Australian Society of Exploration Geophysicists

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PREVIEW

PREVIEW

ADVERTISERS INDEX

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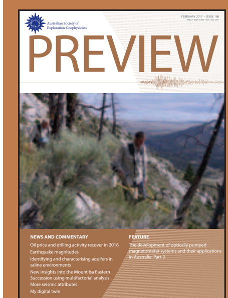
FRONT COVER



The quad-sensor application of the TM-4 magnetometer. The development of this system is described by John Stanley in his article in this issue of *Preview*.

Preview is available online at
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Editor's desk

This issue of *Preview* features the second part of John Stanley's fascinating account of the development of optically pumped magnetometer systems in Australia, and their application throughout the world. In this part John describes diversification in the applications of optically pumped magnetometers and the development of SAM and SAMSON.

We only have room for one feature in this issue because the Associate Editors have pulled out all stops for the New Year. Three of their columns could be considered mini-features! You will be able to read and enjoy a consideration of earthquake magnitudes (*Education matters*), the identification and characterisation of aquifers in saline environments (*Environmental geophysics*), and the value of integrating the interpretation of structural, geochemical and petrophysical analyses to gain new insights into the Mount Isa Eastern Succession (*Mineral geophysics*). David Denham has also sent in a comprehensive report from Canberra (*Canberra observed*) and allows us to hope that the writing is on the wall for a recovery in the oil industry. Mick Micenko and Guy Holmes, for their part, continue to titillate our imaginations with their respective columns on seismic attributes and digital twins!

Turning to rather more serious matters, readers may not be aware that the five-year contract between the ASEG and CSIRO Publishing for the production of *Preview* and *Exploration Geophysics* expires at the end of this calendar year (*Exploration Geophysics* Volume 48 and *Preview* Issue 191). The end of this contract could be the end of an era as I understand that, over the next 6 months, the ASEG Federal Executive will be considering whether one or both publications should continue in their current form (or migrate to another form), and whether one or both publications should continue to be produced by the same publisher or move to a different publisher/service provider. Particular consideration will be given to whether both publications should move to a digital format, and a flipbook format (for ease of use on a smart phone or tablets) is one of the formats being considered.

If you would like to find out what is on the table, and to add your views to the discussion – as a reader, contributor or advertiser – please contact one of the joint Chairs of the Publication Committee, Greg Street or Lisa Vella, at publications@aseg.org.au. Your views are important because neither publication, in any form, will survive without you!

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

Breaking news: Swarm suggests accelerating jet stream in the Earth's liquid outer core

An explanation for two lobe-like fluctuations in the secular variation of the Earth's magnetic field in the northern hemisphere, mostly under Alaska and Siberia, has been provided by 'Swarm', the constellation of three identical satellites launched in 2013 by the European Space Agency (ESA). As well as highly accurate magnetometers, each satellite has E-field measurement capability.

As reported in the 7 January 2017 issue of *New Scientist*, thanks to these new highly detailed observations these fluctuations can be explained by a 'jet-stream' at the molten core–inner core boundary, 420 km wide. It is moving westward at 40–45 km per year, which is three times as fast as the typical speeds of molten iron in the outer core. For reasons yet unexplained, it appears to be speeding up.

The ability of Swarm to make such measurements at the outer core/inner core boundary, 3000 km deep, comes from its ability to strip away gradients across the three measurement positions due, for example, from the ionosphere and the crust, thereby producing the highest resolution data. Studies of this kind can also help us to learn more about the core itself and its influence on the magnetic field.

The *New Scientist* article suggests that the jet stream is due to two parallel vertical cylinders of rotating molten iron tangential to the solid inner core. Where they meet the solid core they squeeze molten iron into a jet stream. The basis for the above conclusions is given in a paper by Livermore et al. titled 'An accelerating high-latitude jet in Earth's core' and published online in *Nature Geoscience* on 19 December 2016.

More on Swarm is available at the ESA website http://www.esa.int/Our_Activities/Observing_the_Earth/Swarm. The Swarm mission is dedicated to study of the Earth's magnetic field.

Roger Henderson
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President's piece

Katherine McKenna

Well 2017 is upon us and so much has happened to the world in the past year. Good or bad we are seeing new leaders, changes to the EU, continuing war, volatile metal and oil and gas prices, and the list just goes on. So much changed in 2016 that there is a solid hope that 2017 stabilises a little, especially in the exploration industry.

What I have noticed around me is the continual use of the word innovation. For example, it is being used politically, by media to identify an institution's stand out character, and as a "buzz" word for fund raising. Over January I had a look at the Australian Government's National Innovation and Science Agenda report (http://www.innovation.gov.au/page/national-innovation-and-science-agenda-report). An interesting read, especially when looking at where Australia sits in comparison to other countries with respect to government investment (see Figure 1).

The Australian Government is recognising the talent that is in the country, and the importance of the development of ideas for future employment and growth of the country. The agenda also identified key sectors of competitive advantage. Three of these sectors would include many ASEG Members being: mining equipment, technology and services, and oil, gas and energy resources.

Our industry in Australia has thrived on innovation and I sat back and thought about what has been developed in Australia for mineral and oil and gas exploration. Such things as Falcon, Sirotem, Hoistem, Startem24, Xtem, Altantis probe, SAMSON, SAM, Tempest and HiSeis equipment. This is a list based on my memory, age and exposure, so I know I have not listed everything and I apologise for what I have missed as I know there will be many. For every piece of equipment developed software has been written and commercialisation of the technology has occurred. The list and the other items that are missing from the list, shows that the exploration geophysical industry in Australia has evolved and grown through innovation. The Australia geophysical industry has that history of developing solutions for exploration. I believe that this has been driven by many factors, including the environment in which we are trying to explore. However, success has resulted from the talent that is a part of the Australian geophysical community.

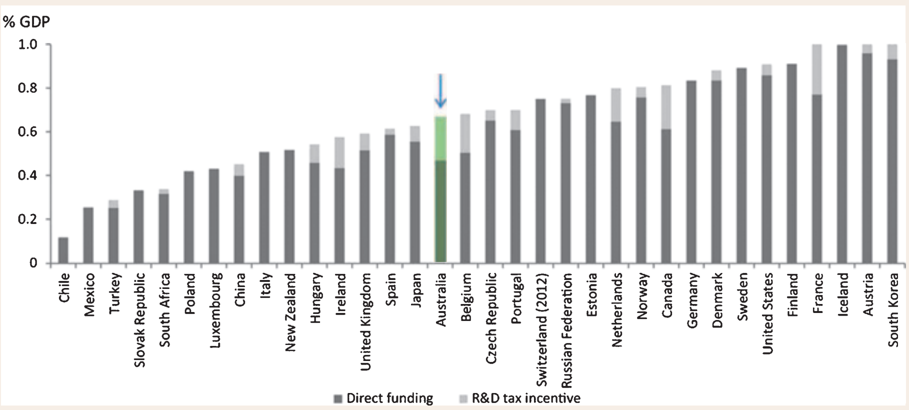

Figure 1. *Government investment in R&D, by country, 2011.*

The employment of graduate geophysicists, during this volatile time, is also changing. In the past exploration companies would hire geophysicists and these young employees would learn and be mentored by people within the company. For some of us, if we sit back with a glass of red and think about the start of our career, we think about the funny stories and the people we worked with and for. Everyone, I suspect, would acknowledge the influence of these people on their present career. My fear is that this is not happening as much now, with many companies increasingly outsourcing their geophysics to consultants. A lot of geophysics has now become a part of the service industry to exploration companies. The other topic in the Government's innovation agenda is the importance of developing talent and skills. We must, as a community, look at how our new graduates are mentored and help in developing their skills. Millicent Crowe and the ASEG Young Professional Committee should be commended for their work in trying to ensure mentoring is accessible to new graduates. If you have any ideas, or are willing to assist, please I encourage you to get in contact with this group.

Well I have rambled on long enough I think and there are roads out there to cycle. If you take anything away from this small piece, it should be that Australia has had a history of great geophysical innovation and it needs to continue. The Government seem to be supporting this so there may be some money available. As an industry, we should also be supporting Australian geophysical innovation and the future talent that is required to see it continue.

vivere est cogitare
(to live is to think)

Katherine McKenna
ASEG President
president@aseg.org.au

Welcome to new Members

The ASEG extends a warm welcome to 18 new Members approved by the Federal Executive at its December and January meetings (see table).

First name	Last name	Organisation	State	Country	Membership type
Aqeel	Abbas	Quaid-i-Azam University		Pakistan	Student
Paul	Belfrage	Beach Energy	SA	Australia	Active
John	Boast		East Java	Indonesia	Active
Mark	Bunch	University of Adelaide	SA	Australia	Active
Louis	Coleshill		SA	Australia	Active
Daniel	De Oliveira	AngloGold Ashanti Brasil	MINAS GERAIS	Brazil	Active
Irina	Emelyanova	ARRC	WA	Australia	Active
Noel	Guppy	Beach Energy Ltd	SA	Australia	Active
Hamza	Hamid	Quaid i Azam University	Islamabad	Pakistan	Student
Ravi	Jonnalagadda	Osmania University	Telangana	India	Student
Afnan	Khan	Quaid i Azam University	Islamabad	Pakistan	Student
Shawn	Kovacs	McMaster University		Canada	Student
Dmitry	Pankin			Belarus	Active
Christopher	Parker	Gap Geophysics Australia	QLD	Australia	Active
Adam	Ramage	CSIRO	WA	Australia	Active
Samantha	Thomas	University of Adelaide	SA	Australia	Student
Mehdi	Tork Qashqai	Macquarie University	NSW	Australia	Student
Lianping	Zhang	Western Geco	WA	Australia	Active

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Executive brief

The Federal Executive of the ASEG (FedEx) is the governing body of the ASEG. It meets once a month, via teleconference, to see to the administration of the Society. This brief reports on the last monthly meeting, which was held in December. We hope you have found these reports interesting and informative. If there is more you would like to read about on a regular basis just get in touch with me (Marina) and I will expand the 2017 briefs accordingly. Anyone who would like to see the full minutes of the monthly meetings should add their name to the mailing list maintained by the Secretariat. FedEx also holds planning meetings twice a year.

To everyone who has renewed for 2017 – congratulations and a very big thank you!

A particular welcome to the new student Members, student membership is up 51%!!! Remember early and mid-career Members can join the ASEG Young Professionals Network https://www.aseg.org.au/about-aseg/aseg-young-professionals.

I hope you have had a chance to look at our new website, its looking really great. Join us on Facebook and please let me know if you found it easy to renew this year.

The planning for the AGM in Brisbane has started, if you would like to attend the AGM in Brisbane let me know and I will keep you in the loop regarding time and location. If you are interested in volunteering for the Federal Executive please let us know. A very big thank you to the 2016 Federal Executive committee and a very big thank you to the local state Branch Committees for all of your hard work during 2016.

Cheers to 2017!

Marina Costelloe
Honorary Secretary
fedsec@aseg.org.au

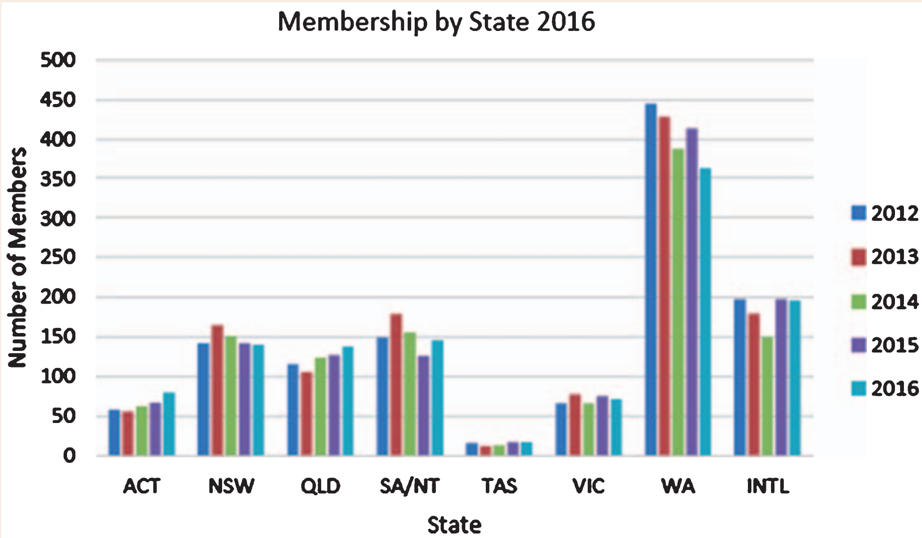
Society finances

The Society's financial position at the end of November:

Year to date income $529 541.95
Year to date expenditure $720 780.59
Net assets $1 104 494.70

Membership

At the end of 2016, the Society had 1151 Members. Overall membership is down slightly on 2015, Active/Associate membership is down 11%, and retired membership is up. The ACT and SA/NT membership is up, but unfortunately numbers in WA and Vic have decreased.



