pyne, speak enthusiastically about innovation and science at a recent National Press Club luncheon. There is no doubt that innovation and science are important if Australia is to deliver new sources of growth, maintain high-wage jobs and take advantage of future opportunities. So, it is pleasing to see this Government, and this Minister, advocating for innovation and science.

Perhaps I am being unkind but, I couldn't imagine either Mr Abbott or Mr Shorten showing such enthusiasm for these subjects.

The plan is for the Government to invest $1.1 billion over four years 'to incentivise innovation and entrepreneurship, reward risk taking, and promote science, maths and computing in schools by focusing on four priority areas:

- Culture and capital, to help businesses embrace risk and incentivise early stage investment in start-ups;
- Collaboration, to increase the level of engagement between businesses, universities and the research sector to commercialise ideas and solve problems;
- Talent and skills, to train Australian students for the jobs of the future and attract the world's most innovative talent to Australia; and
- Government as an exemplar, to lead by example in the way Government invests in and uses technology and data to deliver better quality services.'

These are all worthy themes but, when I read phrases like 'incentivise innovation and entrepreneurship and reward risk taking' I start to get worried. It just looks as though the wordsmiths are now in control rather than the innovators.

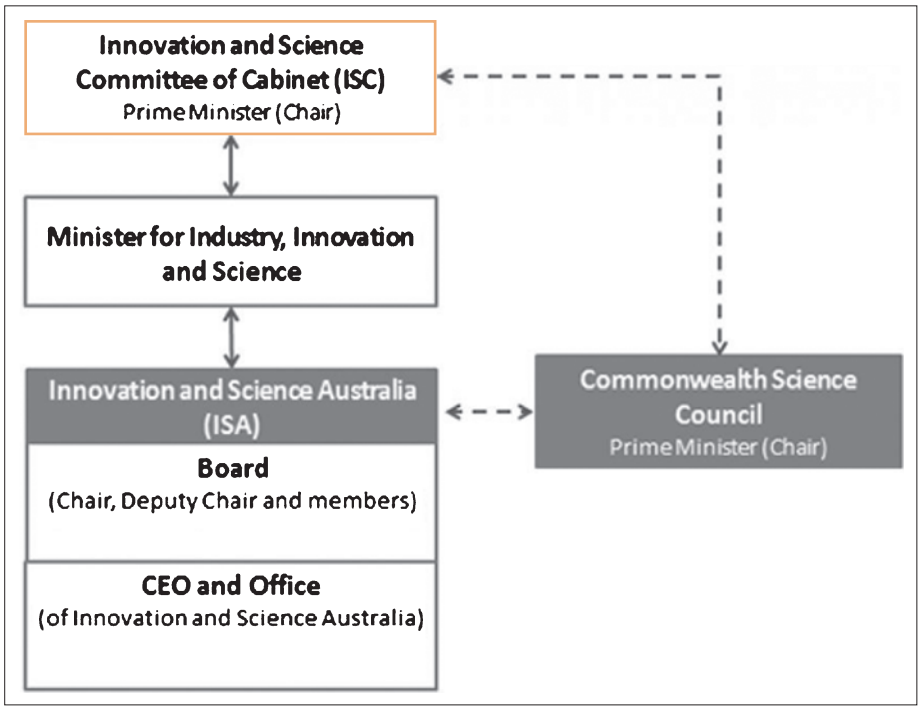
Furthermore, when one realises that the $1.1 billion will be obtained from savings in other Government programs and that approximately $28 million has already been allocated to a 'public information and community engagement campaign to support the National Innovation and Science Agenda and help transform Australia's economy and drive prosperity and competitiveness,' the cynic in me starts to emerge.

There will of course be a new bureaucratic structure, as shown in the diagram below.

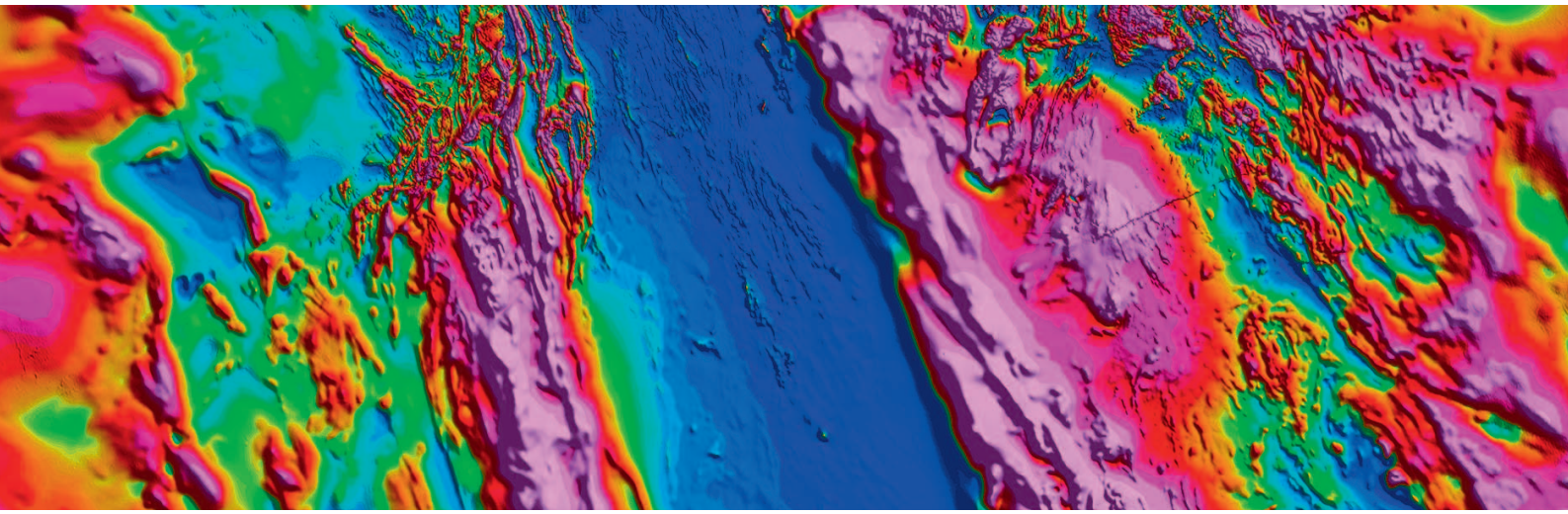
One of the key challenges for the Government will be to assess which of the innovative start-up companies it will support and which it will not. When asked about this at the Press Club, the Minister said 'the Treasury, the Tax Office and others – will be advising the Government'. I'm not sure whether the ATO and Treasury are the best places to go to assess innovation, but you never know – and someone will have to do it!

A key question I would have is: why should you take risks if you can back winners?

In fact, the word 'innovation' has been used so often recently that I began to wonder what it really meant. So I asked a learned and respectable academic friend. He said that he didn't know what it meant, but that he would be including the word multiple times in any grant applications in future!

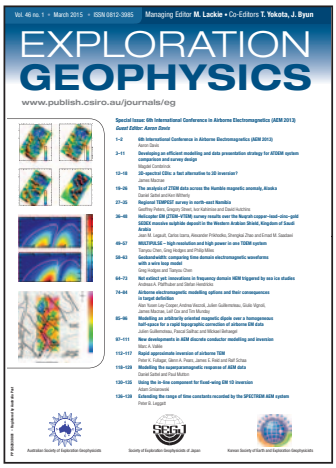


How the Innovation and Science Agenda will work.



Exploration Geophysics

The Journal of the Australian Society of Exploration Geophysicists



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Economy Watch

2015 – a very bad year for the resources industry

David Denham AM
denham1@iinet.net.au

This time last year one could be forgiven for thinking that commodity prices couldn't get any lower but, like a Dostoyevsky novel, that's exactly what happened in 2015. The year started really badly and then managed to get even worse.

Whether you look at the prices of the main commodities such as oil, iron ore, coal and gold, the value of resources industry, or job opportunities in the minerals and petroleum exploration sector, the situation is grim.

Let's look more closely at some key numbers and see how they have changed during the year. The data are taken from http://www.imf.org/external/np/res/commod/External_Data.xls for coal, iron ore and aluminium prices, the Australian Bureau of Statistics for exploration expenditure, the Reserve Bank of Australia for exchange rates and gold prices, the Commonwealth Department of Industry for petroleum production and The Australian newspaper for the ASX.

The oil price continues to fall

Who would have thought that the price of crude oil would have dropped from $US104/bbl in July 2014 to $US60/bbl at the end of December 2014 and continue to fall to $US38/bbl in December 2015? But that's what happened.

On a global scale annual oil production has continued to gradually increase at approximately 0.8% per year, from 3.9 billion tonnes in 2004 to 4.2 billion tonnes in 2014 (BP Review of World Energy June 2015). This is very close to the increase in the global population of 1.0% in 2015. Consequently, the global per-capita production has remained remarkably constant over the last few years.

Figure 1 shows the monthly Australian production of crude oil and gas condensate and the price of West Texas crude from 1990 through to 2015. Notice that oil production has approximately halved from 3600 ML per month in January 2000, to an estimated 1700 ML per month in November 2015.

Surprisingly, during most of this period, when the oil price was increasing, the production numbers show a consistent fall. So much for the classical supply and demand model!

The message from these numbers is clear. We must continue to invest in petroleum exploration in Australia, otherwise our import bill for petroleum and its products could become unaffordable. Exploration investment over the last ten years tells a disappointing story. Although expenditure tripled from 2005 to 2012 the results in terms of production have not been realised and now, with the oil price hovering at around $40 per barrel, it is unlikely that the major oil companies will increase spending on exploration. Nevertheless, there is a very good argument for us to hang in there and hunt for new petroleum resources because of the long term benefits for our future prosperity.

Petroleum and minerals exploration investment decline continues

Figure 2 shows how the minerals and petroleum exploration investment has tracked from 2005 through September 2015. There are two issues of note. The first is that the investment in petroleum exploration continued to rise until mid-2014, whereas the minerals investment peaked two years earlier in June 2012. This indicates the different response times in the two industry sectors and is not really surprising.

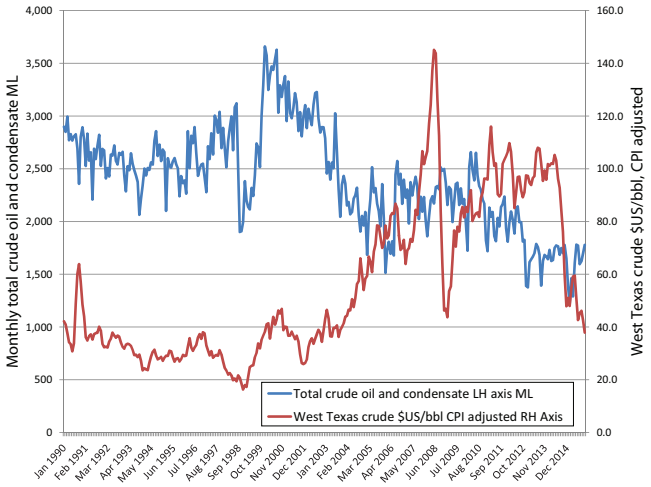

Figure 1. *Australian monthly petroleum production in millions of litres and the price of West Texas crude in $US/bbl. The price is CPI adjusted to 2015 $US.*

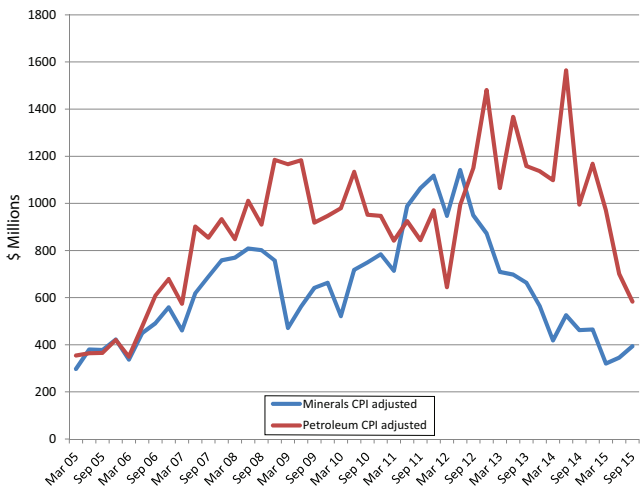

Figure 2. *Quarterly investment in petroleum and minerals exploration in Australia. The data have been normalised to 2015 Australian dollars to allow for CPI changes over the period 2005 through September 2015.*

The second is that if the numbers from both sectors are added for each quarter, there is a maximum of A$2090 million spent in the June 2014 quarter and by the September 2015 quarter the total has dropped to $A980 million. In other words, over a billion dollars per quarter has been removed from Australia's resource exploration budget in 15 months. That's down to the level it was in 2006 and is a disaster for recruiting smart people into resource exploration.

Coal and iron and ore prices also continue to fall

The situation with coal and iron ore is similar to what is happening with oil. The price of all three commodities has been falling steadily since the beginning of 2011 (see Figure 3). Iron ore has decreased from $US187/t in February 2011 to approximately $US40/t in December 2015 and during 2015 the price fell by a massive 40%. As we are all well aware, the effect of this decline has been bad news for all but the more efficient miners; particularly in Western Australia, where the wellbeing of that State is so dependent on the value of its iron ore production.

The coal price peaked at $US142/t in 2011, but has declined steadily ever since and was at $US56 in December 2015. According to the BP review of world energy, global coal production peaked in 2013 at 3.96 billion tonnes of oil equivalent. The rate of increase was approximately 4.4% per year until the production rate plateaued. This is a classic case of over-production pushing the price down, because as the global production increased the price of coal declined. Only the more efficient mines will survive.

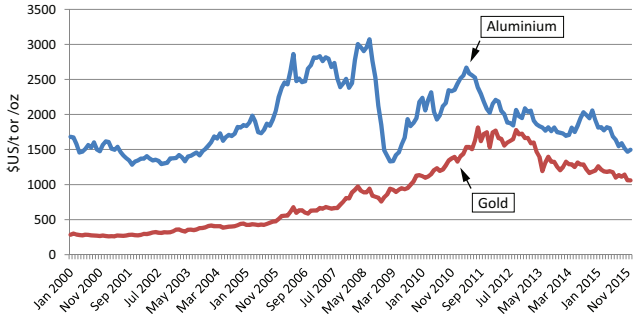

Figure 4. *Prices of aluminium and gold from 2000 through 2015. The data have not been corrected for CPI changes.*

Aluminium and gold

The prices of aluminium and gold (Figure 4), while showing considerable volatility have not declined so rapidly. From 2011, when the price of aluminium reached $US2700/t, it has dropped to $US1500/t, which is where it was in 2003.

Gold has probably fared the best. Its price increased steadily from $US 300/oz in 2002 to $US1800/oz in 2011/12, before the start of the current decline. It has now fallen to $US1060/oz in December 2015, but this is still well above the pre-2009 prices. If you bought gold in 2005, or before, you would have at least doubled your money if you sold it now.

Resource stocks perform badly on ASX

Falling commodity prices played havoc with the value of resource stocks on the ASX and the downward trend evident in 2014 continued throughout 2015. $A65 billion was knocked off the market capital of the resource companies listed in the top 150 companies on the ASX in 2015. This compares to $A61 billion fall in value in 2014. Figure 5 shows the carnage; a fall of $300 billion from 2011. In other words these companies are now worth a third of their value in 2011.

BHP probably took the largest hammering. In 2014 it had been top of the heap for seven years, but it slipped from No. 1 to No. 2 in September and to No. 3 in November. In 2015 it slipped even further and is now listed sixth behind the four big banks and Telstra.

In April 2011 BHP was worth $A160 billion, now it is only worth approximately $50 billion. It must be time to buy any time soon.

Figure 5 shows the data over the last 15 years. Notice that changes in the All Ords Index and the total market capital correlate well until 2006. At that point the value of the resource companies decline and the All Ords Index shows a slight increase within a period of considerable volatility. Allowing for a CPI increase over the 15 year period the annual return from the All Ords is 0.8% per year and from resource companies 1.4% per year. Better than putting your money under the bed, but not very impressive.

Let's hope 2016 is a much better year.

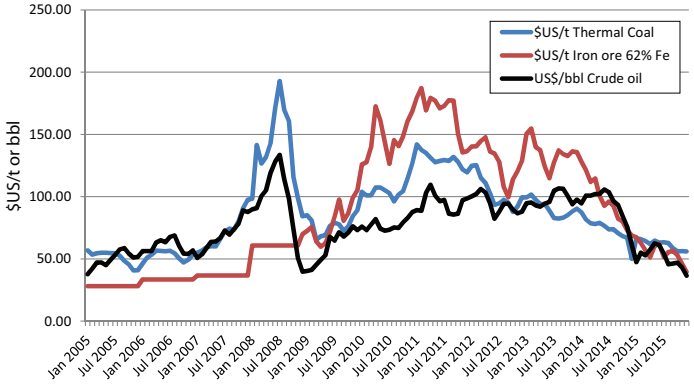

Figure 3. *Prices for thermal coal, iron ore and crude oil from 2005 through 2015. The numbers are all in $US and have not been corrected for the CPI. The peaks in the price of coal and oil in July 2008 have not been used in the analysis.*

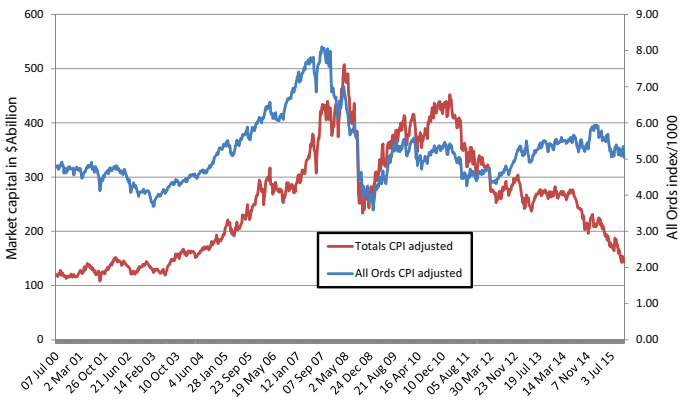

Figure 5. *Plots of the All Ords Index on the ASX (RH axis) and the total market capital of the resource stocks in the top 150 companies on the ASX. The data have been adjusted for CPI changes to 2015 $A.*

Predicting booms and busts in commodity prices

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The accurate prediction, some years in advance, of commodity price busts would help the resources industry, and its personnel, to be better positioned to manage downturns. For most people in the resources industry the large fall in commodity prices during 2015 was a surprise, yet four years ago a scientific prediction using an econophysical approach (Moriarty 2011) indicated a high probability of low commodity prices by 2014–15. This successful prediction prompts consideration as to what an econophysical approach would now predict for when commodity prices will increase.