*This **Jalander fluxgate magnetometer** is from the ASEG virtual museum collection and was generously donated by John Stanley, formerly lecturer at the University of New England and inventor. Fluxgate magnetometers were a new breed of 'electronic' magnetometers, more sensitive than variometers, first invented in Germany in 1928 but not used extensively until just before, and during, WWII. This instrument was built in the 1950s to 60s by the Jalander Company in Helsinki, Finland, and weighed a light 1.3 kg. Like all fluxgates, it only measures the vertical component of the field.*

The fluxgate module is mounted internally concentric with the instrument housing. To operate, after turning the instrument on, it must be suspended to hang vertically and steadied to align the levelling bubble in the centre of its bull's eye. When steady, the relative value of the vertical component of the magnetic field can be read off the analogue scale. A switch can be used to select the most appropriate range scale. The typical measurement time is only 15 seconds and best resolution for this non-stabilised unit is 10 nT.

News from the ASEG Research Foundation

At the 2016 ASEG Conference in Adelaide two events were held that were of particular significance to the ASEG Research Foundation; the conference dinner and the lunch held to acknowledge Professor David Boyd's ASEG Gold Medal.

The conference dinner was held at the Adelaide Cricket Ground with a cricketing theme. It proved to be a very enjoyable night. A number of fund raising activities were carried out including an auction of several bottles of Australia's finest wines and a blind auction for a variety of cricket memorabilia gathered together by the Adelaide Conference Organising Committee. In total nearly $3000 was raised on the night, and several commitments were made for further donations after the conference.

The success of the evening was made possible by the assistance of fellow Foundation Members and also with the help of the Conference Organising Committee, in particular Kelly Keates of Zonge in Adelaide who was a great support in making it all happen.

Also at the conference a lunch was held to celebrate the award of the ASEG Gold Medal to Professor David Boyd. Donations from those attending the lunch were directed to the ASEG Research Foundation and totalled in excess of $2500. Sadly David passed away just a couple of months after the conference. Nevertheless his life's work, as a practical geophysicist and as a truly great teacher, were well honoured at the lunch. It seems fitting that money raised at the lunch should be directed towards assisting future students. Thanks to Dave Isles for taking the lead on this event and for thinking of the Research Foundation as a beneficiary.

The Research Foundation has passed its 25th year and has over the years supported numerous projects with the total moneys granted now exceeding $1.2m. It was set up with the fairly modest aim of providing financial support to enable geophysical students in Australian institutions to carry out the field and laboratory work necessary to complete their post graduate degrees, be it at Honours, Masters or PhD level. Each year students' supervisors submit work proposals on behalf of their students. Two committees of the Research Foundation, one for minerals and the other for petroleum, assess the merit of the various proposals and make recommendations about which projects to support.

Funding the Research Foundation is an ongoing challenge and relies on the donations of companies, individual Members and importantly the ASEG itself. Funds available fluctuate from year to year with the level of donations and also with the overall financial health of the ASEG. The Foundation is only ever able to commit to support projects when it has sufficient funds in the bank to cover its forward commitments.

I thank everyone who attended the ASEG conference in Adelaide for their generosity in supporting the ASEG Research Foundation. I encourage you all to think of the ASEG Research Foundation among the charitable donations that you make every year. It is a worthwhile cause that is investing in the future of geophysics and the future professionals of our industry. It is easy to donate through the ASEG website and all donations are fully tax deductable.

Phil Harman
ASEG Research Foundation Chair
research-foundation@aseg.org.au

News from the ASEG History Committee

The ASEG History Committee is one of the largest ASEG Committees and is very active. 2016 was another busy year. Some of the highlights and a summary of the Committee's plans for the future are presented here.

An exciting recent development has been the initiation of the 'virtual' or 'online' museum. The first inputs to this museum can now be viewed in the History Section of the website, including 15 contributions from John Stanley. More contributions are in the pipe-line but if you think you could add to the museum please contact the Chair of the History Committee. High definition photos are required, where possible, plus a brief description of the item – like the descriptions of the items already on display. This digital museum has evolved from the aim to collect and document old equipment but so much has been received, or is forthcoming, that the physical space required for storage and a suitable and convenient location are yet to be found.

The History Committee aims to add other items of interest to the History section of the website as they come to hand. Two new papers were added in 2016: 'A Brief History of Exploration Geophysics Education in Australia' and 'A Survey of Educators in Australian Universities'. The Committee also aims to have items of historical interest in as many issues of *Preview* as possible. In 2016 there were history feature papers in *Previews* 180, 181, 184, and 185. The second part of John Stanley's paper on the development of cesium magnetometers in Australia appears in this issue of *Preview* and three other papers are in preparation for future issues.

A full list of all items of published since *Preview* 166 (October 2013), which continues from an earlier list published in *Preview* 173 for the period covering *Preview* 53 – 166, appears in Table 1.

Activities planned for the future include firstly, continuing to add to the virtual museum and other parts of the History section of the website, and continuing to contribute articles to *Preview.* Also, a series of biographies is planned of key Members of ASEG, such as Lindsay Ingall, the second President; Laric Hawkins, the first 1st Vice-President, etc. If you have other names to add to this list or, more importantly, are able to assist with writing a biography, please contact the Chair.

Also contact the Chair if you would like to serve on the History Committee or to be on the mailing list for regular reports.

Roger Henderson
History Committee Chair
history@aseg.org.au

Table 1. Items of historical interest published in *Preview* since October 2013

Issue no.	Starting page	Title	Type
169	12	Kenneth Zonge 1936–2013 (by Larry Hughes et al.)	Obituary
171	17	Hugh Rutter 1941–2014 (by Kim Frankcombe, Bob Smith, Jim Lalor & Phil Schmidt)	Obituary
171	18	The geophysics of the Olympic Dam discovery (H. Rutter and D. J. Esdale)	Feature
172	22	Alan Appleton 1934–2014 (by Dave Cockshell)	Obituary
172	39	SIROTEM – Australia's first locally invented TEM system (Roger Henderson)	Feature
173	16	History articles in *Preview* (Roger Henderson and Ann-Marie Anderson-Hayes)	News
173	18	Don Gray 1931–2014 (by Alla Metlenko)	Obituary
173	18	Trevor Jones 1949–2014 (by Marina Costelloe)	Obituary
173	44	The ASEG Research Foundation celebrates its 25th anniversary (Doug Roberts)	Feature
174	13	Robert Sheriff 1922–2014 (by Norm Uren)	Obituary
175	34	Peter Gunn remembers his life as a geophysicist (by Peter Gunn)	Feature
176	14	Alex Copeland 1950–2015 (by Kim Frankcombe et al.)	Obituary
176	17	Dave Hutchins 1948–2015 (by Bob Timmins)	Obituary
177	14	Christopher Wiles 1947–2014 (by Mike Sexon et al.)	Obituary
179	53	The first gravity meter in Australia in 1890s (Roger Henderson)	Feature
180	40	The first lecturer in exploration geophysics in Australia (Roger Henderson)	Feature
181	38	Lewis Albert Richardson: a pioneer of exploration geophysics in Australia (Bob Richardson)	Feature
184	36	High productivity vibroseis techniques: a review (Tim Dean)	Feature
185	46	The development of optically pumped magnetometer systems and their applications in Australia: Part 1 (John Stanley)	Feature

Notice of Annual General Meeting (AGM)

The 2017 AGM of the Australian Society of Exploration Geophysicists (ASEG) will be held at the XXXX Brewery, Black St and Paten St, Milton, Brisbane, on 10 April. The meeting will be hosted by the Queensland Branch. Details to be supplied via email. Drinks will be available from 6:00 pm and the meeting will begin at 6:30 pm.

The business of the Annual General Meeting will be:

- To confirm the minutes of the last preceding 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 Constitution and to law;
- To consider and if agreed approve any changes to the ASEG Constitution;
- To report the ballot results for the election of the new office holders for the Federal Executive;
- To confirm the appointment of auditors for 2017.

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.

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

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

These officers are elected annually by a general ballot of Members. Andrea Rutley was elected as President-Elect in 2016 and as such will stand for the position of President.

The following offices are also recognised:

(i) Vice President,
(ii) the Immediate Past President (unless otherwise a member of the Federal Executive),
(iii) the Chair of the Publications Committee,
(iv) the Chair of the Membership Committee,
(v) the Chair 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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Nominations must be received via post, fax or email no later than COB Tuesday 7 March 2017. 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.

ASEG Branch news

New South Wales

In November, **Ned Stolz** and **Bob Musgrave** from the Geological Survey of NSW presented a talk entitled 'What's been happening at the Geological Survey of NSW? Current and upcoming geophysics, geology and crustal interpretations'. Ned, the new manager of geophysics and modelling, provided an update on activities and products from the Geological Survey including airborne magnetic acquisition and field mapping programmes. This was followed by Bob Musgrave presenting results from potential field modelling and palaeomagnetic studies in the Tasmanides, and discussing implications for the interpretation of the middle crust in eastern Australia. Much discussion followed, with more questions being asked over a few reds.

In December, we held our quiz night. Many difficult and some not so difficult questions both geophysical and non-geophysical were asked and answered (well alright … mostly answered). A fun night and a good way to have our last ever meeting at the Rugby Club.

An invitation to attend NSW Branch meetings is extended to interstate and international visitors who happen to be in town at that time. Meetings are generally held on the third Wednesday of each month from 5:30 pm at the 99 on York Club in the Sydney CBD. Meeting notices, addresses and relevant contact details can be found at the NSW Branch website.

Mark Lackie
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Queensland

The Queensland Branch of the ASEG is looking forward to another exciting year. We plan to hold monthly meetings featuring local and international speakers as well as hosting our annual social events. We are currently looking for people to present to the Branch this year and welcome interstate Members to our Branch meetings. Our first meeting will be held in February with details to be posted on the QLD events tab on ASEG website. We will also be hosting the ASEG AGM at the XXXX Brewery in Milton on 10 April. All Members will be sent information about the AGM as the date approaches.

Fiona Duncan
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South Australia & Northern Territory

Since the last edition of *Preview* the SA/NT Branch has only held one event, the final for 2016, marking a very relaxed and enjoyable end to the year on the way to the Christmas and New Year period. Our November technical evening, the Annual Student Night and Christmas Party, did not disappoint, with a strong turnout as usual to support local students who gave presentations on their recently completed honours projects.

Hugh Merrett, **Gonghua Fan** and **Thomas Lynch** all did a brilliant job presenting the background and results of their chosen areas of study, with a very interesting variety of topics covering both the petroleum and minerals industry. The Branch thanks each of them for their efforts and willingness to present, with special congratulations going to Thomas Lynch who was awarded the prize for the best presentation. 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, student events and other industry events in 2016 with numerous local, interstate and overseas guest speakers, as well as a healthy social calendar, all with the added excitement brought about by the ASEG-PESA-AIG 25th Geophysical Conference and Exhibition. We would like to thank all of our 2016 sponsors, the Department of State Development, Beach Energy, Minotaur Exploration, Borehole Wireline and Zonge. Without their support we would not be able to hold such full programme of events for the local membership. We will be in touch with all our previous sponsors hoping they will return again for 2017. Of course, if you or your company are not in the list above and would like to offer your support, please get in touch at the email address below.

I would also like to thank the 2016 Branch Committee, with special mentions to **Adam Davey** our Treasurer and **Mike Hatch** our Secretary for all of their hard work, especially given the amount of time that was also devoted by them and all the others on the committee who helped on the ASEG-PESA-AIG Conference Organising Committee. Every committee member's efforts are much appreciated by me and the local Branch alike. For everyone continuing I look forward to working with you in 2017. We also welcome any interested Members to the local committee and any commitment, large or small, is appreciated.

Please keep an eye out for events in 2017 on the website and in your inbox, further technical meetings will be held monthly at the Coopers Alehouse on Hurtle Square in the early evening, starting in February with the Branch AGM, date TBA. If you are interested in joining the committee or holding a position on the Branch Executive, nomination forms will be sent out early next year. We invite all Members, both SA/NT and interstate to attend our events, and of course any new Members or interested persons are also very welcome to join us. For any further information or event details, please check the ASEG website under SA/NT Branch events and please do not hesitate to get in touch at joshua.sage@beachenergy.com.au, the email listed below, or on (08) 8338 2833.

Josh Sage
sa-ntpresident@aseg.org.au

Tasmania

ASEG Tasmania branch member **Anton Rada** will be giving a talk in the next few weeks on the UAV (unpiloted aerial vehicle or drone) geophysical survey technology he has been developing. The system acquires magnetic as well as LIDAR data, and has been deployed for UXO among other applications. The presentation is likely to be in the CODES Conference Room at UTas. Exact time/date details are yet to be confirmed; Tasmania Branch members will be advised directly.

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 programme of the University of Tasmania's School of Earth Sciences, which regularly delivers presentations of geophysical as well as general earth science interest. Please contact ASEG Tasmania Branch President **Mark Duffett** with any queries.

Mark Duffett
taspresident@aseg.org.au

Victoria

Happy New Year dear Members!
First of all I would like to thank the Victorian Members who took the time to answer the short survey that we run last December, your feedback was much appreciated.

Our last meeting was held on 15 November, with our annual student night. Congratulations to **Lachlan Hennessy** (PhD, RMIT) who won the 1st prize for his presentation, followed by **Hamish Stein** (Masters, Melbourne University, 2nd prize) and **Jesse Keegan-Osborne** (Honours, Monash University, 3rd prize). A big thank you to the other participants as well, **Elizabeth Grange** (Masters, Melbourne University) and **Andrew Pearson** (Masters, Melbourne University). We closed 2016 with the traditional PESA-ASEG-SPE Christmas lunch. A large assembly gathered at the Kelvin Club to listen to **Glen Nash** from ExxonMobil recapitulating the history of discovery in the Gippsland Basin.

The year 2017 will start on 22 February with a joint summer social event (details to be confirmed).

Seda Rouxel
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Western Australia

The WA Branch finished off 2016 with a technical presentation by **Allan Trench** on current trends in mineral economics, combined AGM and Christmas Party on 7 December. Allan drew from his vast experience in industry and on boards of directors to provide an insightful overview of what successful exploration companies do, and how innovation drives our sector.

During 2016 the WA Branch hosted seven technical nights, three SEG travelling lecturers and three workshops, and co-hosted the annual Golf Day.

We would like to thank our presenters: **Todd Mojesky**, **Mark Baigent**, **Keith Fisk**, **Stanislav Glubolovskikh**, **Jeremy Cook**, **Lee Steven**, **Allan Trench**, **Joe Dellinger**, **Steven Constable** and **How-Wei Chen** for presenting to our Members during the year. We would also like to thank our workshop presenters: **Serge Shapiro**, **James Gaiser** and **Jan Francke**. Finally, the WA Branch would like to extend its thanks to the committee members past and present for their assistance in planning and hosting the busy programme through 2016.

The WA Branch's technical nights were sponsored by the following companies: Globe Claritas (Platinum), Resource Potentials, Western Geco, CGG, Atlas Geophysics, First Quantum Minerals Inc, GPX Surveys, Paradigm (Gold), Geosoft, ExploreGeo, and Southern Geoscience (Silver). The Branch could not put together such a wide range of technical activities without the support of our Platinum, Gold and Silver sponsors, and we look forward to a long standing partnership with these companies.

At the AGM the Branch also recognised a number of Branch Members with awards including a Service Award (**Kathlene Oliver**), Student Awards (**Tahlia Downes** and **Marko Zegarac**), and 25 Year Membership Awards (**Paul Wilkes**, **Tony Weatherall**, **Lisa Vella**, **Laurence Roe**, **Bill Robertson**, **Andrew Long**, **Audrey Leonard**, **Jim Dirstein**, **Mike Dentith**, **Geoffrey Collis**, **Barry Bourne**, and **Andrew Bisset**). Unfortunately not all of the Award recipients could join us on the evening to accept their awards. Congratulations to all!!

The calendar for 2017 is filling up. The first events for 2017 include technical night presentations on 15 February by **Juerg Hauser** (CSIRO) and 8 March by **Shane Evans** (Moombarriga). The Branch will also host the SEG Distinguished Lecturer **Paul Hatchell** on 3 April. We are excited about the programme of events planned for 2017 and look forward to seeing our Members in attendance.

Kathlene Oliver
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Australian Capital Territory

The ACT Branch got in early for the Christmas party season with a combined celebration with the local PESA Branch on 25 November. About 25 ASEG Members and partners enjoyed a Mediterranean feast at the award winning Olive Restaurant (ranked 5 out of 1026 restaurants in Canberra!). The festivities were tempered by serious geoscientific discourse with a feature presentation by semi local structural geologist, **Titus Murray**. The talk's title, 'Road Side Structure of the Southern Sydney Basin: Where Sydney gets its Water, The World Gets Coal and Your Route to the New Year's Fireworks' nicely summarises Titus's ideas about the Hawkesbury Sandstone, and the coalfields around Campbelltown and Wollongong. I'm certainly taking a lot more notice when I drive the Hume motorway between Sydney and Canberra. Unfortunately everyone was having such a good time that no-one remembered to take any photographs to record the happy event!

For those who couldn't make it to the party, a more conventional Branch meeting was held at Geoscience Australia on 15 December. The meeting featured three short presentations. **Laurence Davies** gave an overview of the application of passive seismic techniques to Geoscience Australia's project areas, particularly for imaging cover thickness. Passive seismic is a relatively new and innovative method being used for near surface

Tim Jones presenting his PhD work at the end of last ACT Branch meeting for 2016.

exploration and it is good to see the national geoscience agency supporting development of acquisition processing and interpretation methods. **David McInnes** gave an update on the Virtual Geophysics Laboratory, an exciting project tapping in to the vast power of High Performance Computing to process, model and deliver geophysical data and products. The evening was rounded out by **Tim Jones** (ANU) presenting his PhD work on quantitative modelling of mantle plumes to investigate the heterogeneity of the deep mantle.

The ACT Branch hopes everyone had a great Christmas and summer break, and wishes everyone a fantastic and prosperous 2017.

Ned Stolz
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ASEG national calendar: technical meetings, courses and events

Date	Branch	Event	Presenter	Time	Venue
2017					
Feb	SA-NT	AGM	TBA	1730	Coopers Alehouse, Hurtle Square, Adelaide
Feb	QLD	AGM	TBA	1730	XXXX Brewery, Corner of Black Street and Paten Street, Milton
15 Feb	WA	Tech night	Juerg Hauser	1730–1900	TBA
15 Feb	NSW	AGM	TBA	TBA	99 on York Club, Sydney CBD
22 Feb	VIC	Joint ASEG/PESA/SPE social event		TBA	TBA
8 Mar	WA	Tech night	Shane Evans	1730–1900	TBA
10 Apr	QLD	ASEG AGM	Various	1830–2030	XXXX Brewery, corner of Black Street and Paten Street, Milton
3 Apr	WA	SEG Distinguished Lecturer	Paul Hatchell	1730–1900	TBA

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

Safety in the air begins on the ground: a message to all stakeholders of airborne geophysical surveys

Safety in the air begins on the ground has been IAGSA's motto since its formation in 1995. IAGSA, the International Airborne Geophysics Safety Association, is a Not-for-Profit member-run global organisation dedicated to the safe operation of aircraft conducting geophysical surveys. Through the active participation of our membership, IAGSA develops recommended practices, serves as a centre for the exchange of safety information, and acts as a repository for specialised statistics.

Because we are not a regulator, our impact on our Members and the safety of the industry as a whole is based on how well we can influence our many stakeholders. Our Active Members are directly engaged in airborne data acquisition while our Associate Members are either service providers to their clients or end users of the data, including many of the world's largest mining companies. Non-member stakeholders include regulators, safety consultants, communities that give the airborne geophysical industry its license to operate, as well as many mining- or exploration-companies that contract our Active Members to perform work on their behalf.

In these challenging economic times for the mineral exploration industry in general, and for the airborne geophysical survey industry in particular, we would like to remind all our stakeholders of the importance in remaining focussed on one of the core missions of IAGSA, which is to ensure that survey companies and their clients alike follow a common safety standard. Safety considerations must always trump economic pressures and technical factors.

We know from experience that through their constant focus on safety, many of our Associate Members are able to positively impact IAGSA's goals by ensuring that their standards are passed down to their airborne contractors. As a service, IAGSA performs a Safety Review with all of our Active Members to provide guidance and assistance towards the implementation of IAGSA's recommended practices, document their present level of compliance, and highlight Notices of Difference between their practices and our recommendations. More and more of our Associate Members are now including membership in IAGSA as a prerequisite in their survey procurement process, and some are now requesting to see the most recent Safety Review before awarding a contract. Our Active Members operate in all parts of the world using a wide variety of aircraft, and the ensuing conversation between Active Member, client and IAGSA is where the real value in IAGSA's existence lies.

It is here that IAGSA's motto of safety in the air begins on the ground really rings true. Although an airborne contractor's flight operations are of great importance to us, many of the most important decisions that directly impact the safe operation of an airborne geophysical survey are made during the tendering process: the elevation-drape being requested, the type of aircraft being provided, the safety culture of the contractor, and the competence of the organisation including the crew members who will fly the survey.

In the ideal world we would like every stakeholder in airborne geophysics to not only be a member of IASGA but to wholeheartedly follow our recommendations as well. Regardless, when it comes to IAGSA's goal of safe airborne-geophysical operations, membership is beside the point because the onus of due diligence is a responsibility of all stakeholders. IAGSA is available to answer questions related to the safe acquisition of airborne geophysical data irrespective if the enquiry comes from a Member or not. Furthermore, our 'Contract Annex For Exploration Companies' is also freely available from our website (www.iagsa.ca) and we strongly encourage any company, whether an IAGSA Member or not, to take consideration of IAGSA's recommended practices in your airborne geophysical survey planning and append this annex to your next airborne geophysics contract.

On behalf of IAGSA for the safety of us all,

Lance Martin
COO, IAGSA
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Joel Jansen
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Lead – Geophysics, Anglo American plc
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Where are they now?
Kate Holland: Winner of the 2009 ANU Prize for Best Results in Geophysics

I completed a degree in Global and Environmental Science (with Honours) in 2011. My degree programme allowed me to benefit from the inter-disciplinary nature of Earth science throughout. I pursued multiple scientific disciplines (physics, chemistry, biology and maths), repurposing them to solve problems about Earth, using geochemistry, and geophysics – for which I won a prize in 2009. When it came to my Honours year, I chose a project that combined chemistry and biology to study how foraminifera, a type of plankton, record the temperature and salinity of the oceans in which they live. The composition of their shells (mostly $CaCO_3$) adjusts in response to changes in ocean conditions. Foraminifera are an important source of information for climate scientists who wish to know how the temperature of our oceans has varied in the past. That knowledge will allow us to make predictions about our future oceans. First, however, the foraminifera needed to be collected and re-homed in the lab. I did this over two summers, whilst SCUBA diving, in the oceans off California and Puerto Rico – a fantastic time! I enjoyed my honours year so much, and worked with so many inspiring scientists, that I chose to undertake a PhD continuing the research. This year I will complete my PhD and plan to continue investigating our oceans, now as a fully-fledged scientist.