In the April 2015 issue of *Preview* (Moriarty 2015), I asked whether a scientist (or a geophysicist in my case) could predict commodity price fluctuations. Most people would answer 'no'. This is because the common (post event!) explanation for a large fall in commodity prices is that there was a significant oversupply. I argued that the empirical evidence does not support this assertion. While there was significant oversupply of commodities, particularly oil, in the past few years and a 70% fall in commodity prices did occur, this association does not necessarily imply causation. In the past when there have been similar periods of oversupply commodity prices have not always collapsed. Conversely, commodity prices have not always risen by 50–70% when there have been periods of significant under-supply. The actual correlation between supply/demand and commodity price is near zero.

I proposed that the valuation of the US dollar (USD) has a major inverse impact on commodity prices – when the USD valuation is high commodity prices have downward pressure. This was not a new proposition. What was new was the scientific approach for forecasting the probabilistic 5-year range for the USD. In 2010–11, while the USD valuation was low and falling, I forecasted a high probability of a major increase by 2014–15. This has now come to pass, associated with the large fall in commodity prices.

The next question to ponder is when will commodity prices bottom, and how quickly will they rise? This requires a scientific analysis of the USD valuation – when was it weak or strong? The econophysical technique described in Moriarty (2011) results in the valuation assessments shown in Figure 1.

Figure 1 shows the USD valuation – a declining valuation is consistent with the decreasing proportion the US represents of the world economy (Moriarty 2011) – and standard deviations. From this analysis, we can identify the periods when the USD was statistically overvalued (for example 1982–86; 1998–2003) and undervalued (for example early-mid 1990s; 2009–12).

Figure 2 shows commodity prices in USD since 1980 (left axis) together with USD valuations (inverse right axis) from Figure 1. Observe the USD valuation does have a strong inverse influence on the trend for commodity prices (the disconnect during 2009–14 was a consequence of the excessive optimism regarding China's modernisation). The current analysis indicates that gold is still overvalued.

The next section considers how to use statistical mean reversion modelling to predict the trend of commodity prices for the next five years.

2016–20 forecast for commodity prices

This section shows a predicted trend for commodity prices during 2016–20, based on the same modelling approach as for the 2010–14 prediction (see Moriarty 2011 for details). In brief, USD valuation is treated as a time series that can be modelled with a statistical mean-reversion algorithm. Using this methodology, we can predict in advance the timing and probability of major turning points in the time series (I note econophysical approaches are being

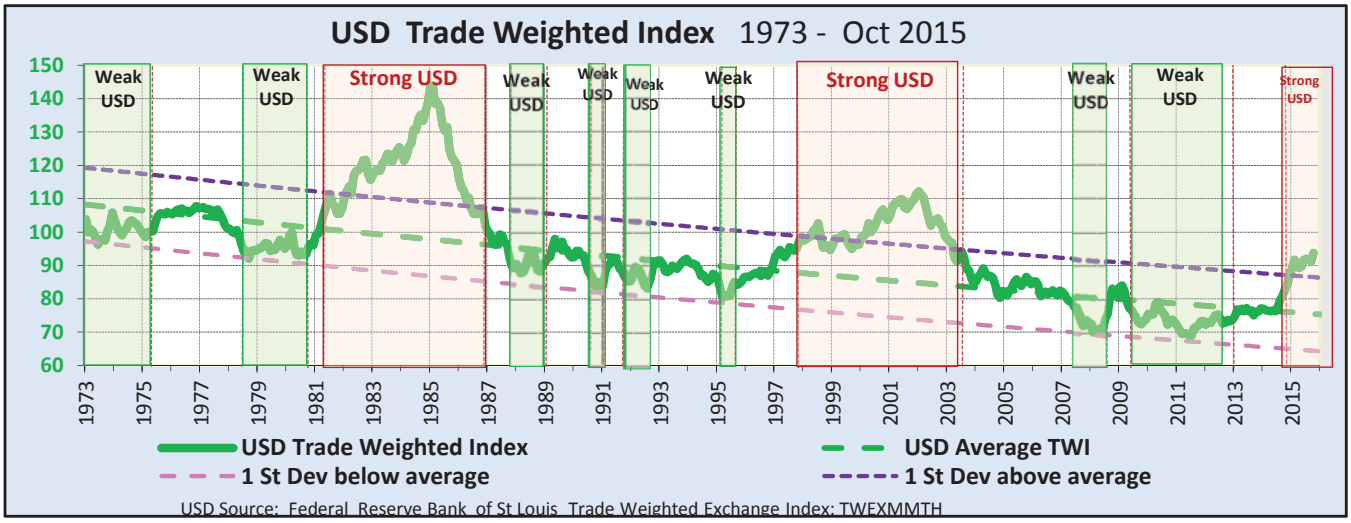

Figure 1. *Monthly values for US dollar valuation, showing the declining mean value and standard deviations, based on the statistical analysis of Moriarty, 2011. The chart also shows periods when US dollar valuation was strong or weak.*

successfully used by physicists such as Sornette (2003) for stock market predictions).

If we accept that the USD valuation does control the trend for commodity prices, how do we predict when the USD is likely to weaken? Also, how quickly will it weaken and what is the outlook for commodity prices?

Figure 3 shows USD valuation since 1973. The recent strengthening of the USD is not likely to continue – it has now exceeded one standard deviation above mean valuation. Since there have only been two previous times the USD strengthened above one standard deviation, statistical prediction cannot be as precise as the 2010–14 modelling was for mean reversion when the one standard deviation below mean occurred (refer Figure 1).

Accepting there is limited data when USD valuation is above 1 standard deviation, mean reversion modelling for the next five years predicts that the USD is likely to stay strong for about two years, peaking around the start of 2017 falling quickly during 2018–20 (Figure 4). Possible P90 and P10 ranges for the USD are also shown, but there is considerable uncertainty in these projections given the limited data for reversion from an above-mean position.

Figure 4 also shows the West Texas Intermediate oil price (inverse right axis). During 1998–2002, when the USD valuation was very high, the oil price stayed low (in the $10–20 BBL range).

Only when USD weakened during 2003–14 did the oil price rise; observe the excellent inverse correlation between the weakening USD valuation and the rising oil price. The P50 prediction for the oil price low point is around $20–30 BBL by 2016–17.

Figure 5 shows the USD valuation during 1997–2015 and the RBA Base Metals Price Index (right axis). The latter, being a composite of metal prices – 40% aluminium; 35% copper; 10% lead; 10% zinc; 5% nickel – will not have price volatility of a single metal. Even so, an inverse relationship is apparent between USD valuation and the Index, particularly during 2003–15.

If this prediction for the USD valuation holds, commodity prices will continue to

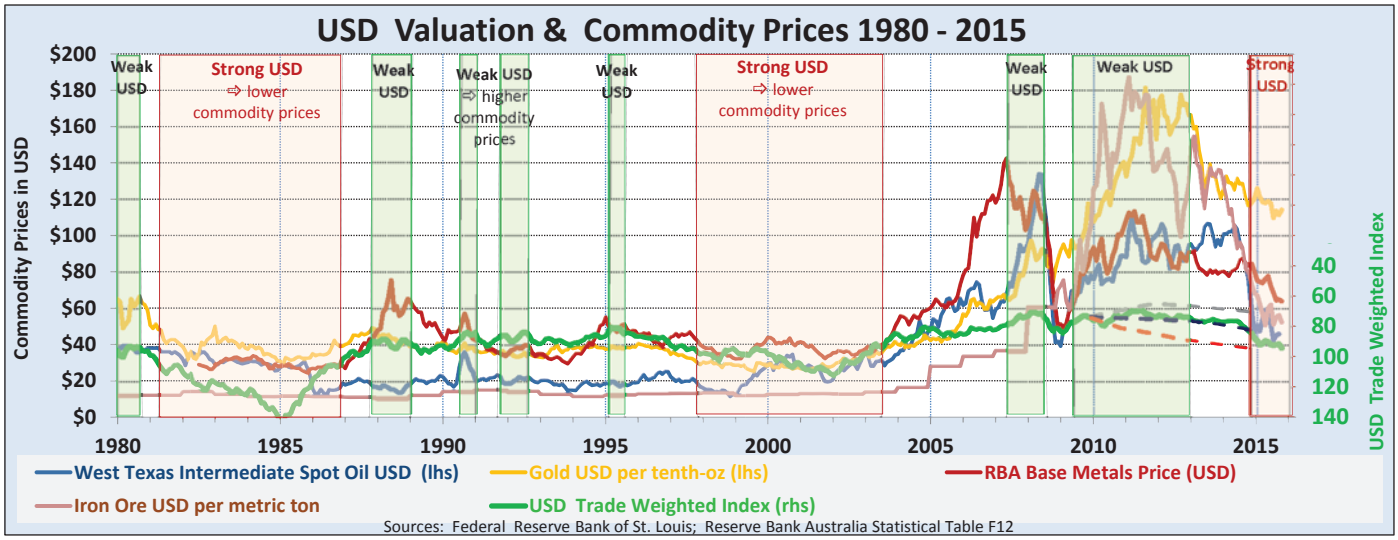

Figure 2. *Monthly values for US dollar strong/weak valuation and commodity prices. A consistent inverse relationship exists – when the US dollar is strong, commodity prices are low, and vice-versa.*

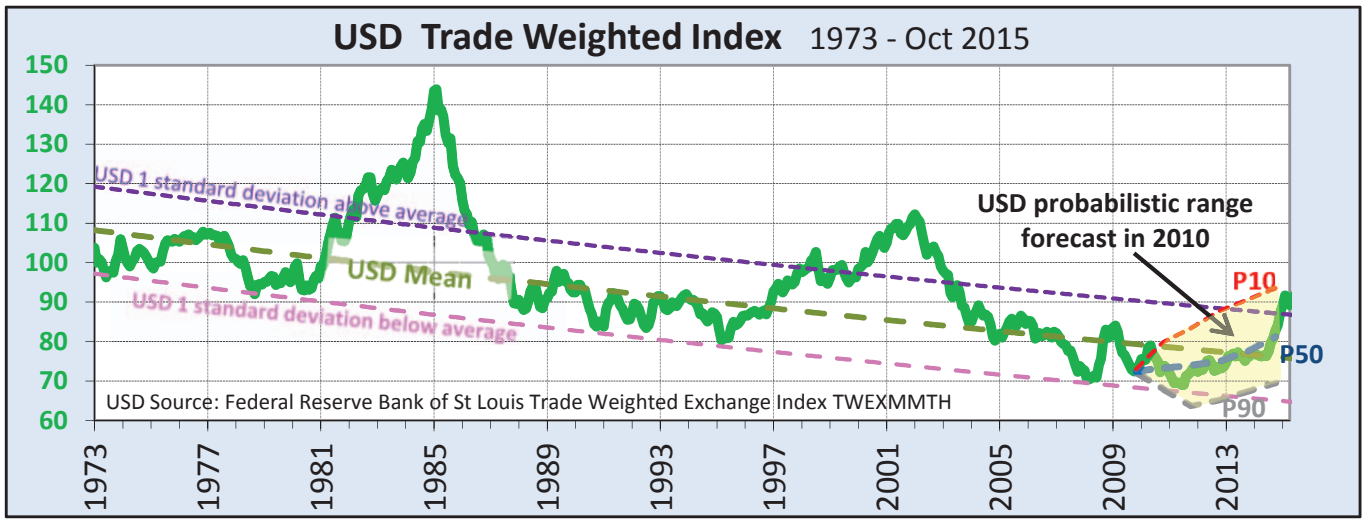

Figure 3. *Monthly values for US dollar valuation since 1973. In 2010 when the US dollar was very weak, an econophysical mean reversion algorithm predicted a strong rebound was likely in the next 5 years.*

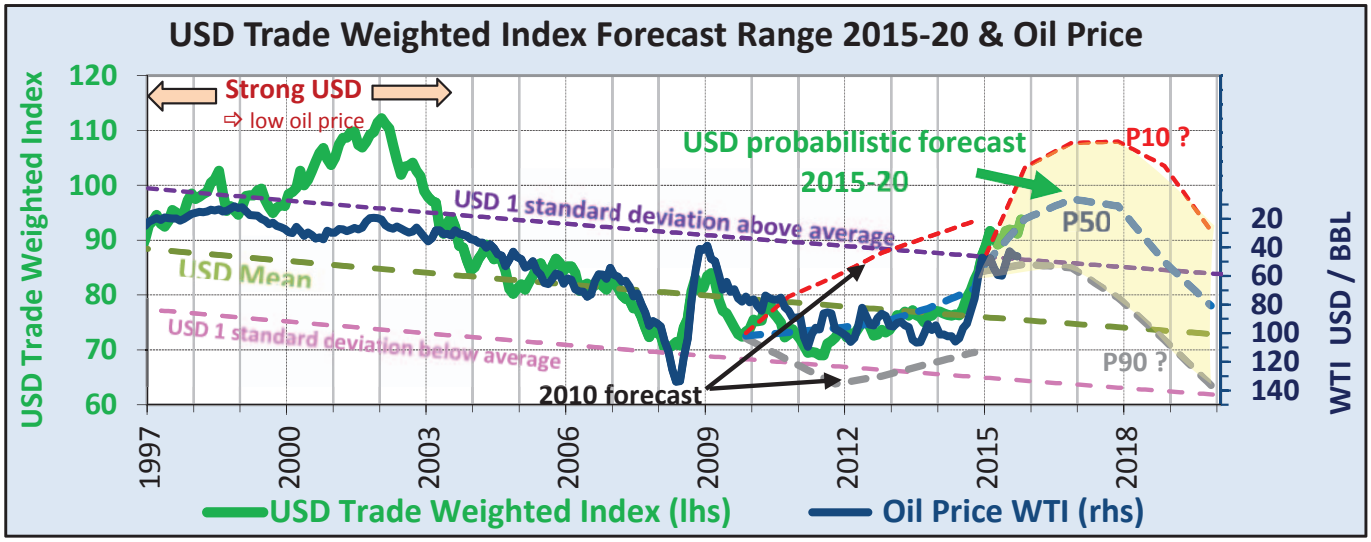

Figure 4. *Monthly values for US dollar valuation since 1997 (starting when USD was very strong), together with 2015–20 predicted range; oil price on inverse right axis. The US dollar is likely to remain strong until 2017, keeping downward pressure on oil price; from 2018 US dollar likely to weaken resulting in higher commodity prices.*

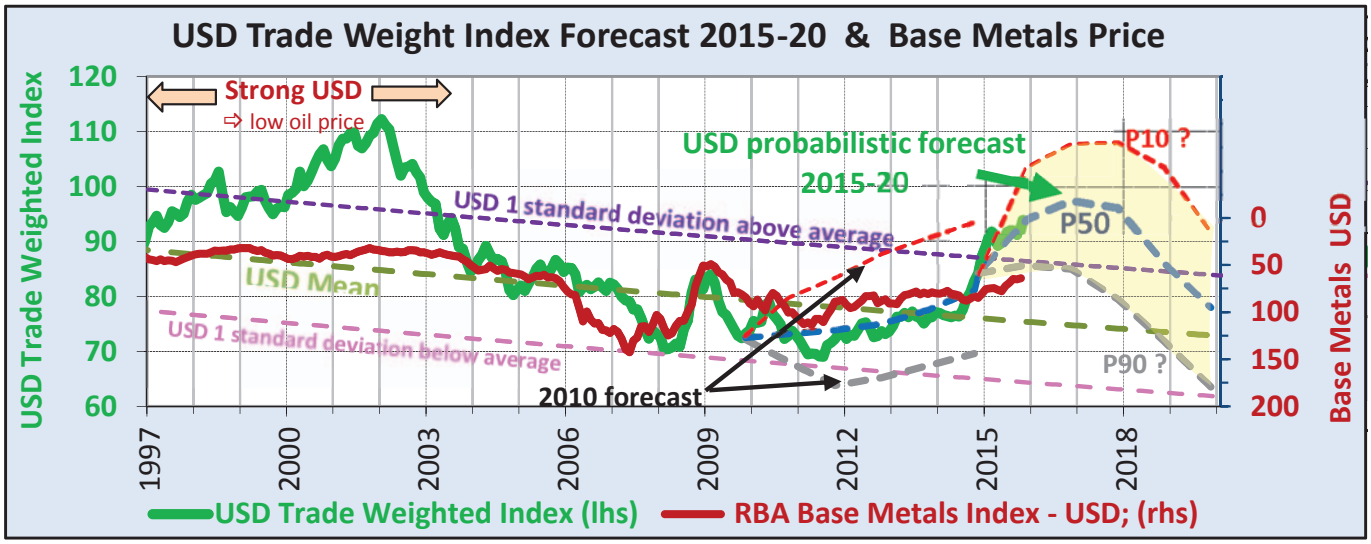

Figure 5. *Monthly values for US dollar valuation since 1997 (starting when USD was very strong), together with 2015-20 predicted range; base metals price index on inverse right axis. The US dollar is likely to remain strong until 2017, keeping downward pressure on base metals price.*

have downward pressure for the next two years. One small point of comfort in this prediction is that the majority of the decrease in prices has occurred, since the USD valuation now is well above average.

My statistical prediction indicates commodity prices are not expected to have significant upward pressure until around 2018–20 when the USD valuation is likely to fall markedly.

Commodity price forecast for the next 20 years

The research presented in this paper contends that USD valuation can be successfully modelled using a statistical mean reversion technique. The consequence is that no-one is actually in control of the USD valuation, instead the valuation is an output of the probabilistic distribution of monthly changes and serial correlation. While this observation is unsettling for people who prefer to believe humans must be in control, for rational minds it opens up the opportunity to predict the future, not with certainty but with a probability based on scientific principles.

To elaborate on this contention, I show a conceptual USD valuation for the next 20 years based on mean reversion and serial correlation (Figure 6). The prediction is for mostly below-average valuations during the 2020s and consequently high commodity prices and the next boom. Somewhere around 2030, the US dollar could rise to an above-average valuation at which time the next commodity price bust would occur. Naturally there is considerable uncertainty about how long the boom and bust last, but the import is that statistical nature of the US dollar is the key.