Kate Holland
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Collecting a foraminifer in the Atlantic ocean off Puerto Rico, April 2014. Photo supplied by Bärbel Hönisch.

SEG Annual Meeting, Dallas, October 2016

Dallas, Texas, is known to me as the place where President John F. Kennedy was assassinated on 22 November 1963. I clearly remember this because it is also the day of the first satellite relay television broadcast across the Pacific. That broadcast was made in preparation for the Olympic Games in Tokyo the following year. On the morning of 23 November (in Japan), I got up early especially to watch the experiment on a 14-inch black-and-white cathode tube television. The news of the assassination was conveyed during that broadcast. The historical success of this experiment with a new communication technology was overshadowed by the historical news carried over the airwaves. Now Dallas can be reached by a direct Qantas flight from Australia.

In 2016, the SEG Annual Meeting was held in Dallas amidst the US Presidential election. On the flat screen colour LCD television in the hotel room, news, debates and comments, some serious and others joking, about the election were very frequently broadcast. In another hotel the SEG conference organisers were worried that the number of delegates and exhibitors at the Annual Meeting might not be as high as usual due to the downturn of the petroleum industry prompted by the low price of oil. The SEG conference usually attracts about 8000 delegates, and as many as 10 000 delegates if held in Houston in a good industrial climate. Only three years ago the SEG conference in Houston was held in a bullish atmosphere, prompted by the increase of shale gas production and the expansion of Texas port facilities for gas export. At the opening ceremony the then Governor of Texas said: ‘If you come to Texas with a truck license, we will find a job for you in a week’.

The Dallas conference was different. The SEG feared that the number of delegates might not reach 4000 and it would make loss. The SEG had already been suffering from the industry downturn and had laid off a quarter of their staff in the earlier part of 2016. We could see their cost saving efforts in the conference as well: the proceedings were all online - not even available on a USB drive; the conference bag was pretty modest with fewer sponsor logos; the end-of-conference party was not included in the registration fee; the frequency of shuttle buses between hotels and the convention centre was reduced; regional luncheons were reduced from four to two by combining large areas – the Americas and Europe/FSU were combined, so were Asia/Pacific and Africa/Middle East. These combinations blurred regional focus.

At the end of the day the number of delegates was 5560, which was a relief to the Society as they made a surplus of around $450 000. The exhibition hall was filled with 251 exhibitors, but we noticed some regular exhibitors were missing. Delegates were talking about how long the low oil price would continue. Despite the downturn in the industry it was apparent that research activities are growing strongly in geophysics. About 1100 papers were presented in the three-day conference. There were 25 parallel sessions, nine of which were posters and e-posters. If you are a petroleum geophysicist, it would have been very hard to choose which session to go. Fortunately the convention centre was well laid out and it was easy to move from session to session. Nineteen workshops were held after the conference. SEG sold 675 tickets but 572 attended. Somehow 100 registrants did not show up! This may be a reflection of the downturn.

The ASEG has three seats in the SEG Council. These seats are filled by the President and two conference delegates. The role of the Council is to advise the SEG Board of Directors. This is usually done through amendments of By-Laws. Once the Council approves an amendment it will go to the Members for consideration via a referendum. The major issue in front of this year’s Council meeting was a motion to remove the membership category of Associate Member. The argument for was that it would encourage young Members to participate in SEG activities including voting and Committee membership

Incoming SEG President, Bill Abriel, addresses the SEG Council meeting.

Voting taking place in the SEG Council meeting.

Koya, Tineka and Mr and Mrs Irwan Djamaludin in the ASEG booth.

and that it would reduce administrative chores. The argument against was that it would jeopardise the prestige of the Active Membership class and expose the SEG to risk of dominance by groups of particular interest. The motion was defeated and this issue will not go to a Members' referendum.

One important task associated with representing the ASEG at a SEG conference is meeting with SEG Executives and Officers to discuss future cooperation. In past years the SEG has organised a separate meeting with representatives of each associated society, but the number of associated societies seems to have become too large and this year they decided to have one combined meeting. The meeting seemed rather crowded with nearly 100 people in the room, but the atmosphere was more relaxed than in an individual meeting. I managed to talk to the outgoing and incoming presidents, and the SEG officers for publication, conferences, exhibitions and education - all of them have dealings with ASEG. During a chat with the incoming SEG President, Bill Abriel, I found that he would be in Australia for three weeks in May and June as his wife teaches part-time at the University of Technology in Sydney. I asked if he would be interested in running an OzStep course during his stay. He was agreeable and the course will be held during his visit in late May to early June.

The next AEGC Conference (equivalent of ASEG's 26th Conference and Exhibition) was promoted at the ASEG booth and in the Exhibition Hall. The ASEG booth was located in a well exposed corner position in the Exhibition Hall. We usually have blow-up kangaroos at the booth, which attract eyes of passers-by. Unfortunately the kangaroos were punctured at the Adelaide conference in August and we could not get replacements. Many visitors came to look at the posters of geophysical maps of Australia. I saw some friends from Australia, many of whom I have not seen for some time.

At the 'wrap-up' meeting after the conference the SEG Officer reported that 215 out of the 251 exhibitors (86%) re-booked their booths for next conference. This sounded an optimistic note for the future. The next SEG Annual Meeting will be held in Houston from 14 to 19 October 2017.

Koya Suto
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GA: update on geophysical survey progress from the Geological Surveys of Western Australia, South Australia, Northern Territory, Queensland, New South Wales, Victoria and Tasmania (information current on 13 January 2017)

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
Gawler Craton Oodnadatta	GSSA	GA	MAGSPEC Airborne Surveys	Estimated by the end of Jan 2017	240 240	200 m 60 m EW	43 680	TBA	TBA	183: Aug 2016 p. 34	TBA
Gawler Craton Ooldea	GSSA	GA	Thomson Aviation	Estimated by the end of Jan 2017	208 560	200 m 60 m EW	37 920	TBA	TBA	183: Aug 2016 p. 34	TBA
Gawler Craton Lake Torrens	GSSA	GA	Sander Geophysics	Estimated by the end of Jan 2017	161 386	200 m 60 m EW	29 360	TBA	TBA	183: Aug 2016 p. 34	TBA
Coonabarabran	GSNSW	GA	TBA	Estimated by mid-Mar 2017	~50 000	250 m 60 m EW	11 000	TBA	TBA	184: Oct 2016 p. 23	A contract is being drafted by GA
Tasmanian Tiers	MRT	GA	TBA	TBA	Up to an estimated 66 000	200 m 60 m NS or EW	11 000	TBA	TBA	TBA	National Collaborative Framework Agreement between GA and MRT was expected to be executed in Jan 2017
Isa Region	QSQ	GA	TBA	TBA	Estimated 120 000	100 m 50 m EW	11 000	TBA	TBA	TBA	National Collaborative Framework Agreement between GA and GSQ executed on 13 Dec 2016

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
Stavely	GSV	GA	Atlas Geophysics	3 Dec 2016	Approx. 3465	200 m station interval along 14 traverses	TBA	Jan 2017	TBA	The proposed survey covers parts of the Horsham, Hamilton, Ballarat and Colac Standard 1:250 000 map sheets. The survey is to collect gravity stations spaced 200 m apart on 14 separate road traverses.	TBA
East Kimberley Airborne Gravity Survey	GSWA	GA	TBA	8 Oct 2016	38 000 line km	2500 m line spacing	82 690	3 Dec 2016	14 Jan 2017	184: Oct 2016 p. 24	The survey covers the Medusa Banks, Cambridge Gulf, Lissadell, Gordon Downs, Mount Ramsay and Lansdowne Standard 1:250 k map sheet areas
Coompana – PACE area	GSSA	GA	TBA	Est 18 Jan 2017	13 801	Regular grid of 2, 1 and 0.5 km	100 000	TBA	TBA	183: Aug 2016 p. 34	The contractor was expected to commence acquisition on 18 Jan 2017
Tanami-Kimberley	GSWA	GA	TBA	TBA	Up to 50 000	2500 m line spacing	110 000	TBA	TBA	TBA	The proposed survey area covers the Billiluna (all), and parts of the Lucas, Cornish, Mount Bannerman, Mount Ramsay, Noonkanbah, Lansdowne, Lennard River, Derby, Charnley and Yampi standard 1:250 k map sheet areas. The Quotation request closed on 31 Jan 2017
Kidson Sub-basin	GSWA	GA	TBA	TBA	Up to 70 000	2500 m line spacing	155 000	TBA	TBA	TBA	The proposed survey area covers the Anketell, Joanna Spring, Dummer, Paterson Range, Sahara, Percival, Helena, Rudall, Tabletop, Ural, Wilson, Runton, Morris and Ryan standard 1:250 k map sheet areas. The Quotation request closed on 31 Jan 2017

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
Musgraves – PACE Area	GSSA	GA	CGG Aviation	18 Aug 2016	8489	2 km; E–W lines	16 371	The survey completed flying on 17 Sep 2016	Expected on 24 Nov 2016	179: Dec 2015 p. 23	Preliminary final data were supplied to GA on 30 Dec 2017
Musgraves – CSIRO Area	GSSA	GA	SkyTEM Australia	15 Sep 2016	7182	2 km; E–W lines	14 320	The survey completed flying on 13 Oct 2016	Expected early Dec 2016	179: Dec 2015 p. 23	Preliminary final data were supplied to GA in Jan 2017
Isa Region	GSQ	GA	Geotech Airborne	8 Aug 2016	15 692	2 km; E–W	33 200	The survey completed flying on 4 Nov 2016	TBA	182: Jun 2016 p. 23	Preliminary final data were supplied to GA on 12 Jan 2017

TBA, to be advised.

Exploring for the Future: North Australian Airborne Electromagnetic survey 2017

Call for expressions of interest and subscribers

Geoscience Australia is planning a programme of regional airborne electromagnetic mapping between the Tennant Creek and Mount Isa regions of the Northern Territory and Queensland. Funded by the Australian Government's Exploring for the Future programme (http://www.ga.gov.au/about/projects/priority-projects/exploring-for-the-future), the survey will consist of 20 km spaced lines over parts of the Newcastle Waters, Alice Springs, Normanton and Cloncurry 1:1 000 000 standard map sheets, as shown in the diagram below. Companies are invited to register their interest in the project by submitting proposals to infill areas within the regional survey lines.

By subscribing to a large regional survey, companies will benefit through Geoscience Australia covering mobilisation and stand-by costs as well as an expected reduction in the per line kilometre charge. Subscribers will also benefit from Geoscience Australia's quality assurance and quality control procedures to ensure that the data released are fit-for-purpose. Due to the size of the survey over approximately 830 000 km², it may take six to twelve months from the completion of data acquisition before data will be available to subscribers. Data acquired under company subscription will be subject to a 12 month confidentiality period from receipt of final data.

Successful proposals must adhere to the following criteria:

- the proposed boundary for the infill area is to be a simple polygonal shape
- the number of line kilometres for each infill area is to be no less than 200 in total
- before Geoscience Australia approaches the panel of AEM contractors, a signed agreement with each subscriber is required
- all infill data will be released at the same time. There will be no early supply of any data to subscribers.

Geoscience Australia will select areas that complement the objectives of the survey from the company proposals received for infill/extension flying. Expressions of interest should be submitted by cob AEDT **Friday 24 February 2017** and should include a regular shaped polygon of the desired infill/extension area with the corner coordinates listed in tabular form.

Geoscience Australia is also seeking assistance with borehole geophysical induction conductivity logging from tenement holders in the survey area.

For more information please contact:

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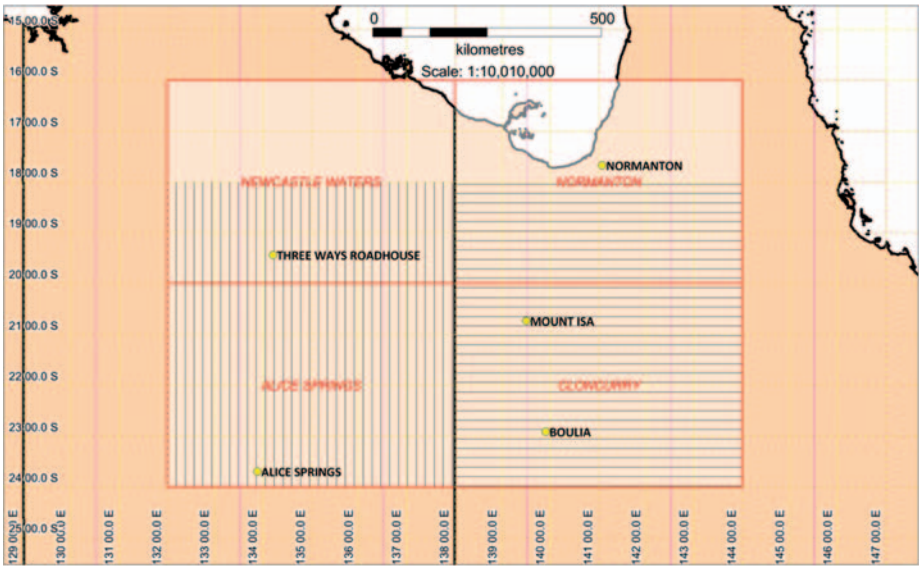

Figure 1. *Exploring for the future: proposed survey area for year one of the AusEM Programme, 11 January 2017.*

Geological Survey of South Australia: a new website and plans for a microgravity survey

Gawler survey webpage

The Geological Survey of South Australia (GSSA) has developed an information website containing up-to-date information on the Gawler Craton Airborne Survey. This major survey is being undertaken by the Department of State Development (DSD) in partnership with Geoscience Australia (GA) and is a key programme within the Plan for Accelerating Exploration (PACE) Copper Initiative, part of South Australia's Copper Strategy.

As well as general information regarding the survey, the website contains a 'live' GIS map showing the positions of aircraft as the survey progresses. The first survey blocks to be acquired will be blocks 2, 3 and 4.

For more information regarding the survey, please visit the website: http://minerals.statedevelopment.sa.gov.au/geoscience/pace_copper/gawler_craton_airborne_survey_community_information.

Coompana microgravity plans

As part of the PACE Copper Coompana Drilling programme the GSSA geophysics team will be undertaking a series of microgravity surveys to detect underground cavities that could pose a risk to the drilling programme. At each drilling location, the team will acquire a regular grid of data. Stations will be spaced 10 metres apart, and each grid will be 210 m by 210 m in size. The mid-lines will extend a further 200 m to the north, south, east and west.

To ensure a high quality of data we anticipate taking 2 minute measurements at each station. We will use two Scintrex CG5 gravity meters and will bring base plates to ensure that base measurements are recorded at constant height. One leg on each of the CG5 tripods will be fixed in place to ensure that heights remain very similar. The distance from the ground surface to the sensor level will be recorded at each station to the nearest centimeter.

The team will use a Sokkia GRX1 Differential GPS system in real time kinematic (RTK) mode for easting, northing, and elevation measurements. Readings will be recorded on a handheld unit and downloaded onto a processing computer at the end of each day.

Due to the close proximity of stations, the survey will be undertaken on foot. Safety being of prime concern, there will be three operators in the area at any time, all being equipped with appropriate safety gear and current first aid training.

Look out for the results of the survey in an upcoming edition of *Preview* or *Exploration Geophysics*!

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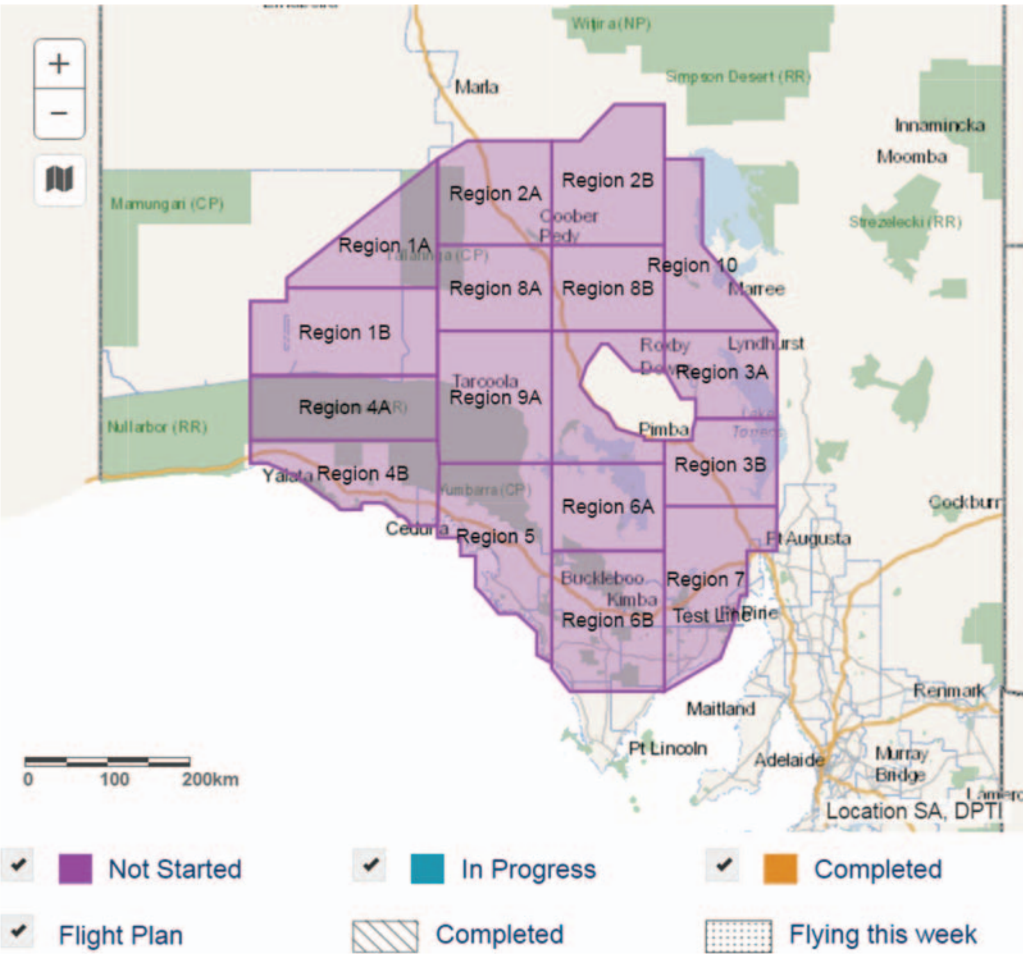

Figure 1. *The webpage contains a map which will track the progress of the survey.*

Canberra observed

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ANU Energy Update 2006; a timely event for Minister Frydenberg

The ANU Energy Change Institute hosts an annual forum on energy supplies. On 29 November the Minister for the Environment and Energy gave the key note address and was followed by 12 other speakers. I am commenting on three of these presentations. All of them are available at http://energy.anu.edu.au/news-events/energy-update-2016, including the Minister's talk.

The venue and the timing was a good opportunity for the Minister to provide information on the Chief Scientist's review of Australia's National Electricity Market (NEM).

Frydenberg's review of the National Electricity Market

Against a background of student activists chanting 'Don't burn dirty coal, keep it in the ground' and 'Keep our gas at home', the Minister gave what I thought was an excellent review of the current situation regarding the NEM.

The NEM is the longest geographically connected power system in the world, extending from Port Douglas in Queensland to Port Lincoln in South Australia. It supplies all the states and territories of eastern and southern Australia and generates around 200 terawatt hours of electricity annually, or about 80% per cent of our electricity consumption. The goal is to have a secure and affordable electricity system for households and industry that is resilient and can handle the loads and stresses that will be placed on the infrastructure that supports it.

The NEM is changing as manufacturing industry contracts and the service sector expands. New technologies are changing the way energy is generated and delivered to consumers and Australia is committed to reducing its greenhouse emissions. A series of recent events brought these issues into focus. The Bass Strait cable between Tasmania and the mainland was severed and remained out of action for six months, the Heywood interconnector between South Australia and Victoria failed, and a storm in September 2016 caused several electricity pylons to collapse in South Australia. To make matters worse, the Hazelwood Power Station is expected to close in March 2017. The Minister pointed out that although it is an older power station and a high emitter of carbon, it also provided 22 per cent of Victorian operational electricity demand in 2015 and is a significant source of electricity for South Australia.

He also reminded attendees that the NEM was based on 'a system powered by the big spinning machines of coal-fired generators - rotating 50 times a second which provide power at a steady frequency of exactly 50 Hz, and that coal is increasingly being replaced by the intermittent, non-synchronous generation of renewables like wind and solar.'

Furthermore, although 'the costs of solar PV and wind generation have fallen further and faster than any pundits predicted even five years ago, new-build solar and wind cannot compete yet with existing coal fired power or gas on price.' 'However, a 2016 Australian Power Generation Technology report estimates that wind and solar PV are cost-competitive with new build generators of equivalent emissions profiles, such as fossil fuel generators with carbon capture and storage, and that by 2030 wind and solar generation will be cost competitive with new build technologies generally.' He also said that 'Consumers, hungry for renewable energy, battery storage and more energy efficient technologies to manage their household energy bills, are driving change in the electricity market and leading to a more distributed grid. There are now 1.5 million households in Australia with solar PV installed and over 1 million solar hot water systems and, by 2030, it is estimated that 24 per cent of installed capacity in the National Electricity Market will be rooftop solar. A major problem is that 'in 2015, only 4.9 per cent of Australia's national electricity generation came from wind generation, and 2.4 per cent came from solar.' There is a long way to go.

Because of these challenges, the Minister arranged for the COAG Energy Council to commission Dr Alan Finkel, Australia's Chief Scientist, to examine what energy market reforms are needed, together with a new national approach to energy security and reliability. A preliminary report was released in December 2016: https://www.environment.gov.au/system/files/resources/97a4f50c-24ac-4fe5-b3e5-5f93066543a4/files/independent-review-national-elec-market-prelim.pdf.

This report identifies some key questions for the future of our energy system. One of these is:

- What role should the electricity sector play in meeting Australia's emissions reduction targets?

This set the cat among the pigeons and some factions of the government objected stridently to this question because the review may recommend a carbon tax or a carbon trading scheme. As a result, Prime Minister Turnbull abandoned a review of the Direct Action emission reduction scheme. It just shows what a sensitive political issue climate change is for the current government.

Anyway, if anyone wants to provide input to the review the details can be found on: http://www.environment.gov.au/energy/national-electricity-market-review. Submissions are invited until 21 February and the report is due to be presented to COAG in mid-2017.

Mark Howden: Climate change: an overview of the science, public attitudes and the politics

Mark Howden from the ANU Climate Institute reviewed the current observations of climate change, particularly those that affect Australia and the public attitude towards climate change here.

According to Howden:

- 46% of Australians consider that climate change is happening and

human-influenced, 38% that it is happening but natural, and 8% say it is not happening (what happened to the other 8% is not known)
- Most of the 'not happening' category related to media 'balance'
- There was an optimism bias (going to affect others more than me) across all groups
- And psychological distancing (problem far away or in the future) across all groups
- BUT climate adaptation was supported across the political divide (74% want more action): linked to relevance, ethics/moral position and trust in the science/scientists.

How big the sample was and what can be done with these results to improve practical policy development is not clear.

What I did find interesting was the climate spirals produced by Ed Hawkins of the Climate Lab in the UK and shown by Howden for temperature and CO_2 levels. The increases in temperature and CO_2 levels globally are well known, but the presentation is usually restricted to simple graphs of temperature or CO_2 concentrations versus time. What Hawkins and his team have done is made a dynamic presentation that provides another way at looking at these parameters.