Conclusions

The usual approach for forecasting prices of freely traded commodities priced in US dollars does not have an empirical

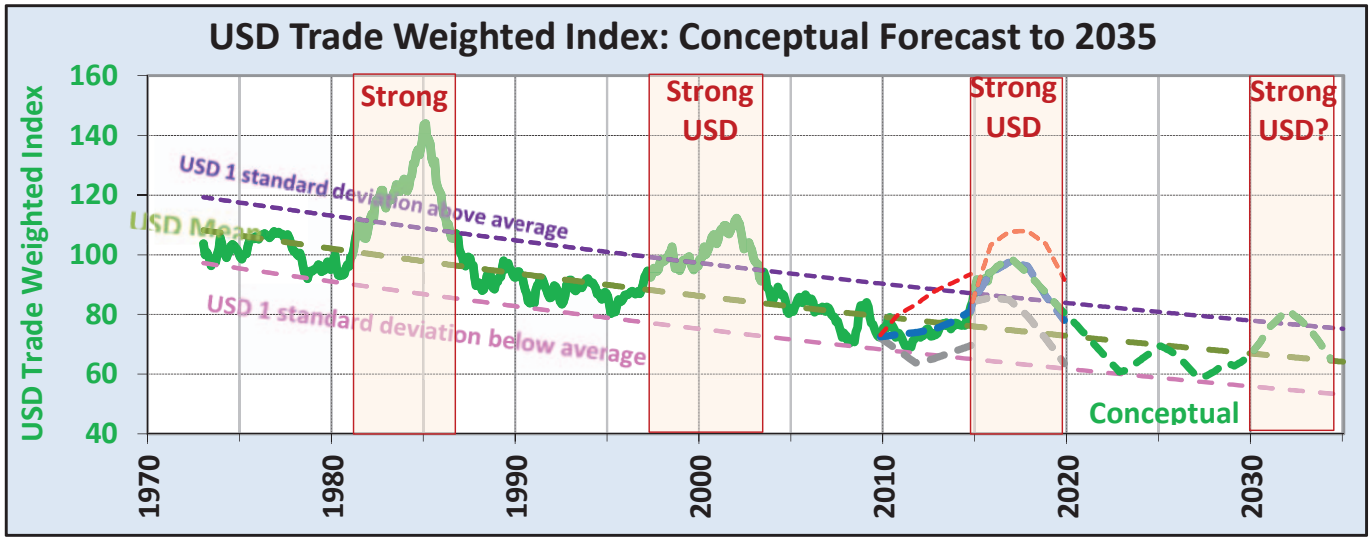

Figure 6. *A mean reversion conceptual prediction for the US dollar indicates below-average valuation during the 2020s (= higher commodity prices), followed by an above-average valuation around 2030 (= next commodity price bust).*

basis or use proven statistical techniques. In contrast, econophysical techniques can accurately predict in advance the probability and timing of major turning points in a stationary time series.

I have demonstrated there is a reliable inverse correlation between the USD valuation and the trend for commodity prices. Commodity prices are expected to remain low, with no upward pressure until around 2018. Astute resources industry management can use this scientific approach to positon portfolio exposure in advance of commodity price booms and busts, which are inevitable since the USD valuation will continue cycling.

I contend that it is possible to have a scientific basis for forecasting volatile time series (not just commodity prices, but also financial series such as stock markets. This is now happening with predicting share market movements – refer Weatherall, 2013). Firstly an observer has to gather empirical data to decide which variables actually matter, discarding those which do not. Mean-reversion statistical techniques can accurately predict the probability and associated outcome range for the next 1–5 years. Having a rationally derived probability goes a long way in evaluating not only when to invest, but also how much. This provides an important advantage over the majority of the public who have an incorrect understanding of what is controlling changes in commodity price.

Take heart those working in the resources industry – a turning point for the better is coming. Smart investors take positions around, or just before, the turning point, informed by a scientific forecasting methodology, and later sell to uninformed investors after prices have risen significantly.

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Noll Moriarty's M.Sc. (Hons) qualifications are in geophysics; during 1982–99 he applied seismic acquisition, processing and interpretation skills in petroleum exploration and development projects for Delhi Petroleum and Origin Energy. In 2000, he founded Archimedes Financial Planning, which now provides financial advice with a scientific basis to resources industry personnel around the world.

Education Matters

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ASEG proud to become a sponsor of Earth Science Western Australia (ESWA)

ASEG has taken another step in supporting science education in schools, becoming a Bronze Sponsor of the Earth Science Western Australia (ESWA) schools programme. In supporting the programme we join sister societies AUSIMM, AIG, and the Australian Geoscience Council. ASEG's Continuing Education Coordinator Wendy Watkins says this rounds out our support for school science programmes, adding to the TESEP programme in the eastern states, reported on in *Preview* December 2015.

The role of ESWA is to support the teaching of earth and environmental sciences in schools by developing teaching and learning resources, providing professional development for teachers, presenting at schools and assisting with field experiences for students.

ESWA: objectives

- Raise the profile of geoscience in the State's secondary schools to a level matching the strategic needs of WA
- Increase awareness of the wide range of career opportunities geoscience provides
- Increase the number of students entering tertiary geoscience studies
- Increase VET participation in related courses
- Increase community awareness of the importance of understanding earth science

The ESWA science programme has now completed its first decade of operation, and in a busy year in 2015 it organised an impressive 440 school visits contacting 7000 students. The programme received a resounding endorsement from government, winning the "Science Engagement Initiative of the Year" at the WA Premiers' Science Awards. May that engagement translate into a few honours theses in geophysics by the year 2025!

Australia's first portable computer for geophysics?

Roger Henderson's article on the first gravity meter built and used in Australia (*Preview*, December 2015) inspires a historical observation on the first portable computer used in field geophysics in Australia.

In 1972 Keeva Vozoff accepted the position of Chair of Geophysics at Macquarie University, and commenced assembling a team to perform natural-field electromagnetic and seismic observations in Australia. This was funded by the Australian Research Council and by the Bureau of Mineral Resources (now Geoscience Australia) and involved a series of surveys in outback NSW, SA and NT designed to determine thicknesses and properties of little-studied sedimentary basins. A parallel line of research was the development of stable inversion methods for electrical and magnetotelluric methods by Keeva and his post-doctoral fellow Dave Jupp.

Field recording required not only recording but computation of spectra and coherencies of multichannel data. How to do this in 1974? Purchase an Interdata Model 70 (eight years before the first IBM PC) with a nine-track tape drive and a rack of compatible analog-digital converters. It all fitted in three instrument racks, with a fourth rack of amplifiers, filters and power supplies for the magnetotelluric sensors. How to carry it?

ESWA starting early, introducing primary school children to the world of hard hats and very large trucks.

Eyes on the rocks; students from Guildford Grammar get out of the classroom with ESWA.

The Macquarie University Mobile Geophysical Laboratory, 1974. Was this the first portable computer used by graduate students in Australia?

A five-ton army-surplus mobile radar van looked good. How to move it? A three-ton army-surplus truck was the perfect solution.

I make the tentative claim that I was highly privileged to be the first geophysics graduate student in Australia to take a portable computer (all eight tons) to my field site, for passive seismic (ambient noise) studies. Those spectra took 1 second each to compute for 1024 points using a computer memory of 32 kilobytes. Thirty-eight years later Nick Smith, as an honours student at the University of Tasmania, did a rather more advanced passive seismic survey to determine regolith thickness at the Prominent Hill mine area, SA.

Nick Smith.

That survey used Guralp seismometers, where the digitizers and data recorders were on a chip within the seismometer case. Larger data sets were allowed; the seismometers had 16 gigabytes of memory each, and when downloaded on to a multi-core laptop computer of 2012, those equivalent spectra were each computed in 50 usec. Check with Nick Smith in 2050 for the ideal passive seismic system of that mid-century epoch. Roger Henderson and I will be very interested, even if by then age has wearied us.

A Guralp CMG-6TD seismometer used for passive seismic measurements by Nick Smith, 2012. Solid state memory is increased by a factor of about 1 million, computation speeds by 20 thousand, and weight of electronics and packaging decreased by about 1000. The power source is a non-spilling gel cell, but is otherwise little different from its 1970s car-battery equivalent.

Coming in March: ASEG one-day short course on rock physics

Dr Serge A. Shapiro

Rock physics and geomechanics of fluid-induced seismicity: hydraulic fracturing, stimulation of geothermal systems and hazard assessment

Presented by: **Dr Serge A. Shapiro**, Professor of Geophysics, Freie Universität Berlin, Germany.

Dates 15 March in Perth (maximum 24 attendees)
21 March in Canberra

Venues

Perth	Canberra
Minespace Level 1, 1292 Hay Street West Perth	Geoscience Australia, Room 1.024 Corner of Jerrabomberra Avenue and Hindmarsh Drive Symonston, ACT (sign in at Reception on arrival)

Pricing

Earlybird prices for registrations paid more than 2 weeks prior to course. Registrations close 1 week prior to course, with no refunds after this date.

	Perth		Canberra	
	Earlybird	Late	Earlybird	Late
Members	$250	$300	$180	$230
Non-members	$425	$475	$350	$400
Students	$0	$50	$0	$50

Course description:

Stimulations of rocks by fluid injections belong to a standard reservoir-development practice. Production of shale oil, shale gas, heavy oil and geothermal energy require broad applications of this technology. The fact that fluid injection causes seismicity has been well-established for several decades. Understanding and monitoring of fluid-induced seismicity is necessary for hydraulic characterization of reservoirs, assessments of reservoir stimulations and for controlling the seismic risk. The course provides systematic quantitative rock-physics and geomechanical fundamentals of these aspects.

Course objectives:

- To demonstrate the potential of microseismic monitoring for characterization of hydrocarbon and geothermal reservoirs.
- To provide a systematic introduction into quantitative interpretation of microseismic monitoring and into assessment of the hazard of induced seismicity.

Approximate course outline:

Rock physics and geomechanics of induced seismicity
- Poroelastic phenomena and seismic waves
- Stress, pore pressure and rock failure
- Geomechanics of earthquakes

The method of microseismic monitoring:
- Observation systems, detection and location of events
- Microseismic wavefields and imaging

Seismicity, pressure diffusion and hydraulic fracturing
- Modelling of fluid-induced seismicity
- Seismicity during a fluid injection
- Seismicity after a termination of a fluid injection
- Hydraulic properties of reservoirs and induced seismicity
- Hydraulic fracturing of hydrocarbon reservoirs
- Seismicity induced by hydraulic fracturing
- Non-linear diffusion and seismicity in unconventional reservoirs

Hazards of induced seismicity
- Rates and magnitudes of fluid-induced earthquakes
- Seismogenic index
- Statistics of large magnitudes

About the lecturer:

Serge A. Shapiro is Professor of Geophysics at the Freie Universität Berlin, Germany and since 2004, Director of the PHASE (PHysics and Application of Seismic Emission) university consortium project. From 2001 till 2008 he was a Coordinator of the German Continental Deep Drilling Programme. His research interests include seismogenic processes, wave phenomena, exploration seismology and rock physics.
Professor Shapiro received the SEG Virgil Kauffman Gold Medal in 2013 for his work on fluid-induced seismicity and rock physics and in 2004 was elected a Fellow of The Institute of Physics.

Who should attend?

Geophysicists, Geologists, Petrophysicists, Reservoir Engineers, Graduate Students, Researchers

The book for the course:

S.A. Shapiro, 2015, *Fluid-Induced Seismicity*, Cambridge (UK): Cambridge University Press, pp. 289, ISBN: 9780521884570.
http://www.cambridge.org/9780521884570
Note: The book is recommended for purchase prior to the course but not compulsory. Digital course notes will be provided, although these will not be as comprehensive as the book.

AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS

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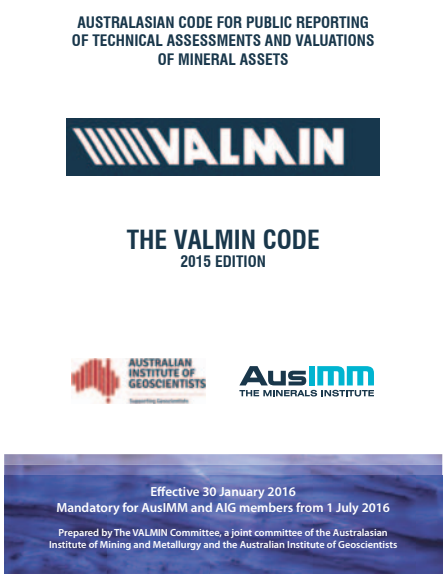
Minerals Geophysics

New VALMIN Code released



The Australasian Code for Public Reporting of technical assessments and valuations of mineral assets, commonly known as the VALMIN Code, sets out requirements for the technical assessment and valuation of mineral assets and securities for independent expert reports, it also provides guidance for petroleum assets and securities. The VALMIN Code was first published in 1995, with subsequent editions published in 1997 and 2005.

After an extensive review process, the VALMIN Committee, which is a joint committee of The Australasian Institute of Mining and Metallurgy (AusIMM) and the Australian Institute of Geoscientists, has announced a new VALMIN Code (2015 Edition) has now been approved by AusIMM and AIG. The VALMIN Code (2015 Edition) will be effective from 30 January 2016 and becomes mandatory for AusIMM and AIG members from 1 July 2016.

During the transition period of 30 January to 30 June 2016, Public Reports are able to be published in accordance with either the 2005 or new 2015 Edition of the VALMIN Code – all Public Reports published in this period should clearly state which version of the Code has been applied.

The core purpose and principles of the VALMIN Code remain unchanged, but this new edition includes some important changes:

- Clearer structure and plain-English Code text
- Alignment with the JORC Code (2012 Edition) and other relevant guidelines and laws
- Clarity about the definitions for and roles of VALMIN Practitioners
- Clarity about the types of Public Reports, their development and use
- Guidance on valuation approaches and methodologies
- Increased transparency requirements for Public Reports
- Exclusion of petroleum from the mandatory provisions of the Code (however, the 2015 Edition VALMIN Code provides guidance that can be applied for petroleum valuation reports).

To access the VALMIN Code (2015 Edition), and for more information about the changes it introduces, see www.valmin.org.

The revised VALMIN Code will be the key focus of the AusIMM Project Evaluation Conference being held in Adelaide on 8–9 March. The conference will feature a keynote presentation by VALMIN Chair Louis Rozman, and a panel discussion involving VALMIN Committee members. Discounted registration is available to AusIMM and AIG members. More information can be obtained from: http://www.projectevaluation2016.ausimm.com.au/.

Environmental Geophysics

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Gas spectrometry: very shallow surface geophysics?!

Welcome to *Preview* readers this month. I thought that this time around I would not concentrate on things strictly geophysical, but instead would write about data collected in the atmosphere and close to the ground (arguably very shallow geophysics?). Over the last few years in my role as a researcher at the University of Adelaide I have been working on a greenhouse gas (GHG) project using some of the new generation of what could primitively be called 'gas detectors' or 'sniffers' but are actually near-real-time, relatively portable, highly accurate (and precise) gas spectrometers. The model that I work with, a Picarro G2201i, has an 'analyser' that uses three different narrow-bandwidth infrared lasers to excite the individual molecules in three different gasses to estimate sample concentrations. This model measures methane (CH_4), carbon dioxide (CO_2) and water vapour. By collecting data at a number of wavelengths, it is able to measure both the concentration of the main isotope of carbon (12C), as well as one of the minor isotopes of carbon (13C) for both CH_4 and CO_2, thereby providing information about isotopic carbon ratio for both gases. This is important as it sometimes allows us to determine the 'source' of the carbon, i.e. whether the CH_4 (or CO_2) that we have sampled is thermogenically created, i.e. sourced from geological processes deeper in the Earth and relatively heavy in 13C; or biogenically created, i.e. sourced from near-surface, biological processes and relatively light in 13C.

For survey work the spectrometer is strapped into the back seat of a vehicle with a charging system and spare batteries, along with a GPS and a portable weather station (wind direction can help us determine source location). A hose is run from the vehicle roof into the analyser inlet to sample the local atmosphere; data are time-stamped allowing GPS location and GHG gas concentration to be synchronised, and, ultimately, maps of CH_4 and CO_2 concentration to be created. The analyser provides a real-time graphical update of what is being measured and it is fascinating to see how levels change with location, time of day, weather, etc.

A little background: CH_4 is at least 25 times more effective a greenhouse gas than CO_2 and is presently the second most important GHG, representing about a third of the radiative forcing factor of CO_2 (Forster et al., 2007). Levels for CH_4 are the highest that they have been in the atmosphere for the last 650 000 years (Jansen et al., 2007) so it is important to get a better feel for its distribution in the atmosphere and get some insight into how it moves and concentrates. In Australia the CSIRO, as part of a larger worldwide network of GHG monitoring stations (http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html), has been collecting greenhouse gas level data since the late 1970s (http://www.csiro.au/greenhouse-gases/) at a site relatively unaffected by local gas contribution; Cape Grim, on the west coast of Tasmania. Table 1 shows the range of concentrations for three of the more important greenhouse gases from Cape Grim (the CSIRO website is well worth having a look at). This data can be compared with similar data collected at Mauna Loa (http://www.esrl.noaa.gov/gmd/ccgg/trends/weekly.html). The methane level at Cape Grim is just above 1.8 ppm, with some seasonal variation. For reference, CH_4 does not explode until concentrations are > 50 000 ppm, so all of the concentrations shown here are well below the explosive limit.

Figure 1 shows methane concentration data collected on a drive around the city of Adelaide in August 2014. While none of the concentrations are particularly high, a number are well above background, with some areas in the 2 to 2.5 ppm range, well above the background level observed at Cape Grim and over much of Australia (and in fact much of the area to the north of Adelaide in Figure 1). The zone of highest concentrations to the north of Adelaide appears to be associated with a disused landfill that was closed in 2001; again the concentration values shown here are not in the explosive range, but it appears likely that at the time of this survey this landfill was leaking CH_4 to the atmosphere. Most of the other small zones of elevated CH_4 levels to the north and west of the Adelaide CBD are interpreted as being related to gas-carrying infrastructure. In 2010 Adelaide newspapers reported that minor leakage was extensive from gas infrastructure in Adelaide (http://www.adelaidenow.com.au/news/gas-leaks-prompt-blast-fear/story-e6frea6u-1225962049328). These results are consistent with the observations in that article. This example illustrates some of the interesting results from this work so far, and highlights some of the complexity inherent in the problem of quantifying the greenhouse gas problem.