If you visit the url: https://www.climate-lab-book.ac.uk/spirals/, you can also see other variables, such as Arctic Sea ice. The figure below is taken from this website and it's certainly worth a look as you can watch the changes month by month.

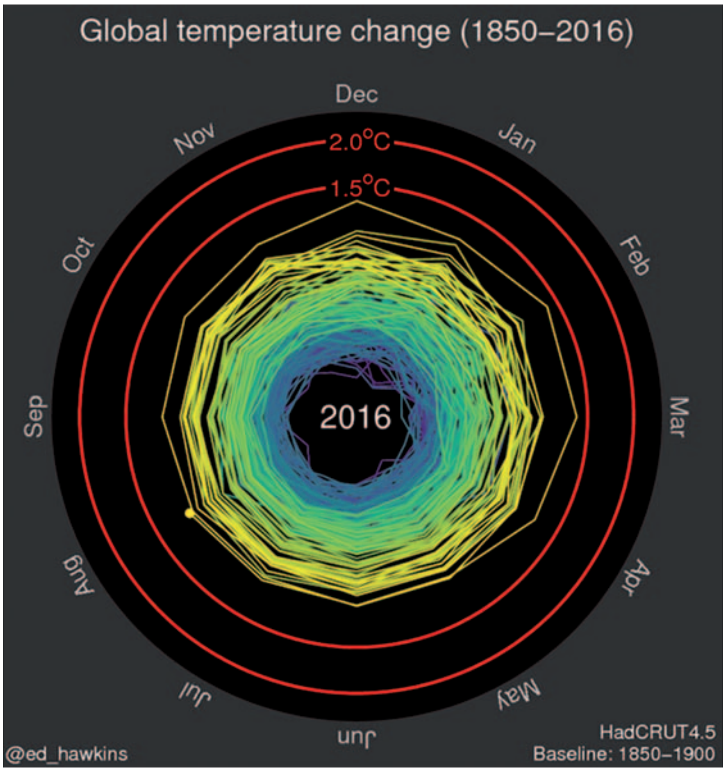

Figure 1. *The final image of the temperature spiral taken from http://blogs.reading.ac.uk/climate-lab-book/files/2016/05/spiral_optimized.gif and presented by Mark Howden. If you visit: http://blogs.reading.ac.uk/climate-lab-book/files/2016/09/co2.gif you can look at a similar presentation for atmospheric* CO_2 *levels from 1958. Well worth a look, but the variation in* CO_2 *levels is much smoother than the temperature curves, as you would expect.*

Andrew Blakers: 100% renewable energy

The critics of wind and solar energy sources argue that you will always need a background supply of coal, nuclear or gas to provide the base load. Andrew Blakers from the ANU Energy Change Institute tackled this argument head-on and proposed that off-river pumped hydro energy storage (PHES) could, and should, be developed to cope with the no wind/no sun situations.

The concept is simple. An array of solar panels is built near two off-river storage dams with a significant elevation difference of greater than 300 m. The surface areas should be at least 20 hectares and the water should be at least 25 m deep. During the day, the solar cells generate power for the grid and drive pumps to fill the upper reservoir. When the sun is not shining the water from the upper dam falls to the lower dam and generates electricity. In theory, there are hundreds of sites in southern Australia where these criteria can be met and that could be developed.

In practice the costs to construct the infrastructure at each site and connect it to the NEM might be prohibitive, but a prototype is being developed at the abandoned gold mine at Kidston, near Georgetown in Queensland. The Kidston Solar Project involves a huge solar panel array on the main tailings store and three reservoirs based on the old mining pits.

It is not clear how an elevation difference of 300 m is achieved at the site, or whether the evaporation losses will be prohibitive, but it is a worthwhile practical test of the technique. For more information go to: http://www.genexpower.com.au/the-kidston-solar-project.html or have a look at Andrew Blakers' presentation.

Sinodinos replaces Hunt as Minister for Industry, Innovation and Science

Prime Minister Turnbull has moved Greg Hunt from Industry, Innovation and Science (IIS) to Health. Senator Arthur Sinodinos is the new Minister for (IIS).

Sinodinos has a Bachelor of Commerce from Newcastle University, has worked in the Departments of Finance and the Treasury, and was a Director of Goldman Sachs JBWere investment bank before being elected to the Senate in 2011.

Government Ministers have to agile and innovative. Greg Hunt took on the IIS Ministry in July 2016 and was moved to Health in January 2017.

As the Prime Minister said: 'The industry, innovation and science portfolio is critical to generating the jobs of the future and Senator Sinodinos' extensive public policy experience over many, many years gives him a strong understanding of the key drivers of new sources of economic growth and how government can ensure that its policies deliver the innovation, the investment, the technology that will secure the future for our children and grandchildren.'

With endorsements like this we expect great outcomes from the new Minister.

Proposed areas for the 2017 Offshore Petroleum Exploration Acreage Release[1]

The 2017 Offshore Petroleum Exploration Acreage Release area nomination and shortlisting processes are now complete. There were 97 area nominations from 21 companies received, which is similar to previous years. Twenty-two areas have been proposed for inclusion in the 2017 acreage release. Information about the proposed areas is available online at http://www.petroleum-acreage.gov.au/2016/2017-nominations and is summarised in Figure 1 and Table 1.

Bidding on the first work programme round of the 2016 Offshore Petroleum Exploration Acreage Release closed on 8 December 2016. In addition, 12 areas will be re-released and bidding will close on 23 March 2017, in line with the second round of work programme bidding for this release. The areas are:

- AC16-1 to 2.
- W16-1, W16-3, W16-10 to 11, W16-13, W16-15- to 16, W16-19 to 21.

Table 1. List of proposed areas for the 2017 Offshore Petroleum Exploration Acreage Release

Proposed areas	
Bonaparte Basin	NT17-1, 2; W17-1 & 2
Bonaparte & Browse Basins	AC17-1,2,3,4 & 5; W17-3; WA 56-R
Roebuck Basin	W 17-4
North Carnarvon Basin	W17-5, 6 & 7
Exmouth Plateau	W 17-8
North Perth Basin	W 17-9 & 10
Otway Basin	V 17 2 & 3
Bass Basin	T 17-1
Gippsland Basin	V 17-1

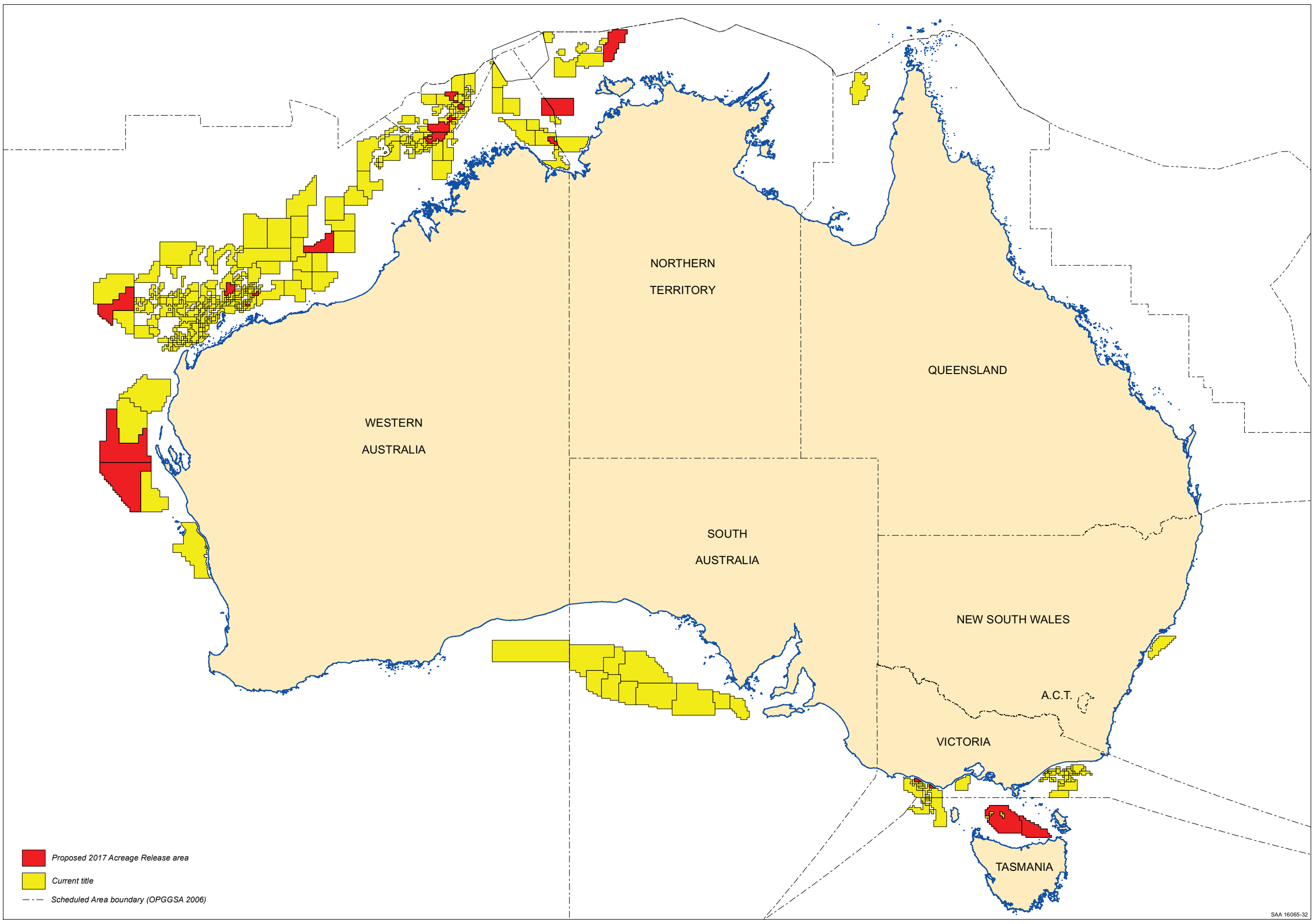

Figure 1. *Location of proposed area for the 2017 Offshore Petroleum Exploration Acreage Release.*

[1]All the information for this article was taken from the December 2016 issue of *Australian Petroleum News*, published by the Australian Government (http://us11.campaign-archive2.com/?u=8ed6f6a545e71ff832ce3e1af&id=d7455f9b32).

The 2015 Offshore Petroleum Exploration Acreage Release finalised[1]

Nine offshore petroleum exploration permits have been awarded with a minimum investment of A$475 million over the next six-years. These are summarised below.

Round one – awarded March-June 2016

WA-521-P (released as W15-5) located approximately 250 km from the northeast coast of Western Australia, was awarded to Carnarvon Petroleum Ltd. It proposed a A$1.32 million guaranteed work programme comprising of 4 000 km of 2D multi-client reprocessed data, 150 km of 2D seismic acoustic impedance inversion and geological and geophysical studies. The secondary work programme comprises acquisition, processing and interpretation of 300 km² of new 3D seismic data and geological and geophysical studies, totalling A$3.57 million. There were no other bids for this area.

WA-522-P (re-released as W14-1) located approximately 400 km from Darwin, was awarded to Woodside Energy Ltd. It proposed a A$13.39 million guaranteed work programme comprising of geotechnical studies, 2D seismic interpretation and acquisition and PreStack Time Migration (PreSTM) processing of 1586 km² of new 3D broadband seismic. The secondary work programme comprises 1500 km² of 3D Full Waveform Inversion studies and one exploration well, totalling A$18.92 million. There were no other bids for this area.

WA-523-P (released as W15-2) is located approximately 470 km from the northwest coast of Western Australia, was awarded to Carnarvon Petroleum Ltd. It proposed a A$2.83 million guaranteed work programme comprising of 3D data reprocessing PreSTM reprocessing of 3 000 km of 2D data and studies. The secondary work programme comprises 210 km² of new 3D broadband seismic data, mapping and one exploration well, totalling A$43.5 million. There were two other bids for this area.

AC/P60 (released as AC14-1) located in the Timor Sea approximately 300 km offshore and 650 km west of Darwin, was awarded to Total E&P Holdings (Australia) Pty Ltd. It proposed an A$8.70 million guaranteed work programme comprising geological and geophysical studies, acquisition or licensing of 700 km² of new 3D broadband seismic data. The secondary work programme comprises geological and geophysical studies and one exploration well, totalling A$26.50 million. There was one other bid for this area.

AC/P61 (released as AC15-1) located approximately 600 km Darwin, has been awarded to Finder No. 1 Pty Limited. It proposed a A$500 000 guaranteed work programme comprising of 330 km² 3D PreSDM seismic data reprocessing and geological and geophysical studies. The secondary work programme comprises 200 km² of reservoir characterisation studies, geological and geophysical studies and one exploration well, totalling A$15.25 million. There were no other bids for this area.

VIC/P71 (released as V15-2) located about 200 km east of Melbourne, has been awarded to Llanberis Energy Pty Ltd. It proposed a A$9.3 million guaranteed work programme comprising of geological and geophysical studies, acquisition, processing and interpretation of 550 km² of new 3D seismic data. The secondary work programme comprises acquisition, processing and interpretation of 1200 km² of new 3D seismic data, two exploration wells and geological and geophysical studies, totalling A$61.8 million. There were no other bids for this area.

Round two – awarded September–November 2016

WA-524-P (released as W15-8) located in the Northern Carnarvon basin has been awarded to Carnarvon Petroleum Limited. It proposed a A$3.4 million guaranteed work programme including 250 km² Broadband PreSDM reprocessing of 3D data. The secondary work programme comprises of well planning and long lead studies and one exploration well, totalling A$26.3 million. There were no other bids for this area.

EPP46 (released as S15-1) located in the Bight basin has been awarded to Karoon Gas Browse Basin Pty Ltd. It proposed a A$25.85 million guaranteed work programme including acquisition or licensing of 5 000 km of new 2D seismic, 2D gravity, magnetic and bathymetric survey data; reprocessing existing 2D data; and acquisition or licensing (and processing) of 2500 km² of new 3D seismic data. The secondary work programme comprises geotechnical studies and one exploration well, totalling A$117.5 million. There were no other bids for this area.

WA-525-P (released as W15-14) located in the Northern Carnarvon Basin has been awarded to BP. It proposed a A$10 million guaranteed work programme including licensing, reprocessing and interpretation of 2300 km²of the Zeus 3D survey plus other 3D surveys over the permit area. The secondary work programme includes one exploration well and data analysis, totalling A$93 million. There were no other bids for this area.

[1]All the information for this article was taken from the December 2016 issue of *Australian Petroleum News*, published by the Australian Government (http://us11.campaign-archive2.com/?u=8ed6f6a545e71ff832ce3e1af&id=d7455f9b32).

Oil price and drilling activity recover in 2016

For the first time in eight years OPEC agreed, in September 2016, to limit oil production to a range of 32.5 to 33 million barrels a day. This is down from an estimated 38 mbl/day produced in 2015.

Given that global consumption has increased consistently by about 1.2% per year from 2005 through 2015 (Table 1), and is expected to have reached 96 million barrels in 2016, it is not surprising that it didn't take long for the oil price to increase after the OPEC decision.

And of course, when the price goes up, exploration investment increases, particularly drilling activity. Baker Hughes has compiled the rotary rig counts as a service to the petroleum industry since 1944, when the Hughes Tool Company began weekly counts of US and Canadian drilling activity. In 1975 Hughes initiated the monthly international rig count. These counts are an important indicator, not only for the drilling industry and its suppliers, but for the whole petroleum exploration industry.

The most recent results plotted in Figure 1 cover the period 2000 through November 2016. As you would expect, there is a strong correlation between the oil price and the number of operating rigs. It turns out there is a lag time now of about four months between a significant price change and the number of rigs operating. In the early 2000s the lag was sometimes as much as two years. If nothing else the drilling industry is now able to respond very quickly to changes in demand.

Canada and the US continue to dominate the rig numbers, probably due to the demand for hydrofracturing, even though the total number of rigs is declining. In 2000 there were approximately 1500 rigs operating each month in North America, while in 2016 the number had dropped about 620. Not only has the number of rigs dropped, but the ratio of North American Rigs to the world total has also declined (Figure 2). This ratio remained between 0.6 and 0.7 from 2000–2014, but by 2016 the share had dropped to 0.4. The Australian count in 2016 averaged only five rigs per month; a huge fall from 1980s when an average of over 30 rigs were operating each month.

There won't be much more oil discovered here unless more drills are working.

Table 1. Global consumption and production of oil

Global consumption and production of oil in millions of barrels/day 2005–2016*											
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Consumption	84.7	85.7	87.1	86.6	85.7	88.8	89.8	90.7	92.0	93.1	95.0
Production	81.9	82.5	82.3	82.8	81.2	83.3	84.1	86.2	86.6	88.8	91.7

From BP Statistical Review of World Energy, 2016; note that 100 million bl/day is ~4.6 billion t/year. https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf.

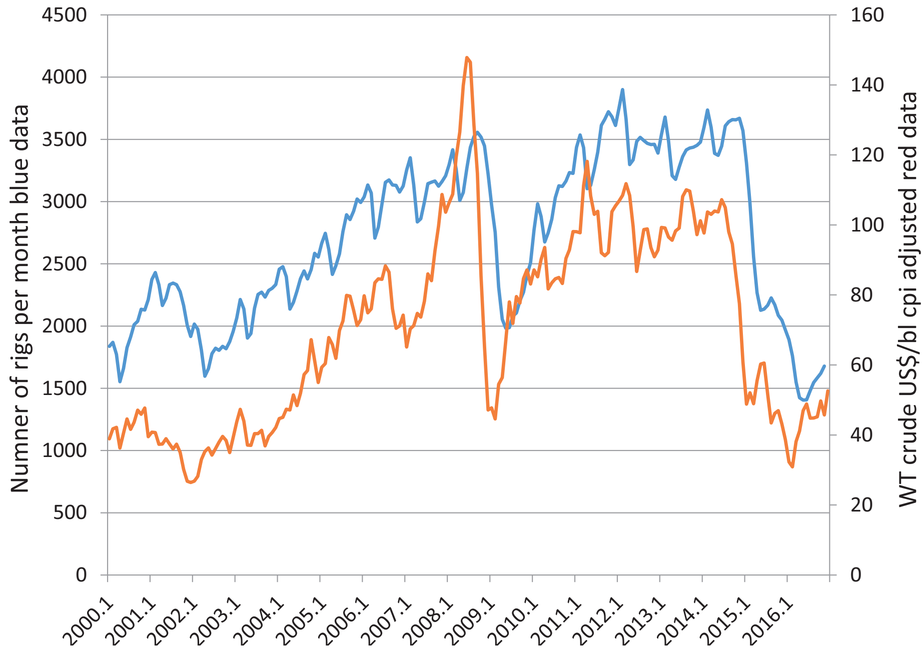

Figure 1. *Monthly global operating rig numbers from January 2001–November 2016, taken from the Baker Hughes rig count (see: http://phx.corporate-ir.net/phoenix.zhtml?c=79687&p=irol-rigcountsoverview). The oil price is the monthly spot price for West Texas crude (http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RWTC&f=M) and the price has been adjusted to December 2016 US dollars to correct for changes in the US consumer price index (http://www.bls.gov/cpi/cpid1503.pdf).*

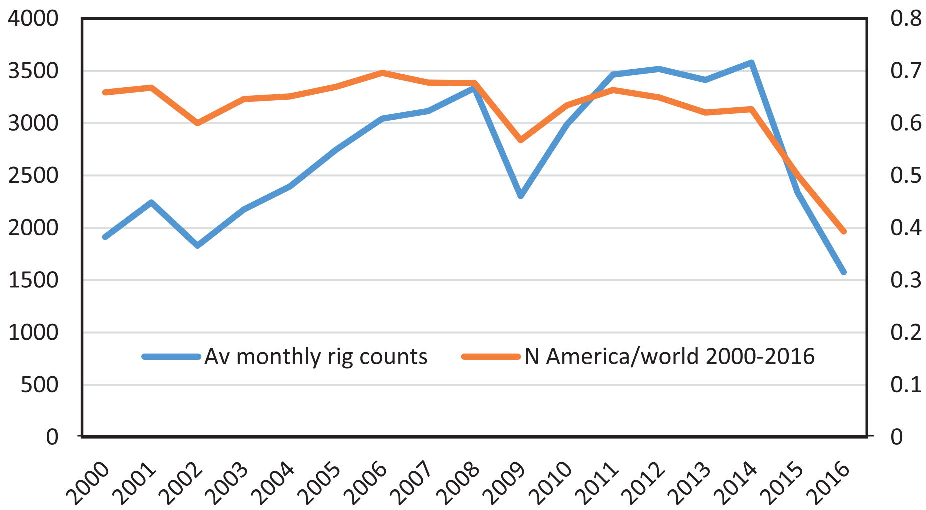

Figure 2. *Average monthly number of rigs operating globally (blue curve), for the period 2000–2016 and the ratio of North American rigs to global count (red curve).*

Education matters

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It is a sad truth that in the present era of compressed undergraduate courses few students of geophysics get to study seismology.

Last year, during a collaboration between Deakin, Melbourne and Monash Universities on using seismometers for the unlikely task of detection of megafaunal bone beds, I asked Gary Gibson to clarify for me the meaning of the many measures of earthquake magnitudes and, with tongue somewhat in cheek, I also asked for his comment on our 2016 ASEG conference logo. Gary is a Principal Research Fellow at Melbourne University, and one of Australia's most senior seismologists.

25th ASEG-PESA-AIG conference logo.

Gary's discussion of quake magnitudes, ranging from rumbles we barely feel to those which notionally split the earth, appear in the article below.

Emma Brand, Chair of the ASEG Education Committee, also brings us a review of the role of the Committee and advance notice of two forthcoming OzStep courses in our continuing professional education programme; with one seismic and one EM-inversion course, there is something for each of us to enjoy as we sharpen our skills.

Earthquake magnitude 12?

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We hear about very large earthquakes with magnitudes 10 or 12, especially from fiction writers and Hollywood, but just how large can an earthquake be?

Earthquakes vary widely in scale. The largest earthquake recorded (Chile, 22 May 1960, (energy) moment magnitude Mw 9.5) released about 106 times as much energy as Australia's most damaging earthquake of recent decades (Newcastle 1989, ML 5.6). Extending the scale, the Chilean Mw 9.5 quake released 1012 times as much energy as a very small earthquake that is only felt within a couple of kilometres (ML 1.5) – such as minor movements in the Sydney basin. More on the different units Mw and ML is given below.

An earthquake is the motion produced when stress within the earth exceeds the strength of a fault, which then fails, with one side of the fault moving (slipping) relative to the other giving a permanent displacement. The point on the fault where the rupture starts is called the earthquake hypocentre or focus, and the point on the earth's surface vertically above it is called the earthquake epicentre.

Once started, a rupture can propagate predominantly in one direction from the hypocentre, so that the hypocentre may be at one end of the rupture (e.g. Nepal, 2015, Mw 7.9). Alternatively, it can propagate in all directions so that the hypocentre may be near the centre of the final rupture (e.g. Chile, 2010, Mw 8.8).

Much energy is required to maintain the propagation, with most being converted to heat and some to seismic wave energy. The fuel maintaining the rupture is the available stored tectonic strain energy in the volume surrounding the fault. If the fault ruptures into an area without high stress (i.e. with low tectonic strain energy density), the rupture will slow and/or stop.

As the tectonic deformation continues the strain, strain energy density and stress rebuild, and the weakest point on the fault is the likely location of the initial rupture for future earthquakes. After each earthquake the total slip between the two blocks increases and the fault dimensions (length, width, area) may increase slightly, so the fault may be capable of a slightly larger earthquake next time. The fault may eventually become the dominant fault within the locality, and will be the mechanism for most of the strain energy release within the vicinity.