Table 1. Cape Grim GHG levels (http://www.csiro.au/greenhouse-gases/)

Date	CO_2 (ppm)	CH_4 (ppm)	N_2O (ppb)
October 2015	398.388	1.802	327.49
June 1976	328.988		
April 1978		1.479	299.19

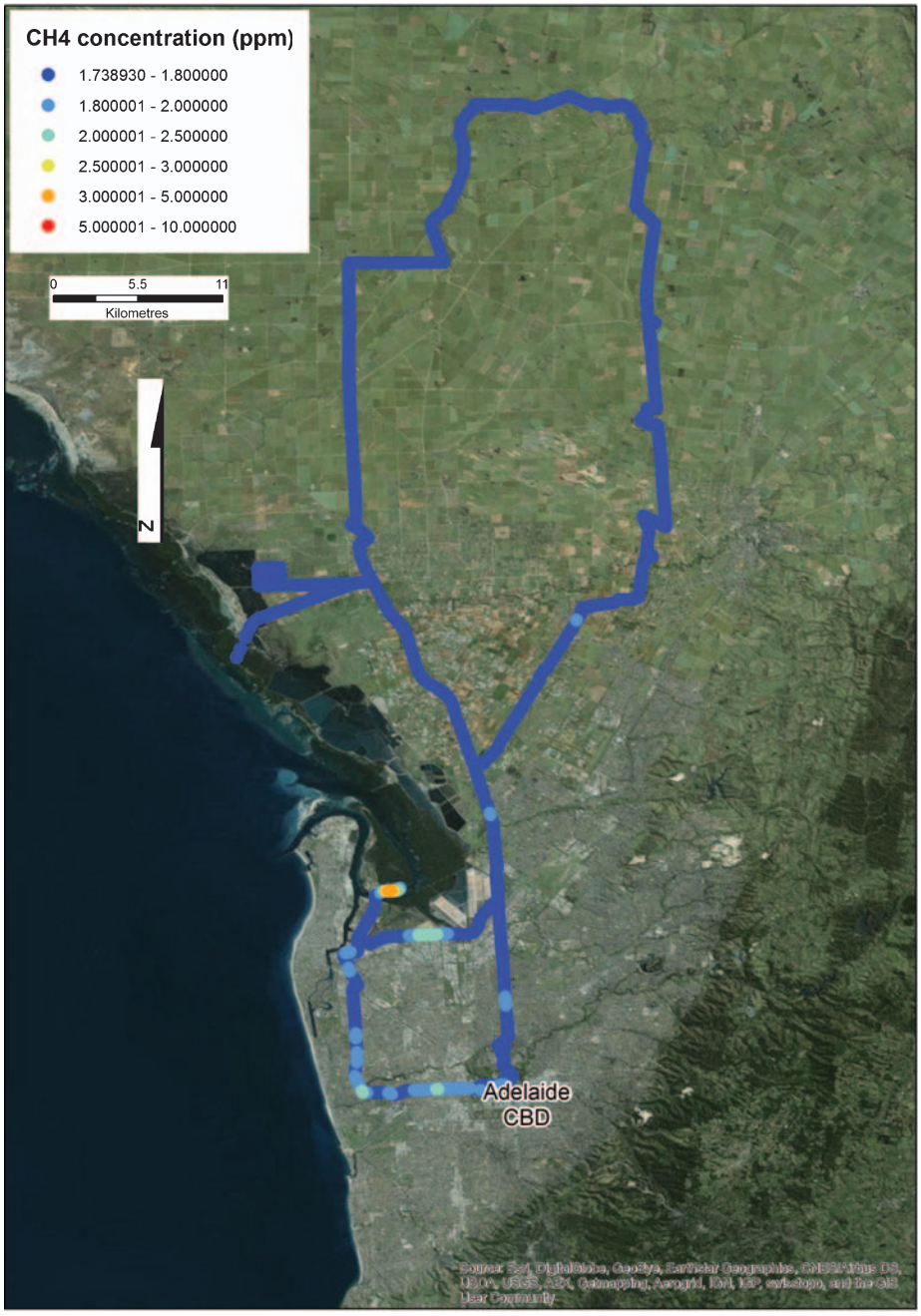

Figure 1. *CH_4 levels around Adelaide, South Australia. Data collected during March 2015. CH_4 concentrations ranged from 1.74 to 3.74 ppm. Image background sourced from ESRI (Digiglobe, GeoEye, Earthstar Geographics, USDA, USGS, AEX, Getmapping Aerogrid, IGN, IGP, swisstopo and the GIS community).*

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Seismic Window

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A look back – 4D, seismic noise, broadband, modern interpretation and bees

A seismic potpourri follows with a look back at the 2015 articles. Some stimulated a great deal of interest and feedback, while others appear to have been too geophysical. In future I will pitch my writings at the modern seismic interpreter rather than the true geophysicist – who knows about maths and physics but can be a bit geeky. There will be no more articles on Mallat scattering transforms, although I will still get stuck into Nintendo geos if the situation warrants.

4D seismic

Last issue I wrote about 4D seismic and noise cancellation and I'd like to follow that up with some modelled results displayed in map view. The reason for this modelling was to show one of the operating companies I deal with that useful data can be obtained from 4D seismic surveys even when there is a large amount of noise and a weak 4D response. Figure 1 shows a simple model of an area with 3% amplitude change between base and monitor surveys and random noise up to 6% of the total signal. Each survey has different random noise. Normally the difference between the base and monitor surveys is displayed to highlight areas where there has been a change in rock or fluid properties. In this example the difference display has a hint of a change but it is difficult to recognise. But, applying a 6x6 averaging filter produces an amplitude anomaly in the centre of the survey where the changes were made in the model. This anomaly may not be sufficiently well defined for quantitative analysis but it does indicate an area of change which can be related to changes caused by production. You might see the anomalous area more clearly on the monitor survey (Figure 1b) rather than the difference display, but this is a model and in real data the geology varies and tends to obscure the smaller 4D effects.

Broadband

Broadband seismic data acquisition and processing is now almost standard in the industry because the benefits can be significant. But what is broadband? At a recent seminar I attended I was told that surveys in the Norwegian North Sea are now being acquired with 6 octaves of useful frequency content – that could be 2–128 Hz or 3–192 Hz. This is an incredibly wide range, almost unbelievable, but if the contractor says it is so, it must be true.

Modern methods

At the start of the year I tried out some modern interpretation tools on the Jackson 3D seismic. Since then automatic fault picking has progressed rapidly and is now affordable for most interpreters. An example of the latest fault identifying software is shown in Figure 2. Compared to the similarity volume, which was until recently my best effort to show faults, the fault likelihood attribute looks to be significantly better. This attribute can be used as input into a module that identifies faults and produces sticks or planes automatically thereby speeding up an interpretation project.

Bees

Actually I have nothing to add about bees but they did stimulate feedback.

Finally, if you have an article suitable for this column please contact me.

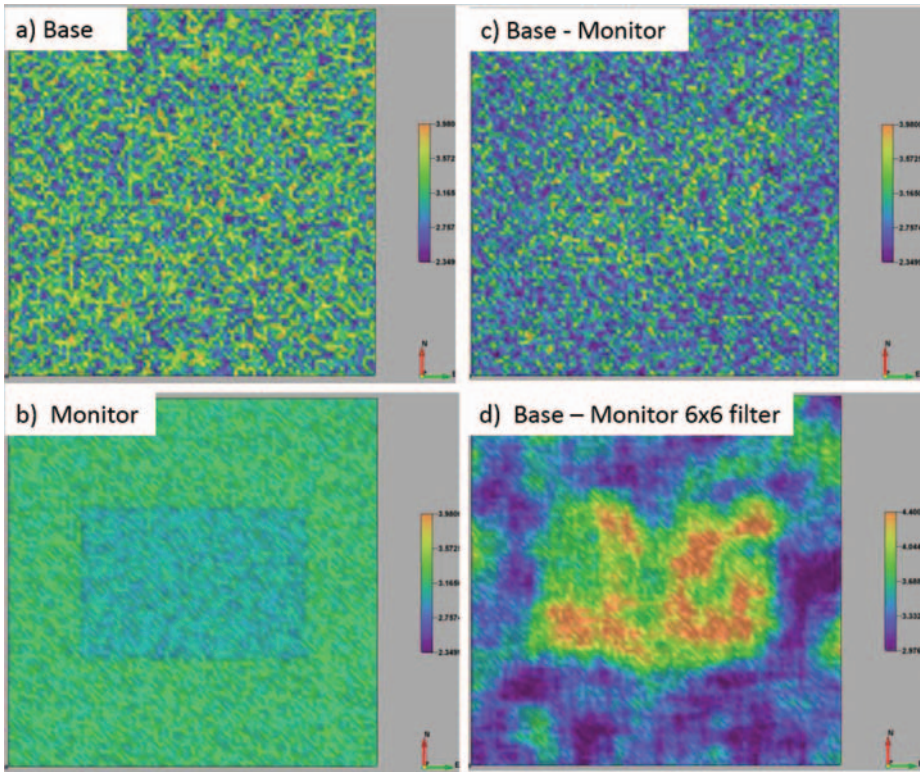

Figure 1. *Modelled 4D seismic response in map view: (a) base survey with 6% noise added; (b) monitor survey with 3% decrease in amplitude in centre of survey and 6% noise added; (c) base – monitor difference with 4D response difficult to recognise in noise; and (d) 6x6 average filter applied to difference shows easily recognised area of decreased amplitude.*

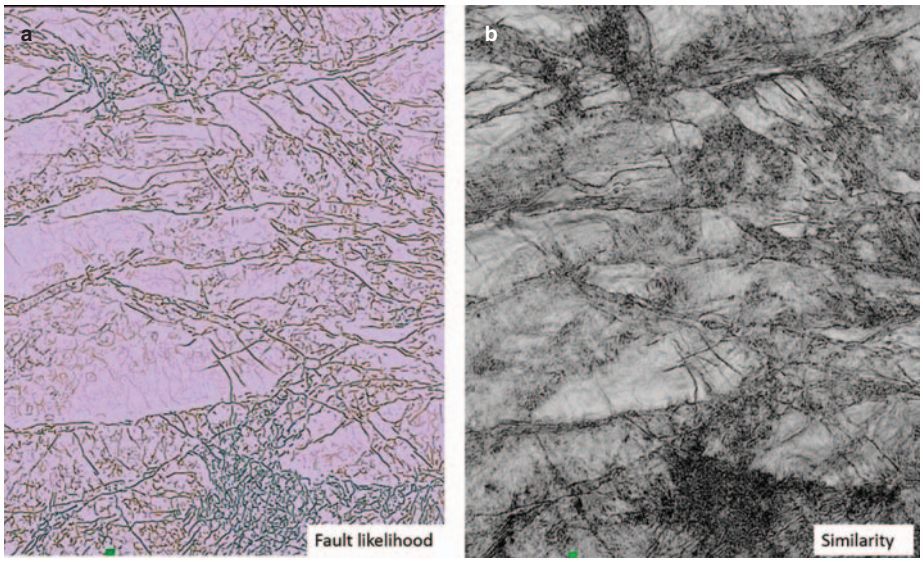

Figure 2. *Map view comparison of the fault likelihood attribute (a) and the similarity attribute (b) on a time slice at 2s TWT. Both attributes calculated using OpendTect Pro.*

Petroleum permits awarded in 2015 with lowest bid level in decades

As consequence of low oil prices the number of Australian and New Zealand petroleum exploration permits awarded in late 2015 is down on previous years and committed work programmes are smaller.

In Australia, 30 offshore areas were announced in the 2014 acreage release but only 10 permits have been granted. This is the lowest number of permits granted in more than two decades and indicative expenditure and activity in these 10 permit areas is the lowest level of expenditure and activity in 10 years, with only one well committed in all the primary work programmes (Tables 1 and 2). Round 2 of the 2014 release closed in April 2015 and successful bids were announced in October last year. Of the 12 areas in Round 2 only four permits were awarded.

Areas W14-1 and W14-2 received one bid each but were not awarded to the bidder. They are open for bidding as re-released areas, as are areas AC14-1 and W14-6, which received no bids. All remaining areas received no bids and revert to open acreage.

In New Zealand the Minister for Energy and Resources noted the fall in oil prices had seen companies drastically reduce their exploration budgets, with acreage on offer in frontier basins receiving no bids. The industry steered clear of substantial acreage offerings in the offshore Northland-Reinga, Pegasus-East Coast and Great South–Canterbury Basins. The block offer was designed to help stimulate frontier investment but it has also generated significant interest in onshore and offshore Taranaki.

Nine blocks were awarded in December – six offshore and three onshore (Table 3). All were in the Taranaki Basin. Collectively the nine permits awarded include contingent work programme expenditures of NZ$364 million but only $4.4 million is committed.

Table 1. Australian permit awards: Round 1 2014 acreage release

Release area	Permit	Basin	Applicants	Primary work programme	Indicative expenditure
AC14-2	AC/P59	Vulcan	Murphy Mitsui	316 km^2 MC 3D 2D broadband reprocessing, geophysical and geological studies, AVO studies	$3.9 million
W-14-15	WA-510-P	Barrow	Apache (Quadrant)	Acquire 3D broadband seismic, rock physics and inversion	$10 million
W-14-4	WA-513-P	Caswell	Santos Inpex	MC 3D acquisition, geophysical and geological studies	$5.65 million
W-14-5	WA-514-P	Caswell	Santos Inpex	MC 3D acquisition, geophysical and geological studies	$4.8 million
W-14-7	WA-515-P	Dampier	Tap	Reprocess 415 km^2 3D, rock physics and geological studies	$800 000
W-14-16	WA-516-P	Dampier	Tap	Reprocess 415 km^2 3D, rock physics and geological studies	$800 000

Table 2. Australian permit awards: Round 2 2014 acreage release

Release Area	Permit	Basin	Applicants	Primary work programme	Indicative Expenditure
W-14-19	WA-517-P	GAB	Santos JX Nippon	2000 km 2D seismic, seepage survey, geophysical and geological studies	$3.1 million
W-14-10	WA-518-P	Exmouth	Hess	885 km^2 MC 3D seismic, reprocessing and inversion, geophysical and geological studies, 1 well	$61.75 million
W-14-12	WA-519-P	Exmouth	Hess	257 km^2 MC 3D seismic reprocessing and inversion, geophysical and geological studies	$4.5 million
W-14-17	WA-520-P	Exmouth	Finder	1200 km^2 3D broadband seismic, geophysical and geological studies	$5 million

Table 3. New Zealand 2015 permits awarded

Permit	Bidder	Work Programme
PEP 60089	OMV Mitsui	Seismic reprocessing, studies
PEP 60091	OMV Mitsui	Seismic reprocessing, studies
PEP 60092	OMV Mitsui	Seismic reprocessing, studies
PEP 60093	OMV Mitsui	Seismic reprocessing, studies
PEP 60094	Todd	
PEP 60095	Mont D'Or	Acquisition of geochemical data, geological studies
PEP 60097	Petrochem	Geological studies, seismic reprocessing
PEP 60098	Petrochem	Geological studies, seismic reprocessing
PEP 60099	Petrochem	Geological studies, seismic reprocessing

Data Trends

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The start of another exciting year

I settled into my favourite chair, eyes closed, clenching my fists, releasing them slowly, clenching again, releasing slowly. I did the same with my feet repeatedly until I felt warm and as light as a feather. After a few minutes I started to enter a deep state of relaxation.

Before starting this process, I read all of the technology predictions for 2016 from a variety of sources including the Harvard Business Review, Forbes and FurtureTimeLine.net, and stored them away in the back of my mind. Once relaxed, I thought about those predictions and tried to imagine and immerse myself in them fully.

To be honest, I simply could not wait a full year to start to try the new technology that I have been assured will be making my life easier by the end of 2016. So, off I went.

There I am in my driverless car talking to my virtual assistant in the office. Could I get a ticket for talking on a mobile phone if there is no driver? The car seamlessly and swiftly transports me to my office – and like a lot of things that are easy – it is nothing short of boring. Just for a bit of fun, I try and convince it to take me to a drive thru for breakfast. Would it open the correct window of the car so I can get the food handed to me when we pull up? Does the driverless driver have his own window, and if so – why? Had the developers thought of everything?

Turns out the developers had in fact thought of everything. The car rejects my request as my wife has already informed the car of my cholesterol levels. It offers me some fresh fruit instead.

After changing my selected destination midway through a few roundabouts to see what the car will do, my mind drifts to other technology.

I decide to use my augmented reality device to contact my microwave oven to inform it of the incoming pizza that is being delivered by drone to the office. My wearable fitness wrist band gives me an electric shock and the car offers more fruit.

I start to wonder why I was even in the driverless car on my way to the office when I could have sent my telepresence robot to the management meeting instead. What about a driverless office? This future stuff is not what I was hoping for.

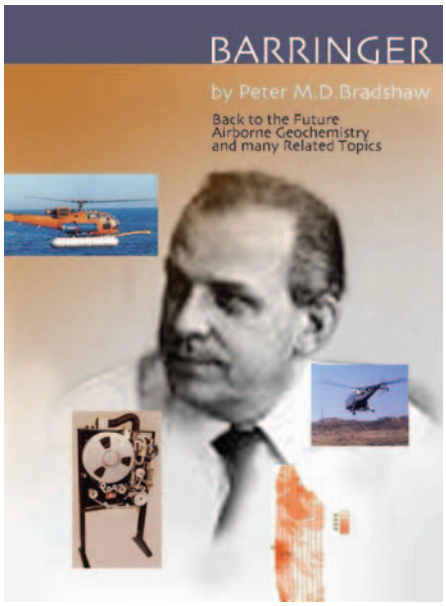
In one of the biggest industries on the planet, although maybe a little smaller than it was last year, what does 2016 hold for the oil and gas industry?

1. More uncertainty: I know that this one is a little obvious – but it sure is great to be right.
2. The industry finally 'gets' Big Data: the oil and gas sector generates massive volumes of data. This year the industry finally realises that it can use all of it at once to do things it never thought possible.
3. The Cloud: the industry's IT leaders will stop saying 'but the Cloud is not secure'.
4. Unprecedented adoption of automation: with low oil prices, cheaper wireless sensors and well developed mesh networking, oil and gas companies will continue to find a way of doing things without the need for more people.
5. Alternative energy: increased pressure to diversify into alternative energy production by the Majors. It can't be ignored much longer.

My 2016 predictions don't really sound like things will be much fun this year. I may have to find a way to live in augmented reality for the next 12 months to avoid having to actually see my predictions unfold.

Barringer, Back to the Future: Airborne Geochemistry and Many Related Topics

By Peter M.D. Bradshaw



Publisher: Association of Applied Geochemists, Nepean, ON, Canada, 2015, 159 pp.
Hard Cover book, including shipping US$ 68.00
Soft Cover book, including shipping US$ 58.00
ISBN: 978-0-09691014-5-1

In the years after the Second World War mineral exploration grew exponentially, driven by advances in instrumentation and development of airborne survey methods. Large areas could now be scanned for mineral potential without having to put people on the ground (of course that still would be needed to follow-up on targets found in regional surveys). Not surprisingly, many early discoveries were in Canada, Australia, and the western United States, where there was a good base of technical expertise, and vast areas that were relatively unexplored in the geological sense, but still fairly accessible on existing transportation infrastructure.

Many of the successes came from new companies willing to gamble on untried methods, needing only a small core group with knowledge in the geosciences and electronics to get started. One of these was Barringer Research in Toronto, founded by Tony Barringer in 1961 (based in Denver after 1977). Their INPUT time-domain EM system was credited with discovering numerous base-metal deposits collectively worth billions of dollars. They went on to develop several other geophysical devices and geochemical sampling and analysis systems. Their equipment was adapted for many other uses, such as tracking oil spills and other environmental problems, security scanning for drugs and explosives, detecting nuclear tests, and monitoring heavy water levels in nuclear power plants.

Rather than cover the complete range of Barringer Research's work, this volume concentrates on the airborne geochemical systems developed in the 1960s and 70s. These systems provided rapid sampling of trace elements as pathfinders to mineral deposits, oil fields, or pollution sites, often in conjunction with geophysical measurements deployed on the same aircraft. The approach included collecting both atmospheric gases (e.g. mercury, sulphur dioxide, hydrocarbons) and particulates (in the air or from contact with vegetation or the soil surface), which could be analysed for many elements. Many practical problems arose in the transition from lab to field, requiring innovations in material collection, sample analysis, and logistics (e.g. how to mount the devices in aircraft, get a sufficient amount of material, and avoid entanglement of towed sensors).

The book opens with brief introduction to Tony Barringer and his company, then is organised into three parts with 13 independent review papers as chapters. The first part (about half of the text) describes systems used in exploration, primarily for minerals but also covering the search for oil and gas, and monitoring oil spills. AIRTRACE and SURTRACE captured gases and particulates, and FLUOROSCAN detected hydrocarbons on water surfaces. System components are given in detail, followed by discussion of operational procedures and examples of successful field use. A detailed review of bio-geochemistry gives the context of relating the survey results to metals (and potentially valuable metal deposits) in the ground.

Part Two reviews systems for environmental and security screening, specifically COSPEC (a correlation spectrometer for detecting sulphur and nitrous dioxides), GASPEC (other gases), and IONSCAN (a spectrometer the detecting explosives and drugs, extensively used in airports).

Some analytical systems are briefly described in Part Three, for example an airborne mercury spectrometer, and the LASERTRACE system that was the key to real-time analysis of particulate samples (laser ablation removes particulates from the sticky tape collection device and passes them to an ICP (induction coupled plasma) multi-element spectrometer). In the 1980s, Barringer adapted satellite remote-sensing technologies to portable surface use (HHRR, a handheld ratioing radiometer, and REFSEC, a reflectance spectrometer).

Many people who were directly involved in these projects contributed to the book (Barringer employees, academic researchers, and industry staff). Bradshaw is the lead writer, with nine others credited on different sections, and more than 70 listed under 'assisted in the compilation'. The text contains many insights into the practical problems that arise in getting a new technology to work in the field. It also touches on the business side, with examples of funding new projects, field testing with partners, and deciding to suspend the project when the probability of financial success becomes remote.

The book presents an impressive amount of technical detail in a clear, concise style, adding numerous personal stories to demonstrate that real people are behind these innovations, and things frequently go off course. Each chapter has references to original published accounts of the subject systems. The illustrations are excellent, including schematics and photographs of the instruments; photographs from field tests; and summary tables, graphs, and maps of survey results. As a nod to the broader range of the company's successes, the book ends with a brief description of the INPUT system, and a list of Barringer's many U.S. patents.

The book would have benefitted from more background on the development of exploration technologies and airborne systems, and more detail on how Barringer Research fits into that time and place. Despite this minor weakness, it is an impressive book, one that will be of value to anyone interested in the practical side of developing innovations in the geosciences. It is also worthwhile for its insights into the multi-pronged approach to exploration, as the overlaps between airborne geophysics and the geochemical systems described here are broad and illuminating.

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The first lecturer in exploration geophysics in Australia – later to become a world renowned seismologist

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The first full-time university lecturer in Australia in exploration geophysics was Dr Henry Ivison Shipley Thirlaway, who was appointed to the position in the University of Sydney's Department of Geology in 1949. Dr Alan Day (1966) reports that the only teaching in geophysics before this was in 1931, when E. H. Booth gave a series of lectures, demonstrations and three days field work in geophysical prospecting 'under the auspices of the Extension Board of Sydney University'[1].

Thirlaway only held the position in Sydney from October 1949 to April 1951, and on return to the UK in 1960 he went on to become a leading expert in detecting illegal underground nuclear testing. Figure 1 is a photo of him, probably taken just before he came to Sydney.

An obituary of Thirlaway in the *Guardian* newspaper (Davies, 2010), states that 'Hal', as he was known to his colleagues, graduated in geology from Durham University in 1938 and completed his PhD in 1950 in the Department of Geodesy & Geophysics of Cambridge University under the supervision of Edward ('Teddy') Bullard[2].

According to Dr David Branagan (pers.comm.) who was an honours student in the Department in 1950, Thirlaway was appointed when Professor C. Marshall was Head of Department from 1949 to 1973, as part of Marshall's efforts to re-invigorate the Department as he had found on his arrival that 'much of the teaching was out-of-date' with a need for 'new staff experienced in 'practical' geology' and more funding[3]. Marshall set about acquiring new staff and, recognising the need to include geophysics, made Thirlaway the first ever academic

Figure 1. *'Hal' Thirlaway taken, it is thought, just before he arrived in Australia. Reproduced from* The Guardian *newspaper, 20 January 2010.*

geophysicist. In Branagan's view, Marshall would have liked to have had a Professor of geophysics at this time but it could not have been Thirlaway as he lacked the appropriate qualifications; he was only 32 at the time[4]. At least, as Branagan points out, Marshall was able to have the department named the Department of Geology and Geophysics. In 1951, a Chair in Geophysics was established at the Australian National University but only for graduate studies.

According to Dr Alan Day (pers. comm.) who was one of four honours students in the Department in 1951, Thirlaway gave a one-term segment on geophysics in the honours year using as textbook 'Geophysical Prospecting for Oil' by Nettleton (Nettleton, 1940), which Day states was heavily favoured at the time for its emphasis on seismology. Thirlaway's teaching method, according to Day, was to require his students to read one or two chapters of Nettleton each week, which led Day to conclude that he hadn't 'had much contact' with pupils at that stage. While Thirlaway only stayed in the position for one full year and two part years, Day (1966) claims that Thirlaway 'successfully pioneered both teaching and research' in Australian universities. Doyle (1987) makes a further point in relation to the consequence of Thirlaway's appointment; that the spread of geophysics courses to other universities was gradual and 'mostly single appointments were made at first, (thus) restricting research possibilities'.

After Thirlaway's departure in 1951, lecturing in geophysics in the Department was continued by Hari Narain, who came from India in 1950 on a UNESCO Fellowship. At first, he was a Teaching Fellow (1952), then a Temporary Lecturer (1953–55), and finally Lecturer (1955–56). In 1955 Narain was awarded the first PhD in Geophysics in the Department (and possibly, therefore, in Australia)[5].

The *Guardian* obituary of Thirlaway (Davies, 2010) reports that he moved from Sydney 'to Pakistan to help UNESCO establish

[1]Edgar Booth was on the staff of the Physics Department from 1915–1937 where one of his interests was geophysics. The Extension Board provided courses to non-students of the University.

[2]Bullard, who was an 'early researcher on the dynamo theories of Earth's magnetic field' (Turner, 2010) became head of the Department in Cambridge in 1956 and Professor in 1964.

[3]Branagan (pers.comm.) noted that the Department had become overwhelmed from 1947 by the huge increase in student numbers due to ex-service men and women enrolling.

[4]Branagan (pers. comm.) suggested that this desire at this time would have most likely met with opposition from the Department of Applied Mathematics of the University, which conducted research in global geophysics under Professor Keith Bullen.

[5]Narain returned to India in 1956, where he later became Surveyor-General of India

a geophysical observatory in Quetta. He remained Head of the Observatory there until he moved to Blacknest'. Blacknest, in Berkshire, was where, from 1961 to 1982, he was head of a research group that was an offshoot of the British Atomic Weapons Research Establishment (AWRE) at nearby Aldermaston, 75 km west of London. The group's main function was to develop and maintain expertise in using seismic techniques to detect and identify underground explosions.

According to Davies (2010), this group was deliberately an unclassified research arm, separate from AWRE, which 'meant that [the purely scientific] work at Blacknest could be discussed openly with seismologists from around the world, including the Soviet Union'[6]. No doubt it was hoped this would engender similar openness from the Soviets, as it did on occasions.

Thirlaway was a rare seismologist in the group at a time when seismology was riding a wave of new-found use in enabling the detection of underground nuclear tests[7]. He had just published an article in *New Scientist* in May 1963 (Thirlaway, 1963) entitled, 'Earthquake or Explosion?', in which he was able to show different seismic characteristics between earthquakes and those of underground tests. In particular, he showed that the original idea of distinguishing explosions from earthquakes based on differences in direction of first motion was unreliable. His group developed a better way to improve signal quality using crossed seismic lines of both vertical and horizontal geophones, summing the signals to produce a combined trace of each line and then correlating both lines. The resulting 'correlograms' showed clearer differences between the two types of signal (see Figures 1 and 2 of Thirlaway, 1963). A copy of Thirlaway's *New Scientist* article is appended to this paper.

In 1972 Thirlaway was awarded the Gold Medal of the Royal Astronomical Society (RAS) for, firstly, his team's development of large seismic arrays able to act as tunable filters and, secondly, for initiating the recording of data directly onto magnetic tape[8].

The following highlights of Thirlaway's career at Blacknest were obtained from 'Geophysics in the Affairs of Mankind' by Lawyer et al. (2001), in which there are seven references to him over a 24-year period.

Thirlaway showed, by late 1963, that seismic signals in a zone 3000 to 9000 km from the source were less complex and distorted and, therefore, it was a better region in which to carry out analysis.

In April 1964, he represented Great Britain, in Paris, at a UNESCO organised; 'First Intergovernmental Meeting of Experts in Seismology and Earthquake Engineering', at which representatives of 33 countries participated including a Soviet delegation. Before this, in early September 1961, the Soviets had broken the test ban and this supposedly non-political conference may have been a means to discuss the matter scientifically. Later Thirlaway held a seat on a UN Disarmament Committee as a scientific expert representing Great Britain.

In 1984, Thirlaway was a keynote speaker at a USA Project review meeting in Santa Fe, New Mexico where he was described as 'one of the Western World's leading forensic seismologists'[9].

Finally, quoting from the Obituary again (Davies, 2010), 'Thirlaway's success can be attributed mostly to his ability to work effectively with ….his staff, university academics, and seismologists from abroad, as well as diplomats and politicians' (Davies, 2010).

Thirlaway died in 2009 at the age of 92, survived by his wife, Billie, and their two daughters.

Acknowledgements

I thank Dr David Branagan and Dr Alan Day for their generous time in sharing with me their irreplaceable memories.

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[6]David Davies, the author of the obituary in the *Guardian*, was a contemporary of Thirlaway.

[7]A partial test ban treaty in 1963 banned atmospheric testing but not underground testing. An agreement was not reached on the latter for a further 33 years.

[8]The gold medal of the RAS was awarded for achievement in astronomy or geophysics. Professor Bullard was also awarded one in 1965.

[9]Thirlaway had himself coined the term 'forensic seismology' in 1961 for its application in legal matters and especially in detecting test-ban treaty violations.

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Earthquake or explosion?

With his task of distinguishing between small earthquakes and nuclear test explosions, the new seismologist has to be far subtler than his predecessors. The rate of arrival of energy in the first minute after the initial shock, together with indications of the depth of the "event", provides clues for identifying its character

by Dr H. I. S. Thirlaway

UK Atomic Energy Authority, Blacknest

EARTHQUAKES and explosions are frequently in the news these days, and seismology is flourishing as never before. This situation has arisen from what at first seemed to be an easy problem: that of distinguishing man-made explosions from earthquakes for the detection of nuclear weapons tests. On closer examination, the problem proved to be difficult, because of the need to achieve 100 per cent success in identifying the few hundred earthquakes which may occur each year in the areas of interest. Research has been directed to (1) the refinement of instrumentation, (2) a search for new principles, and (3) the application of new processing techniques to well-known principles. The first and last of these approaches have been particularly rewarding, and this article outlines some of the progress by the United Kingdom Atomic Energy Authority in this field.

Earthquakes have been studied for many years by British seismologists. For example, John Milne in Tokyo invented a seismograph which formed the basis of the first network of seismographs organised by the British Association in 1896, and R. G. Oldham, in India, was the first to demonstrate that certain impulses on a seismogram were in fact the records of elastic waves travelling through the Earth. They were of two kinds: the compressional, or P, waves analogues to sound waves, in which the ground movement was of the push-pull variety; and the slower-travelling shear, or S, waves, analogous to the motion of a vibrating string in which ground movement was perpendicular to the direction of travel of the waves.

Up till now, however, the best experimental work by British seismologists has always been done while they have been located in seismic areas. In Britain itself there has never been any serious interest in experimental earthquake seismology because the dramatic effects of earthquakes do not occur here. Even the largest earthquakes in the British area, for instance the Dogger Bank earthquake of 1931 or the Midlands earthquake of 1957, have rarely caused injury. In the whole of the recorded history of earthquakes in the United Kingdom, only one person has been killed and only four injured. Compare this with, for example, the Quetta earthquake of May, 1935, which, within the space of a minute, killed 30 000 people, most of whom had to be left buried among the ruins for the whole of that summer and winter because of the impossibility of digging them out. The chaos was such that rebuilding did not start seriously until 1939, after major decisions had been taken about building designs for the new Quetta, and in fact about whether the town should be rebuilt at all. In 1960, when I last visited Quetta, it was still possible to see earthquake ruins, and to meet people whose entire families had perished on that fearful morning.

The impression I have of moderately sized earthquakes is one of almost continuous activity for several hours after the first major shock. Even the first frightening shake seems to be anything but a single impulse and in fact most earthquakes of this size are multiple events which can be easily identified instrumentally even at long range. The difficulty that arises when one tries to identify small earthquakes, of energy equivalent of a few kilotons of explosive, is partly that some of them are very simple shocks and partly that the subsequent activity is at a very low level.

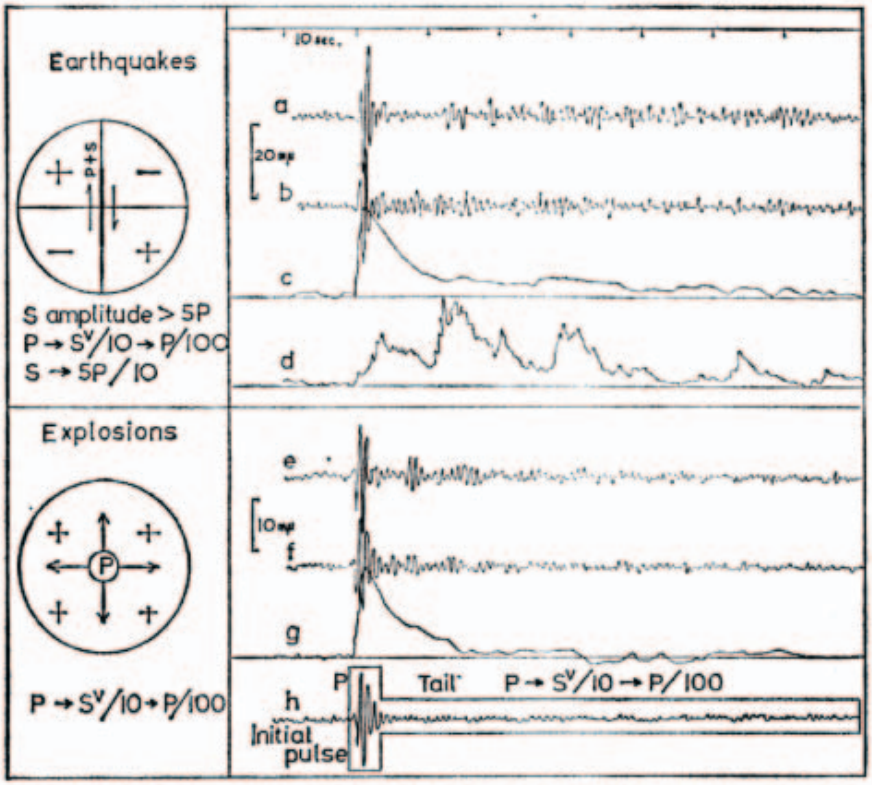
Detection.—The first problem in the new seismology, therefore, is to be able to detect small earthquakes. This was not a requirement in classical seismology, since large earthquakes, recorded by many hundreds of observatories using standard seismographs, provided all the data required for understanding the major internal structures of the Earth. However, at ranges between 5000 and 10 000 km, an earthquake with the energy of a few kilotons of explosive (the smallest disturbance in which we are interested) gives a ground displacement of not more than about 1 millimicron (the diameter of a 'flu virus is about 50 millimicrons) at a frequency of about 1 cycle per second. Small, random Earth disturbances, "Earth noise", of the same frequency has, in the quietest parts of Britain, an amplitude of about 10 millimicrons, so that the signal of a small, distant event recorded on a single seismometer would be overwhelmed by Earth noise. It is possible to reduce the effect of random noise by summing the signals from a number of seismometers. The improvement is proportional only to the square root of the number of instruments used, so that, in Britain, to record a millimicron signal with a signal-to-noise ratio of 3, about 1000 seismometers would be required even in the quietest parts.

Fortunately, most of this noise originates in the oceans and, as one moves inland from the coastal areas, it is rapidly attenuated. Locations in the hearts of continents with Earth noise amplitudes of 1 millimicron at 1 c/s are reasonably common, provided one goes well away from industry and traffic. In such places, 100 seismometers will give a maximum signal-to-noise ratio of 10 from the smallest events in which we have a practical interest.

Identification of earthquakes.—One of the first methods suggested for distinguishing earthquakes from explosions was to note the initial direction of movement detected by the seismograph. The scheme shown in the upper circle on the left-hand side of Figure 1 is based on the observation that the overwhelming majority of earthquakes are generated by shearing blocks of rock: that action will compress the rocks in some directions while expanding them in others. Thus some recording stations will show an initial ground motion away from the origin of the earthquake (+) and others will display one towards the origin (−). Explosions, on the other hand, produce compressions in all directions and positive first motions at all stations (lower circle, Figure 1).

Unfortunately, the first motion is the smallest signal in the seismogram, and nothing that anyone has been able to do instrumentally has improved the situation

Earthquake or explosion? *continued*



a. *Conventional record of the P waves from a simple earthquake combined from one line of seismometers*

b. *Conventional record from the same earthquake combined from the other line of seismometers*

c. *Smoothed curve obtained by correlating the two lines of seismometers*

d. *Smoothed curve for a typical complex earthquake*

e. *Record of an explosion, combined from one line of seismometers*

f. *Record of the same explosion, combined from the other line*

g. *Smoothed curve obtained by correlating the two lines of seismometers*

h. *Idealised seismogram of explosion deduced from g; the random signals in the tail have been eliminated*

FIGURE 1. *How earthquakes and explosions may be distinguished. An early idea was to exploit the difference indicated in the two circles at the left, that at some stations the very first motion detected from an earthquake is a "pull" (−), while from an explosion all stations will record an initial "push" (+). However, as the traces* a, b, e *and* f *show, the initial movement is weak, which makes the method unreliable. A better method uses crossed arrays of seismometers to obtain smoothed, correlated curves* c *and* g. *The initial pulse of the earthquake is followed by a relatively strong "tail" (of P waves generated from S waves near the site of the earthquake) while in the record from an explosion, which does not in principle produce S waves, the tail is missing or very weak.*
Note: The untransformed S waves do not appear on these initial records because they travel more slowly.

during the last three years. The size of this first motion relative to the rest of the signal is well illustrated for both an earthquake and an explosion in Figure 1. So, even if one is on a "1-millimicron" site with 100 seismometers, the first motion of a small event will be barely distinguishable from Earth noise. One cannot be really certain about the direction of motion until it is three or four times greater than the background noise; therefore, in practice, only earthquakes of moderate size, equivalent to a few tens of kilotons of explosive or more, can be identified with certainty by this technique.

Another idea is to make use of the ratio of "transformed" seismic waves. If a compressional (P) wave strikes a rock boundary at an angle, part of its energy is transformed into an S wave (with vertical motion) designated S^V. Conversely S waves may be transformed to P. In 1899, C. G. Knott showed that the energy ratio (and therefore the relative amplitudes) of these transformations can be calculated. It turns out that, at the small angles of incidence observed at ranges greater than

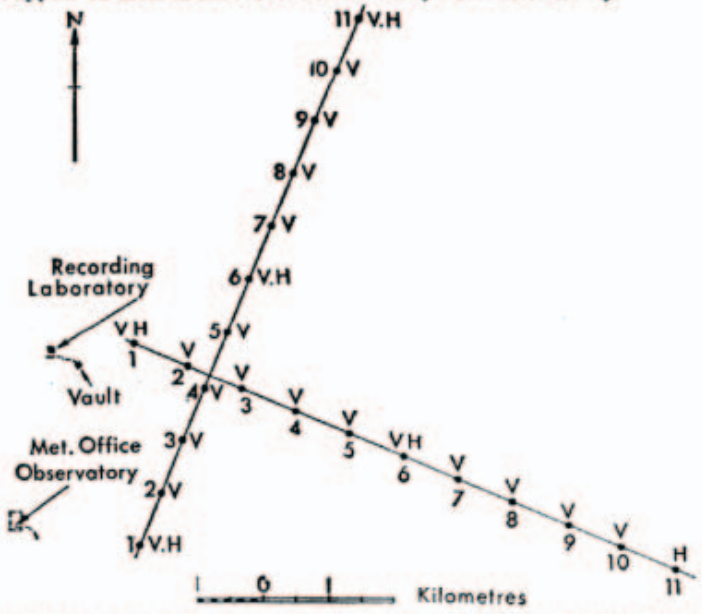


FIGURE 2. *Layout of the cross array of seismometers at Eskdalemuir. Both lines contain instruments, V and H, that record vertical and horizontal displacements of the Earth's crust. The vault is for a long-period seismometer.*

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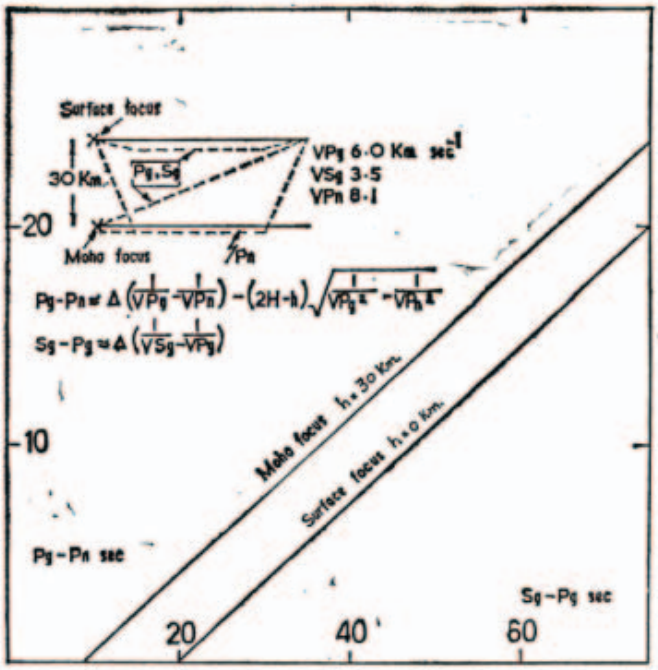

FIGURE 3. *The method of estimating the depth (h) of an "event" within the Earth's crust using the delay in the arrival of the P waves which travel via the "Moho"—the boundary between the crust and the underlying mantle. The equations relate observed time differences to observed velocities (VP_g, etc.) to the depth to the Moho (M), focal depth (h) and range (Δ). P_g and S_g stand for the P and S waves that travel by direct route from the event to the detector.*

5000 km, the amplitude of the transformed waves are only one or two tenths of those of the incident waves. Transformations of the type P→S^v→P from explosions and earthquakes are therefore not likely to be recorded at long range above the ambient noise level. However, earthquakes *generate* S^v waves which are observed, at close range, to be five to ten times the amplitude of the initial P wave. Transformations of the type S→P should therefore be recorded at long range and, if suitable rock boundaries are present to a depth of 250 km below the event, the P signals resulting from the S^v→P transformations should arrive at the recording station for at least a minute after the initial pulse. No S signals will be recorded in this time interval since the velocity of S waves is little more than half that of P waves.

Explosions, on the other hand, do not in principle generate S energy, and records of explosions at short range generally show that the S^v energy (which must be due to transformation of P energy at rock boundaries near the source) is only two or three times that of the energy in the P group. This hypothesis therefore suggests a possible discrimination technique based on the analysis of the first minute or so of the seismogram of a long-range event. It can be summarised as follows:

1. P→S^v→P transformations occur in both earthquakes and explosions but the resulting P waves are very weak at long range.

2. S→P transformations occur with earthquakes and the resulting "tail" of transformed P waves should be a considerable fraction of the initial P.

Unfortunately, when conventional long-range ("teleseismic") seismograms of explosions and earthquakes were examined the signal amplitudes following the initial impulse proved to be similar, as a comparison of Figure 1a with Figure 1e will show. Last year, however, we recorded two fairly large underground explosions on a cross array of seismometers similar to that at Eskdalemuir (Figure 2). The arrangement is similar to that described by Mr I. Maddock in the *Journal* of the British Institute of Radio Engineers (June, 1962, pp. 415-427) in which the linear dimensions are comparable with the longest wavelength of the signals of interest—about 25 km for P signals recorded at 10 000 km range. This type of array, with its associated analysis system, enables us to sum and cross-correlate the recorded signals.

Figures 1a and 1b, for example, are conventional seismograms of a teleseismic earthquake after the two lines of seismometers have been separately phased and summed. Figures 1e and 1f are the equivalent seismograms of one of the explosions of similar magnitude recorded at a similar range. In Figures 1c and 1g are the smoothed curves obtained after point-by-point multiplication of the pairs of traces from the seismometers. These curves show the variation in the rate of arrival of correlated energy.

It is at once apparent that, although the

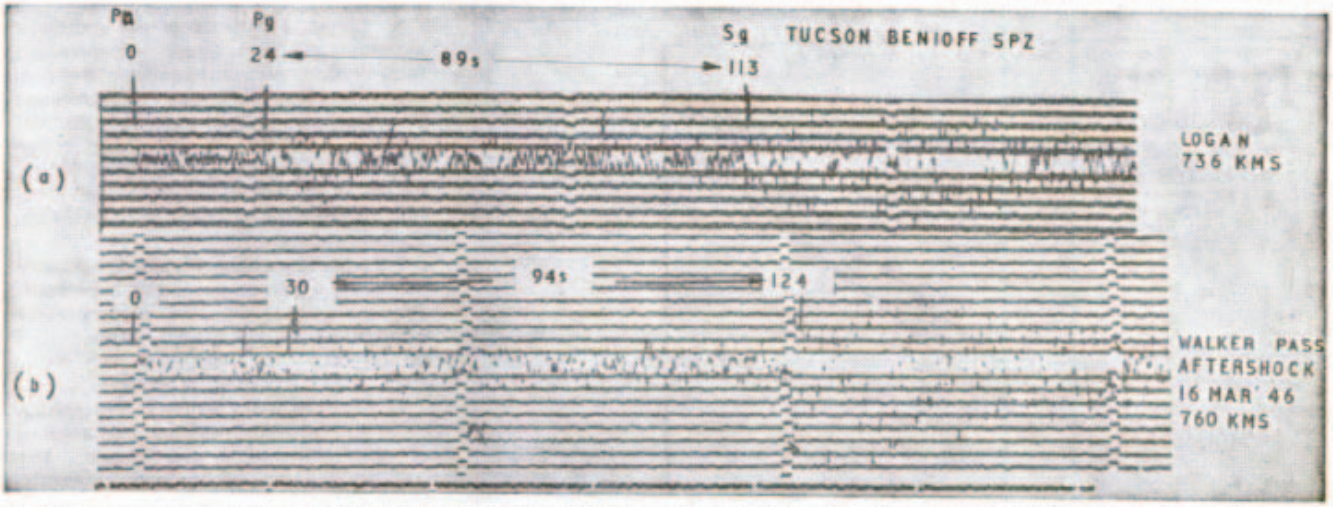

FIGURE 4. *An example of the use of P_n delay time showing that the earthquake* (b) *occurred at a greater depth than the explosion (Logan,* a*). Compare the complexity of these short-range records with the relatively simple long-range records in Figure 1.*

Earthquake or explosion? *continued*

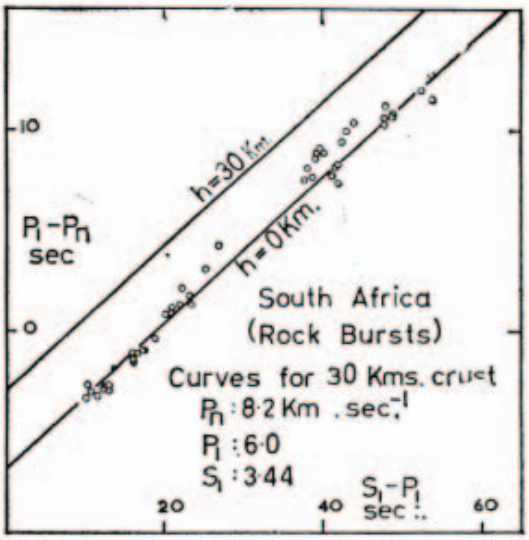

FIGURE 5. *Readings from seismograms of mine rock-bursts. After Hales and Willmore.*

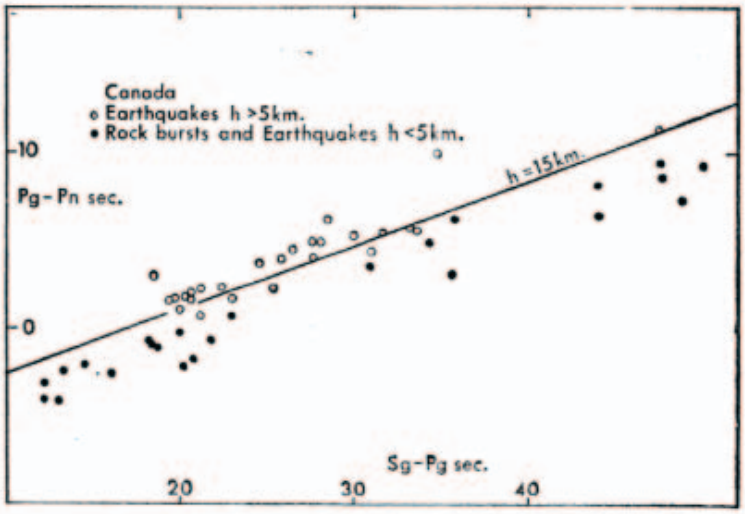

FIGURE 6. *Readings from Canadian records. After Brune and Hodgson.*

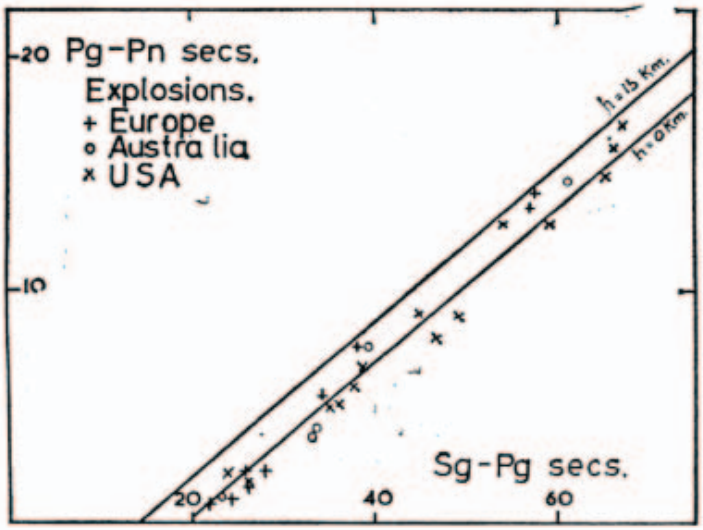

FIGURE 7. *Readings from records of chemical and nuclear explosions.*

initial pulses are indistinguishable, the subsequent rate of arrival of energy is higher in the case of the earthquake—as predicted by the hypothesis. This must mean that the earthquake signals are more strongly correlated across the array. Figure 1h is an *idealised* seismogram of an explosion based on the correlator output 1g. I think that the *observed* signals in the tails of explosion seismograms are generated by random transformation and scattering of the initial pulse as it enters the complex structures in the Earth's crust underlying the recording station. These signals would be poorly correlated across a large array. They may be analogous to shock-generated noise identified by oil prospecting seismologists who have used linear arrays for many years. Records of random signals from both explosions and earthquakes are "cleaned" by the correlation process to leave only signals which originated near the source.

The hypothesis predicts that the rate of arrival of energy in the tail will decrease with time since the number of $S^v \rightarrow P$ transformations will decrease as the signal travels by longer paths through deeper and more homogeneous regions of the Earth's mantle. This effect can be observed in Figures 1c and 1g. By the same token, it predicts that, as the depth of the event increases, so the rate of arrival of energy will decrease because the environment of the source becomes more homogeneous. This effect has also been observed experimentally using linear array processing techniques.

The results to date are clearly interesting enough to follow up in more experimental and theoretical detail. At the moment only two distant explosions have been recorded in the form required for processing by the technique described, and, though these were fired in two different continents, we have enough experience of the enormous variability of seismic signals to be prepared for a third to upset the hypothesis. Furthermore, the events illustrated in Figure 1 are of magnitude greater than the smallest events of interest. It will therefore be appreciated from a study of Figure 1c that the amplitudes of transformed signals from small events will be equal to or less than the ambient noise.

Further research on this idea is evidently necessary, firstly to prove the hypothesis, and secondly to improve the signal-to-noise ratio in the detection system, before the technique can be applied with confidence to the identification problem.

Fortunately, it is possible to concentrate effort on that fraction of the total number of earthquakes which are "simple". The majority are more or less complex events. Figure 1d, for example, is the smoothed, correlated curve for a typical earthquake which occurred in the same general area

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as that represented by 1c. I think event 1d is a series of four "aftershocks" which follow so closely on the first onset that the conventional seismogram (not illustrated) has the appearance of a single event with related but unidentified phases. The aftershock hypothesis fits in with the subjective impression of people experiencing an earthquake and with commonsense thinking on the way a fault must move in an environment as complex as that of the Earth's crust.

Depth of events.—Sometimes the initial P wave of an earthquake at long range is complicated by a signal (pP) which is reflected at the Earth's surface near its site before being propagated to the recording station. Deeply buried explosions will give a double pulse effect for the same reason. When such a signal is seen, the time delay relative to the onset is a sensitive measure of depth at long range. As the depth of the earthquake increases, the surface reflected signal arrives progressively later than the initial signal until two well defined signals are seen on the seismogram. Correlation of two groups of seismometers separates this signal from unwanted signal and noise with great clarity. I am sure, however, that the depth indicator pP is often confused with a pulse generated by aftershocks.

This technique begins to break down when the depth of the event is less than 30-40 kilometres as the surface reflection, pP, follows so closely on P that the two signals may be confused.

At ranges of a few hundred kilometres, another depth indicator for events occurring within the Earth's crust (which is 25-50 km thick) is the delay of the P signal (P_n) refracted by the Mohorovicic discontinuity ("Moho") where the crust meets the underlying mantle, relative to the direct P signal (P_g). If the direct S signal (S_g) can also be identified, the depth of the event is determined by a single station. The principle is illustrated in Figure 3, which shows the paths of the signals concerned both for a surface event and for one at the base of the crust. For the surface event, P_n takes some 4 seconds longer than for an event at the "Moho" to reach the recording station. At ranges greater than 150 km, the P_g and S_g travel times are, within the required accuracy, independent of depth, but with increasing depth P_n will arrive earlier relative to P_g.

The two seismograms in Figure 4 demonstrate this effect for an explosion and an earthquake. This figure also serves to show the inherent difficulty in identifying the required signal components when confused by other signals. The principle has been recognised for some 40 years but it has never been seriously used by seismologists for depth studies because of this problem.

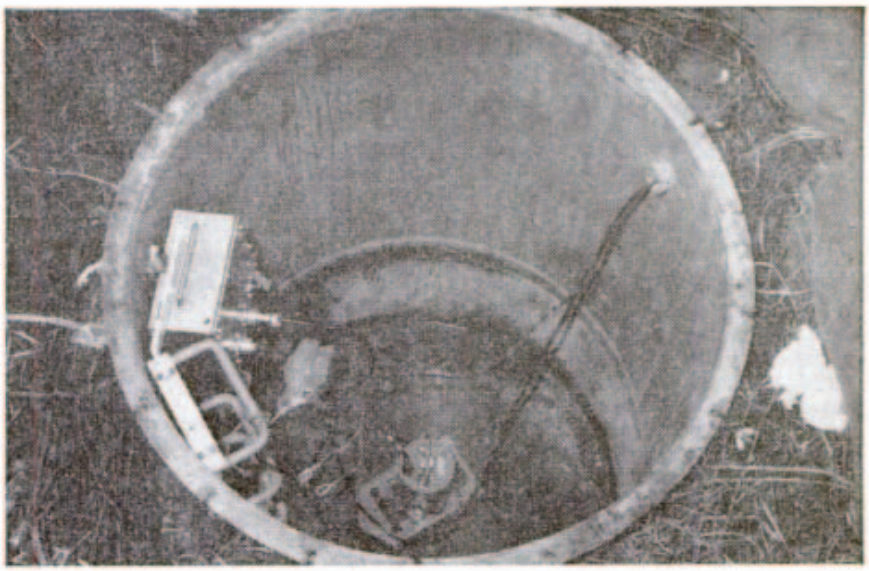

FIGURE 8. *An instrument pit at Eskdalemuir, showing seismometer and preamplifier.*

The use of a linear seismometer array, however, enables us to pick out and enhance a selected component of the signal.

Figures 5, 6 and 7 show some results of depth studies in several continents using conventional seismograms. The range in kilometres can be roughly estimated by multiplying S_g—P_g by 8. As might be expected, the best results to date are from continental shields where the crust is, seismologically speaking, a good deal simpler than mountainous areas. It is also interesting that the most consistent results are those of the South African rock bursts in Figure 5, where the measurements were made with nine seismometers in groups of three, each group being separated by some 400 metres. It was therefore possible to select the signals more certainly by eye. The signals for Figures 5 and 6 were picked by independent observers; those in Figure 5 designated P_i and S_i by Hales and Willmore are evidently equivalent to P_g and S_g.

Allowing for observational uncertainties we could confidently identify all events below 15 km as earthquakes in these regions. In mountainous areas, where the crust is more complex, detailed knowledge of the area would be necessary before the method could be reliably applied.

Future of arrays in general seismology.—A new way of studying earthquakes has thus been created by a group of UK Atomic Energy Authority scientists and engineers who, only two years ago, were complete strangers to seismology. During the course of the next year they plan to publish the theory and practice of their systems and processing techniques.

It is already evident from the results arising from this research that the new methods of recording and processing will have a wide application in the whole field of seismology. Using reflected and refracted body waves it looks as though a few arrays around the world could throw light on, for example, the energy and numbers of earthquakes, the nature of the Earth's inner core, the detailed structure of the Earth's crust and upper mantle, and the distribution of earthquakes in depth. They will be able to select the relatively small number of larger, single shock earthquakes which are worth detailed study using the existing network of conventional seismographs. Arrays set up in the earthquake zones themselves could record, in a form capable of precise analysis, the large number of very small, near shocks which must be carefully located before useful seismo-tectonic maps can be drawn —these are base maps for civil engineering development in such regions. Had such maps been available at the time, the first Quetta garrison would either have been built some 25 miles north of the present town, or would have used reinforced construction on more consolidated ground.

At present there are five seismological arrays in the USA, one in Canada and one in Britain. They were built to seek the scientific data required to further the conclusion of a treaty to end nuclear weapon testing. Whatever happens politically in the future, the seismological results are promising enough to warrant a special effort to make sure that the arrays are maintained by interested research groups for many years to come.

End of the Flat Earth: a new era at GSWA

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The Geological Survey of Western Australia (GSWA) has entered the 3D era with the release, in December 2015, of the first three dimensional (3D) digital geological models in a new line of digital products called '3D Geomodel Series'. In such a large state as Western Australia these two models are just a taste of what is to come. The actual 3D models are part of a complete package replete with a full suite of GIS data, such as is included on other two-dimensional GSWA digital packages. The new addition is a 3D geological model, which can be viewed in the included free visualisation software, Geoscience Analyst, provided by Mira Geoscience. Alternatively, the models are also provided in widely used file formats for import into the users' own 3D modelling software.

The aim of the publication of 3D geological models is to better represent the growing amount of structural information at depth, which has been derived from recent seismic and magnetotelluric surveys and modelled from potential field data at increasing resolution. By releasing models that include structure at depth GSWA hopes to promote a better understanding of the Earth's structure, and to develop an improved knowledge base to underpin exploration for mineral and energy resources in Western Australia.

Faults, fracture zones and shear zones can be pathways for fluids and melts within the solid Earth. The Earth's 3D structure, therefore, not only reflects the distribution of physical properties of the rock mass in bedrock, sedimentary basins and regolith cover, but often relates very closely to the spatial distribution of the mineral deposits and energy resources that formed as a consequence of fluid flow in Earth's crust. 3D structural modelling and numerical simulation of geological processes are emerging techniques that can be used to extend knowledge from exposed and well-understood areas to inaccessible or data-poor parts of the Earth's crust and lithosphere, and to test the validity of conceptual models and interpretations.

The construction of the 3D models utilized the full spectrum of the extensive geological mapping and geophysical (magnetic, gravity, deep seismic reflection) data acquired by GSWA as part of the Exploration Incentive Scheme (EIS), a State Government initiative that aims to encourage exploration in Western Australia for the long-term sustainability for the State's resource sector.

Since its inception in 2008, EIS funding has enabled GSWA to undertake state-wide high resolution regional aerial magnetic surveys at 400 m standard line spacing. This data, together with open source data of higher resolution, means that the state magnetic image is now gridded at 80 m spacing. Gravity surveying has progressed at 2.5 km spacing across as much of the State as has been made accessible, with additional high resolution gravity and magnetotelluric surveys in areas of special interest. This include transects sampled by deep reflection seismic surveys which, as part of the EIS scheme, have been targeting areas where the deep structural architecture is of particular interest.

The stimulus for both of the recently released models was the acquisition of the deep crustal reflection Youanmi seismic lines (Wyche et al., 2014) across the northern Yilgarn Craton. The interpretation of those lines provided the first insight into the structural architecture at depth in this area and showed the two-layer nature of the Yilgarn Craton. The Archean greenstones and igneous complexes sit in granite surrounds. The shape of each layer is determined by a network of trans-crustal faults, some of which define domain boundaries. The faults are also potential pathways for ore-bearing fluids.

The areas covered by the two models are within the Windimurra Igneous Complex and the Sandstone greenstone belt (Figure 1). These regions, which are located in the northern Yilgarn Craton, host deposits of gold and vanadium. The models support exploration and enhance the possibility that more gold, platinum group elements, nickel, and copper will be discovered.

Windimurra model

The Windimurra model is located where the three Youanmi seismic lines intersect. The region hosts the largest relatively

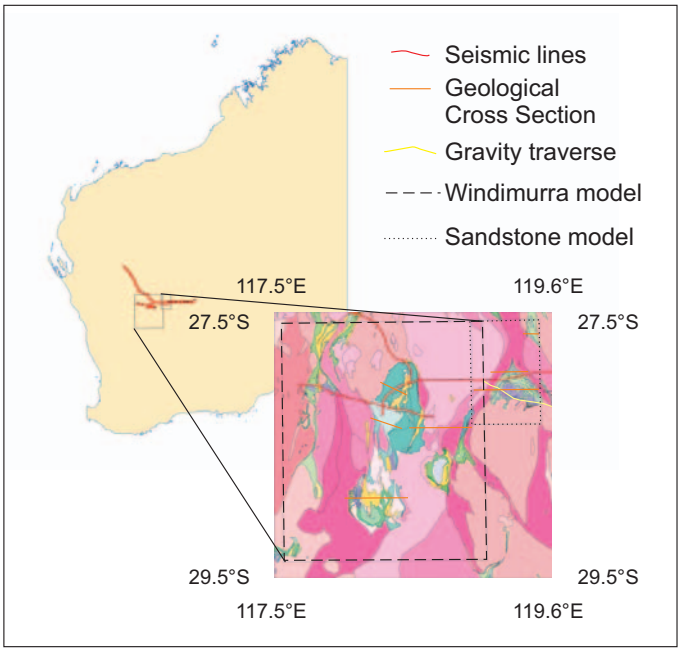

Figure 1. *Location of the 3D model areas and the deep reflection seismic lines on which the models are based.*

intact and exposed mafic and ultramafic intrusive complex in Australia; the Windimurra Igneous Complex. The Complex has a surface expression of about 2500 m^2; approximately 85 km north-south and 37 km east-west. It is widely believed that the intrusions are the result of a mantle plume affecting a significant area of the Yilgarn Craton (Ivanic et al., 2010; Wyche et al., 2012; Wyman and Kerrich, 2012; Van Kranendonk et al., 2013). The intrusions host significant V–Ti mineralization in the Fe-rich upper zones. The exposed Complex has an overall felsic composition compared to other layered gabbro intrusions worldwide, and has been described as a having an anorthositic affinity (Ahmat and De Laeter, 1982) and a high Ca-Fe tholeiitic composition (Ahmat, 1986). However, it is possible that its composition is more typically tholeiitic (c.f. Nebel et al., 2013) if it can be shown that a large volume of ultramafic zone material exists at depth.

The seismic images show that the Windimurra Igneous Complex is a shallow, funnel shaped cone with a lower zone of strongly layered reflectors. The upper and middle zones are less reflective, but still layered, and all follow the overall form of the Complex. The lower zone is about 6.9 km thick and the upper zones are about 3 km thick, giving a total thickness of about 10 km (Figure 2).

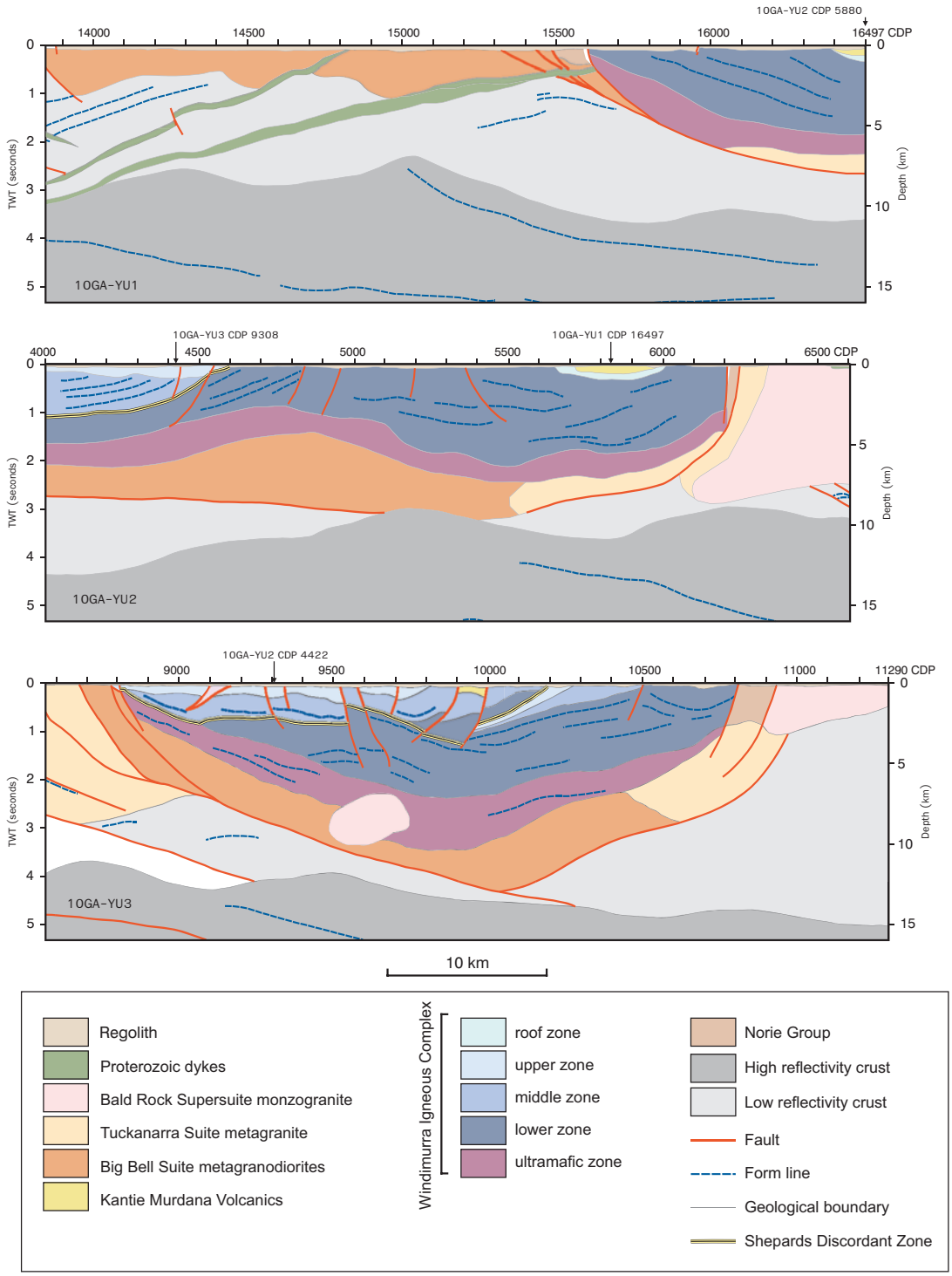

Figure 2. *Seismic interpretations from the Youanmi seismic lines, which were the framework for starting the Windimurra model (Ivanic et al., 2015).*

Using the seismic interpretations a 3D volume of the area was generated (Ivanic and Brett, 2015) and then populated by generic densities for the given rock types. Early models, before the bounding faults were added, showed that the original complex was potentially twice the present size. Forward models were run and the geometries of the layers away from the seismic lines were adjusted to give a better fit to the observed gravity data. This resulted in simple geometries with curvatures across the body that fitted the seismic images. Inversions were then run using this starting model. This showed that lower density rocks were required below the complex, rather than thick ultramafic rocks. This was reconciled with the seismic interpretation in that granitic sills parallel to the layering would also produce the layered seismic character of this area (Ivanic and Brett, 2015). Other results from the inversions showed that the densities or volumes of the upper and middle zones should be reduced, but since the initial densities were only estimates they could easily have been overestimated. For example, as the ultramafic zone has not been directly sampled it may contain significant proportions of pyroxenite or gabbroic rocks thereby reducing the average density. Likewise the density of the upper zone was estimated from drillhole data that sampled mainly the magnetite-rich part of the zone.

Overall, the model (Figure 3) and structural reconstructions established that the igneous complex is at least 10.5 km thick, making it one of the largest known on Earth. The model also revealed that a 3 km thick ultramafic unit underlies the whole complex making the overall composition closer to the usual tholeiitic/komatiitic basalt composition and thus a potential target for Ni–Cr–PGE mineralisation.

Sandstone model

The Sandstone model focuses on the Sandstone greenstone belt, which hosts a number of gold deposits and is being explored for nickel deposits. The model building started as a training exercise but became the blue-print for the production of small, localised models and the development of a full package for production purposes (Murdie et al., 2015).

The Sandstone greenstone belt is a refolded syncline located east of the Windimurra Igneous Complex. The belt was also sampled by the 10GA-YU2 seismic line and had been mapped at 1:100 000 scale in 2003 (Chen, 2003; Chen and Painter, 2005). The margin of the greenstone belt was defined by two major faults; the Youanmi Shear Zone on the west, dipping to the east, and the Edale Shear Zone on the east, dipping to the west. The Youanmi Shear Zone is the boundary between the Murchison and Southern Cross Domains of the Youanmi Terrane of the Yilgarn Craton. In the seismic data it is apparent that the Youanmi Shear Zone is the more recent fault, truncating the Edale Shear Zone and continuing to the Moho.

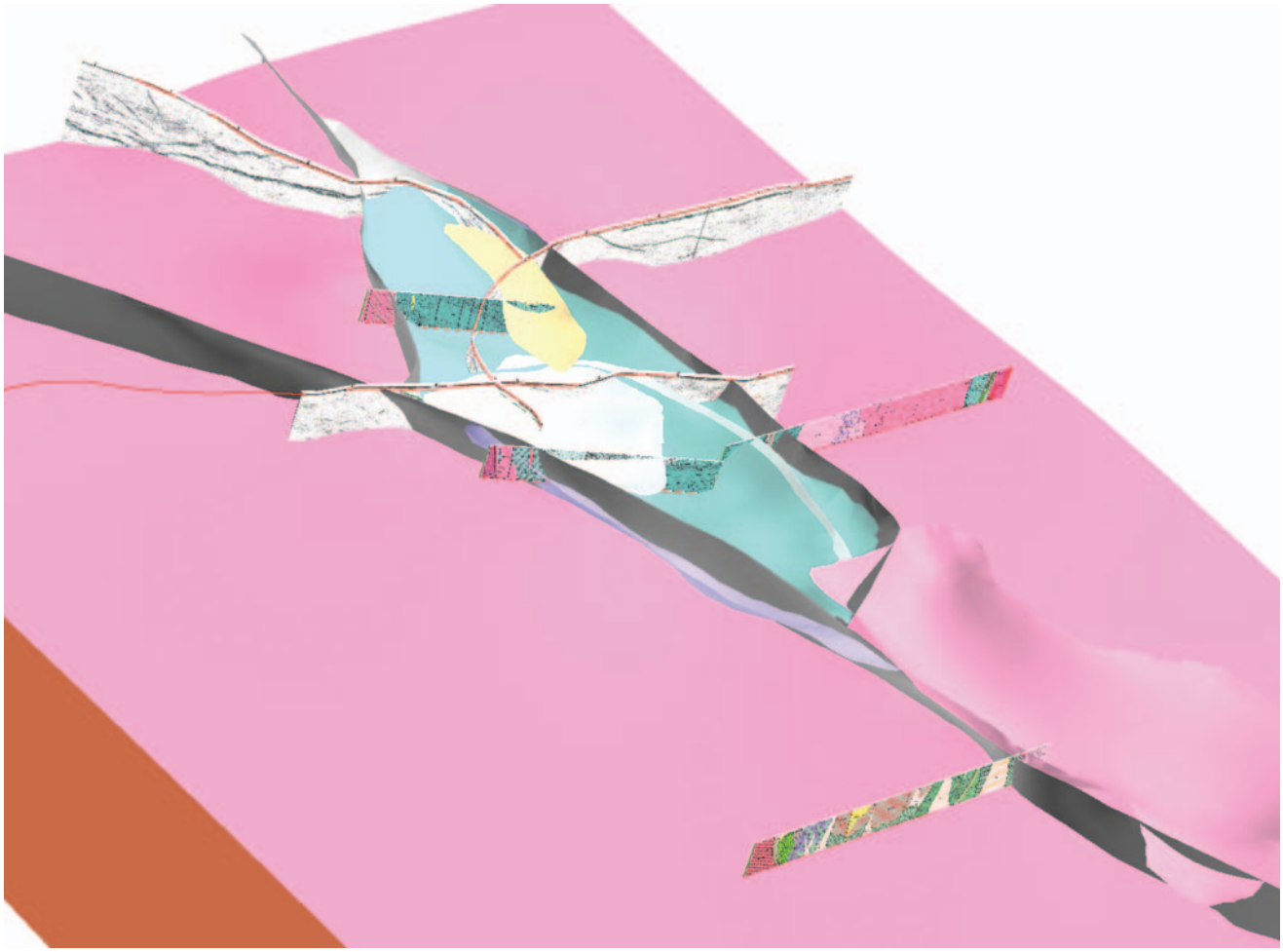

Figure 3. *A screen shot of model surfaces from the Windmurra model. These are shown in the same colour as would be found on the State geological map sheets. Grey surfaces show the geological faults in the model. Also shown are the geological sections from the 1:100 000 map series and the seismic interpretations, all correctly located.*

The first aim of the model was to establish the thickness of the greenstone belt. A 1 km spaced gravity traverse had been made over the western limb and the southern extent of the belt and it was estimated that the greenstone was about 4 km thick (Figure 4a) (Chen, 2005). The interpreted cross section provided with the 1:100 000 Atley map indicated that the author felt that the bottom of the greenstone belt was relatively flat, with an undulating surface generated by an intrusive/faulted contact with the underlying granite (Figure 4b).

The seismic interpretation, however, had indicated that the greenstone belt had a 'V' shape with a typical keel (Figure 4c) (Zibra et al., 2014). Forward models could replicate both theories, depending on the parameters used. A basin inversion

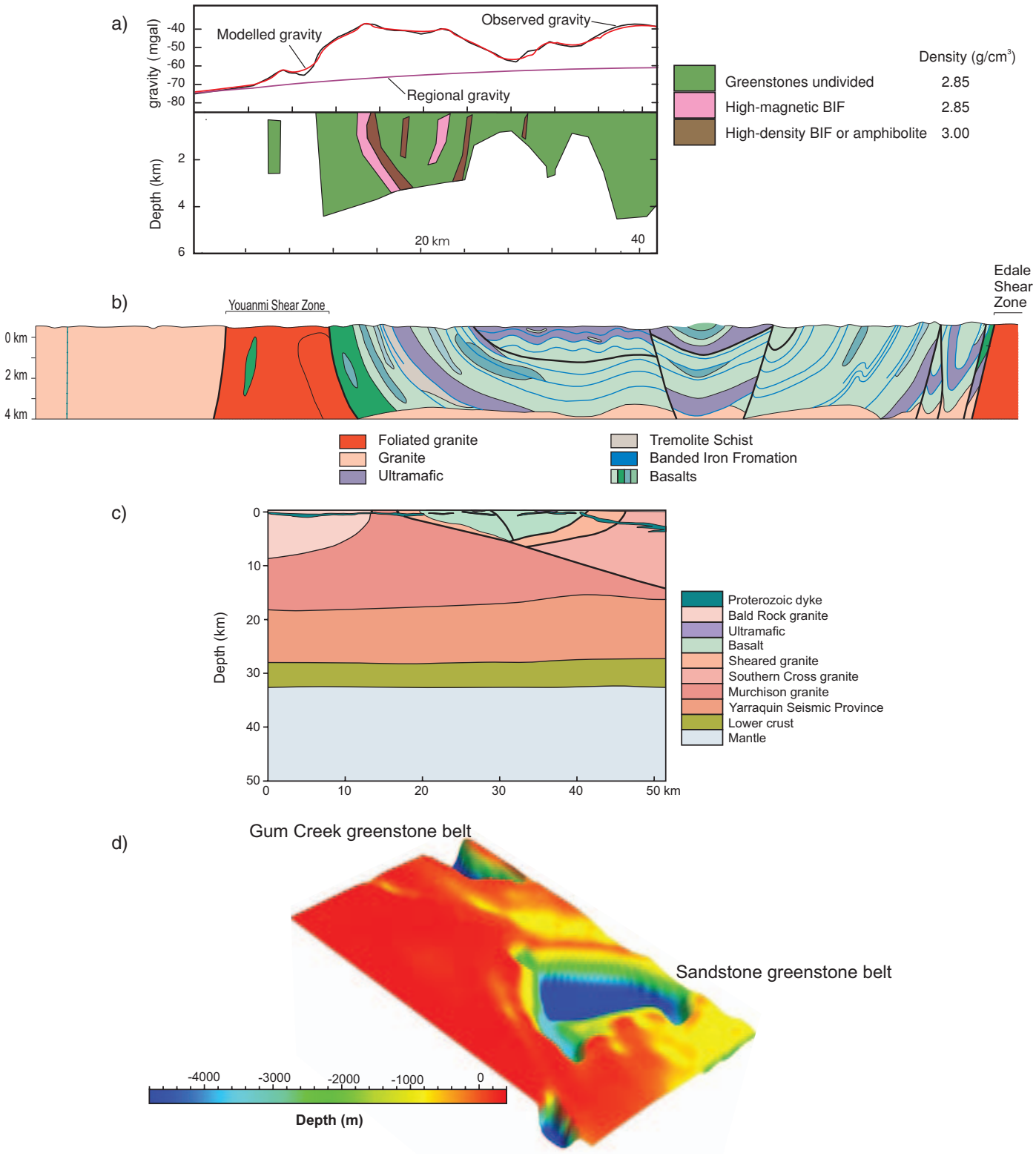

Figure 4. *Estimated depth of the Sandstone greenstone belt. (a) gravity model of Shevchenko from Chen (2005), (b) cross section of the 1:100 000 Atley map by Chen (2003). This section lies along the widest part of the greenstone, (c) interpretation from the seismic reflection survey (Zibra et al., 2014), (d) basement inversion of the whole greenstone belt (Murdie et al., 2015).*

routine was used in the reverse sense i.e. a dense body in a less dense surround, to find the depth of the dense body (Figure 4d). This gave a thickness to the western limb of 3.8 km and a maximum thickness to the eastern limb of 6.5 km.

The 3D modelling showed that the greenstone belt was more likely to be irregularly shaped; influenced by the refolding of the syncline and intrusion by the younger granite (Figure 5). The seismic section was probably showing the whole package of greenstones and associated bounding shear zones in a wedge between the Youanmi and Edale Shear Zones.

As the gravity spacing was not close enough to resolve the individual units within the greenstone, and the units themselves not of sufficient density contrast, modelling of the internal structure was based on the magnetic data. The greenstone contains several units that include coherent layers of banded iron-formations, which have a very strong magnetic signal and trace the folding in the greenstone. Inversions of a basic initial model showed the structure associated with the highly magnetic zones. A continuous band around the north was delineated and this band was repeated on the southern edge, supporting the interpretation of the initial structure as a syncline that had been subsequently been deformed by north-south folding. Scattered areas in the centre showed less coherent banded iron- formations in the upper layers.

Accessing the models

The 3D modelling of both the Windimurra Igneous Complex and the Sandstone greenstone belt was carried out using Geomodeller software as the implicit code was easy to use and the models could be rebuilt as ideas were being generated.

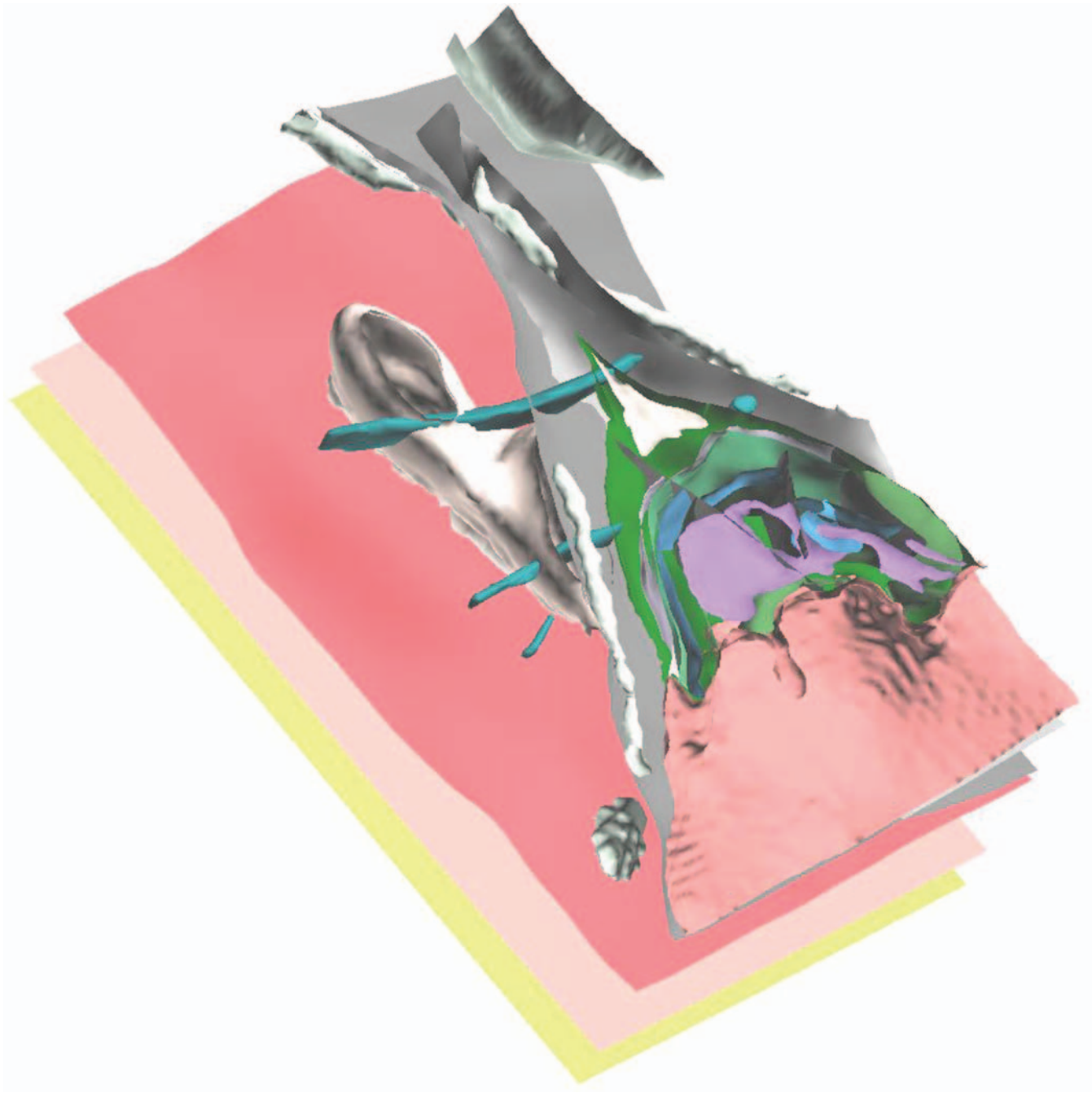

Figure 5. *A screen shot of the Sandstone Greenstone Belt model surfaces within Geoscience Analyst.*

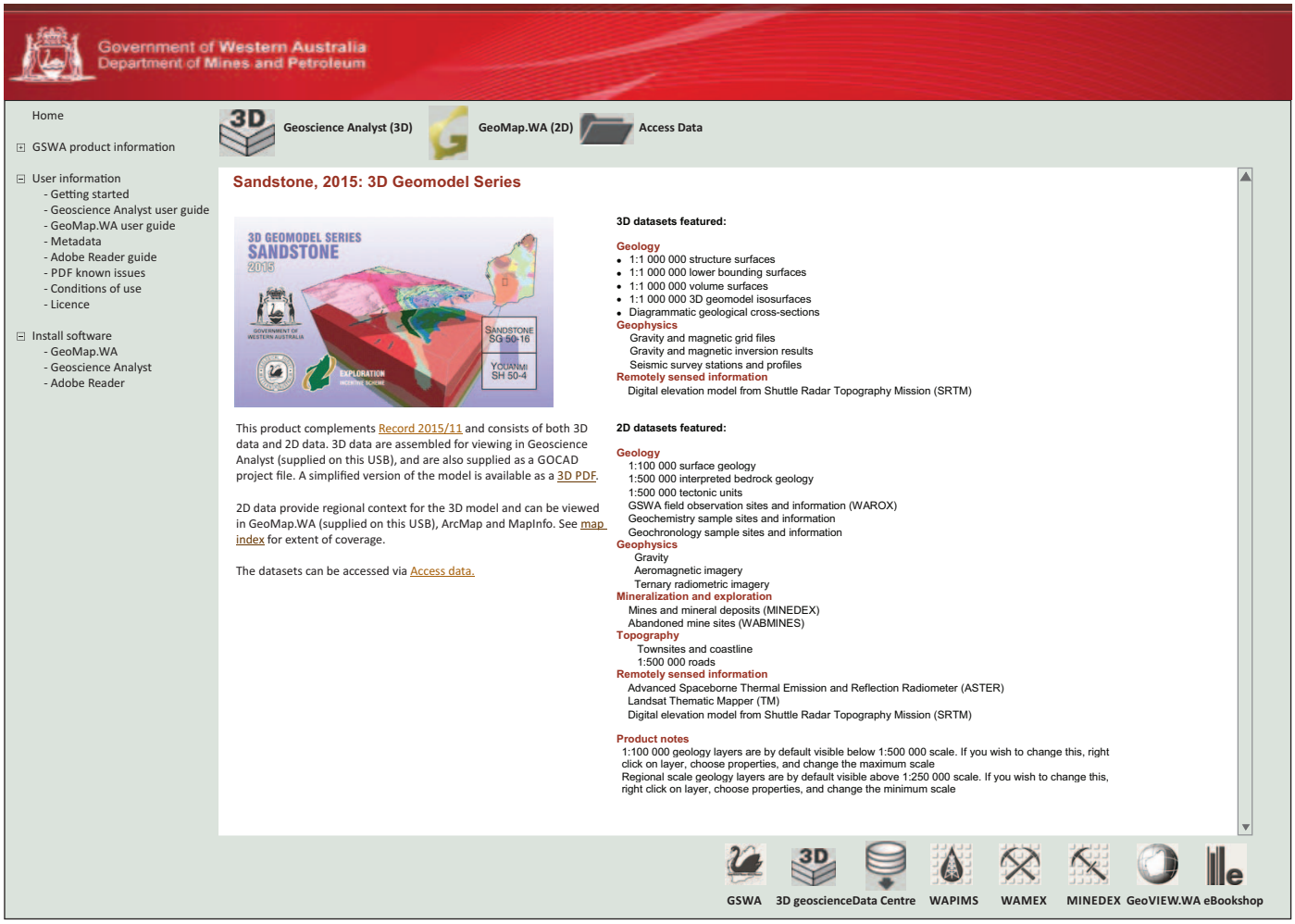

Figure 6. *The html start page of the Sandstone 3D Geomodel package with all the links to all the data and software clearly visible.*

Some inversions were run within Geomodeller and others were run using VPmg code once the model had been taken into GOCAD.

The final models were produced in GOCAD and exported to Mira Geoscience's free visualisation software, Geoscience Analyst. Geoscience Analyst is an easy to use package that reads in almost all the components of a GOCAD project with no loss of quality in the objects, as is the case with other visualisation options such as 3D PDF. Geoscience Analyst also allows the user to import, visualise, annotate, save and distribute the various objects within a model, and has the capacity to include links to external documents. There is quick interrogation of data values, attributes and histograms via dynamic links between 3D views and data tables. The software is able to import ASCII, ESRI, Geo-referenced images, Geosoft and GOCAD Mining Suite files/objects.

For some years, GSWA has been producing 2D digital packages that provide a whole suite of information on a particular area including geology, geophysical data, remote sensing, tenement and title information. The 3D product was simply linked into this platform. All data is supplied on a USB stick. A html start page (Figure 6) has all the links to the 2D and 3D packages as well as links to download the software. All reference material and any help documents are also included.

Future projects include a 3D fault model of the northern Yilgarn Craton and a 3D model of the Capricorn Orogen. The ultimate goal is a state-wide 3D model portfolio.

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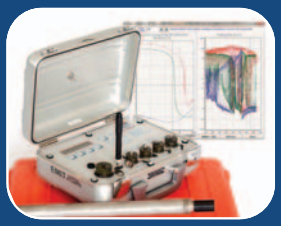

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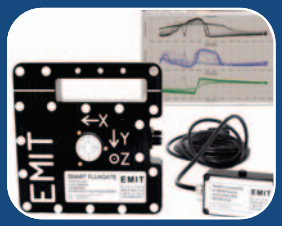

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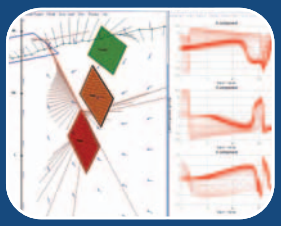

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