Earthquake size can be measured in many ways, such as energy release, fault rupture length, duration of motion, radius of perceptibility, and especially the level of ground motion recorded at a seismograph some distance from the earthquake.

Energy release is difficult to measure because the proportion of energy released as heat and seismic ground motion varies, the seismic wave radiation pattern varies with direction depending on the orientation of the fault, and the absorption of seismic wave energy with distance varies with geology, leading to uncertainties in attenuation of ground motion with distance, especially for the higher frequency motion experienced from smaller earthquakes.

Earthquake magnitude scales are defined to characterise the size of an earthquake using one of these measures, most commonly a measure of earthquake ground motion.

These can include measures of motion that are permanent, such as the area, length, width or the slip that occurs during the earthquake. They can also be measures of the transitory seismic wave motion as recorded on seismographs, with the wave motion measured as displacement, velocity or acceleration, usually recorded as a function of time in three orthogonal directions (east, north and up). This motion can be simplified by using parameters such as peak ground displacement (PGD), velocity (PGV) or acceleration (PGA), or alternatively using parameters relating to the spectral content (also using displacement, velocity or acceleration, and three components).

Unfortunately, the ground motion measurements possible vary greatly from small to large earthquakes, and from near to distant earthquakes. This has resulted in a range of different magnitude scales from ground motion measurements that are each applicable for certain magnitude ranges, and distance ranges.

For example, the original Richter magnitude, ML, is used for small earthquakes recorded within 600 kilometres. This takes the logarithm to base 10 of the peak body wave (P or S) horizontal ground displacement and applies a simple empirically determined correction for attenuation that varies with distance. This depends on the properties of local rock types, with unconsolidated sediments giving rapid attenuation with distance, while hard crystalline rocks (e.g. Australian Shield) give relatively little attenuation with distance beyond inverse square geometric spreading.

The body wave magnitude, mb, is used for moderate magnitude earthquakes beyond 2000 km, also uses ground displacement and has a tabular distance correction that corresponds to the less variable attenuation of waves through the mantle compared with the dominance of crustal motion as used with ML.

A range of moment magnitudes Mw, Mww, Mwp, Mwc, etc are determined from long-period frequency spectra used for moderate to large earthquakes. The variation in spectral attenuation in crustal rocks limits the use of this method for nearby earthquakes, especially smaller earthquakes with dominant high frequency motion.

In addition, there are magnitude scales based on the duration of motion, MD, and radius or area of perceptibility, MP, used mainly for determining magnitudes of historical earthquakes.

All scales were defined to conform as closely to the Richter magnitude ML as possible, but since each uses a different measurement, the relationships are non-linear, and conversion plots or functions and range limits for magnitude and distance are needed. Since these are different depending on local geology, local differences in methodology and practice have developed.

It might seem reasonable that to reduce confusion, the magnitude should be converted to a single defined value. Modern conventions include the GSHAP method where magnitude M is based on ML, mb and Mw, over different magnitude ranges (ML or mb depending on distance for events below Mw 5.0, and Mw for those events larger than Mw 5.0), giving a scale that retains all past values.

An alternative is a trend to converting all magnitudes to Mw, although it is not easy to measure Mw values smaller than Mw 5.0, and certainly not less than Mw 4.0. This method also results in the need to re-compute millions of earthquake magnitudes (mainly ML and mb) using empirical conversion functions that will not be universally applicable.

Most earthquake hazard studies consider only earthquakes above Mw 5.0, as damage from smaller events is rare, so a conversion, if used, has little impact on hazard estimates. At this stage giving the magnitude type and value as measured, without a conversion, is probably the best we can do.

If an earthquake is very shallow it may rupture the surface. For some earthquakes, the surface rupture gives the total length of the fault, while for others the rupture may extend further at depth, so the surface rupture length is only a fraction of the total length. However, most earthquakes do not rupture the surface at all.

A better way of establishing the fault length and width is to install a high-resolution seismograph network that will allow determination of precise locations of aftershocks to an accuracy of one kilometre or less in longitude, latitude and depth. For this reason groups such as Geoscience Australia and University of Melbourne maintain boxed sets of seismographs ready for immediate shipping and deployment when a significant quake occurs on the continent, such as the Petermann Ranges (west of Uluru) earthquake of magnitude Mw 6.1 on 20 May 2016 (the largest earthquake within Australia for 19 years).

Aftershocks are often on the original rupture or around the edge of the rupture, thus delineating the rupture and allowing estimates of area, length and width. However, many aftershocks may be on smaller related faults and delineate the surrounding volume that has experienced stress change in the earthquake, rather than the main rupture itself. Although relatively few earthquake ruptures can be delineated, and these are mainly only for larger earthquakes, they are used to determine relationships between magnitude and fault rupture parameters.

The following table shows approximate empirical relationships between magnitude and several parameters such as rupture area, fault length and width, fault slip and rupture duration. Earthquakes vary from simple one fault ruptures to very complex ruptures, some have simple geometry (e.g. approximating a circular plane rupture or a rectangular plane as often used in theory) while most have varying rupture outline shape or varying slip across the rupture. The aspect ratio of a fault rupture can vary from length = width, to length = 10 times width or more, especially for large crustal faults.

The values of area, length, width, slip or duration will usually be within the range from half to double the quoted value, depending on the stress drop from the earthquake, with a higher stress drop giving smaller ruptures.

The slip value depends on fault strength, and gives an indication of the deformation needed to trigger the earthquake. The rupture duration depends on fault properties that determine the rate at which the rupture propagates across the fault plane, usually at about three kilometres per second.

The actual slip motion between the two sides of the fault at any point along the fault is much slower, and is usually up to a couple of metres per second. At such a point the time between the start of slip movement until the slip has ground to a halt will be measured in seconds for larger earthquakes, and fractions of a second for smaller earthquakes. This is a much shorter period than the total rupture duration along the fault as a whole, as described above. For larger earthquakes, by the time the slip finishes at one point on the fault, slip movement may have initiated kilometres away, further along the fault.

The table was empirically determined using earthquakes in the range from Mw = 4 to Mw = 8. Because of the

Table 1. Approximate fault parameter values as a function of magnitude. Extrapolation to magnitudes higher than about Mw 9.5 requires faults larger than are currently available

Moment magnitude Mw	Rupture area (km^2)	Typical rupture size Length × width (km × km)	Fault slip Length/20 000 (metres)	Rupture duration Length/3 (seconds)	Average number, World (per year)
4	1	1 × 1	0.05	0.3	20 000
5	10	3 × 3	0.15	1	2000
6	100	10 × 10	0.50	3	200
7	1000	30 × 30 50 × 20	1.5	10	20
8	10 000	100 × 100 200 × 50	5	33	1
9	100 000	500 × 200 1000 × 100	25	170	0.05
10	1 000 000	1000 × 1000 5000 × 200	50	333	0
11	10 000 000	3000 × 3000 30 000 × 300	150	1000	0
12	100 000 000	10 000 × 10 000 300 000 × 300	500	3000	0

arbitrary definition of the original Richter magnitude, it is probably just a coincidence that a magnitude Mw = 4 gives a 1 square kilometre rupture, and that there is a factor of 10 in rupture area for each unit change in magnitude.

For intraplate earthquakes within continents, where the seismogenic zone extends down to just tens of kilometres, usually just 20 to 30 kilometres, and faults are rarely much longer than 100 kilometres, the typical maximum credible earthquake is usually less than about Mw 7.5.

Large subduction interface earthquakes may reach a little over Mw 9.5, but require very long subduction zones (over 1000 km), and deep subduction that can give a rupture width extending down to about 300 km. The largest subduction zones are along the west coast of South America, the Tonga-Kermadec Trench south of Fiji, the Sunda Trench south of Indonesia, and the large trenches in the north-west Pacific (Aleutian, Kuril, Japan and Mariana Trenches). All known earthquakes larger than Mw 9.0 have occurred on these subduction zones.

For plate boundary earthquakes, large strike-slip earthquakes may rarely exceed Mw 8.5, because of length limitations along existing boundaries and especially because of rupture width limitations imposed by the shallow seismogenic depths available.

The table can be extrapolated down to smaller earthquakes, below magnitude 0.0 and will give reasonable estimates (within half to double depending on stress drop). If we extrapolate to magnitude 12, then the values for magnitude 9 seem reasonable, but for magnitudes 10 to 12 the fault lengths and/or widths available at plate boundaries are not enough to provide the tectonic strain energy needed. An Mw 12 quake implies a 10 000 km × 10 000 km displacement, comparable with the Earth's diameter of 12 742 km.

Perhaps the impact of a large object from space may give such an event. Or, returning to the question Michael Asten asked me last year, a truly earth-shattering ASEG conference might just do it!

The ASEG Education Committee: what can we do for you?

Emma Brand
ASEG Education Committee Chair
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2016 was a tough year, once again, for geophysicists. If you weren't personally affected by the cuts across the industry, I'm sure you will know plenty of friends and colleagues that were. It's not news to state that geophysics is a highly specialised profession. We are deep technical experts. In boom times our profession is in high demand and we are very well compensated for our skills. During down times the first cuts are to the exploration budget, which means our once highly prized, well compensated skill set is no longer valued by our industry. This leaves many of us in the unenviable position of having to fight it out against more and more candidates in a smaller pool of roles, waiting for the industry to pick back up.

The question that I posed to myself during the uncertainty of the last several years was: what happens if my role is made redundant? In an industry with very few new roles and an uncertain future, how do I 'future proof' myself? How do I ensure that I have a skill set that is mobile and flexible and, more importantly, if worst came to worst, understood outside of my industry?

As I took up the role of chair of the ASEG Education Committee late last year, stepping into the huge shoes left by Wendy Watkins, I began to think further about what it means to be a practicing geophysicist. Throughout my ten year career in the oil and gas industry I've interpreted seismic data and undertaken quantitative analysis, I've planned and drilled wells, I've worked on exploration prospects and on oil fields that have been producing for 50 years, I've planned and executed seismic surveys, I've managed people, I've managed projects, I've collaborated in multi-disciplinary teams.

How many times have you been to a dinner party and had to explain what it is that a geophysicist actually does? My typical line is that we work out what is in the ground without having to dig a dirty big hole. That might be all well and good over a cocktail but, if you had to, how would you translate your deep, specialised skill set and incredible range of experiences into something that is recognisable outside of our industry?

This year the Committee, consisting of the wonderful, thoughtful and experienced crew of Jarrod Dunne, Megan Nightingale, Chris Wijns and Tim Dean will tackle the broad question of how the ASEG Education Committee should respond to our current resource industry landscape in order to benefit our Members. For instance, how do we determine topics for OzStep? How can we provide the support needed to our Members to translate their skill sets outside of our industry? Should the Education Committee 'push' OzStep topics, or 'pull' topics that are requested by Members or is needed by the industry? Can we do more to address upskilling recent graduates into the industry? And more importantly, what else might our Members be interested in?

So, I throw this question out into the ether and solicit your responses: what would you be interested in seeing the ASEG Education Committee organise in 2017?

Upcoming OzStep courses: 'Reservoir Geophysics – Applications', a one-day course by Bill Abriel will be held at various locations in May. Doug Oldenburg will also be giving a course on EM-inversion. Stay tuned for more information.

SEG Distinguished Lecturer 2017: Paul Hatchell

Getting more for less: frequent low-cost seismic monitoring solutions for offshore fields

Paul Hatchell

Summary

Time-lapse seismic reservoir surveillance is a proven technology for offshore environments. In the past two decades, we have seen this technology move from novel to necessary and enable us to monitor injection wells, water influx, compaction, undrained fault blocks, and bypassed reserves. Value is generated by influencing the management of our field operations and optimising wells to reduce cost, accelerate production, and increase ultimate recovery.

Significant advances in technology are improving the quality of our data. Errors in acquisition repeats are nearly eliminated using permanently installed systems or dedicated ocean- bottom nodes. We now routinely obtain surveys with such a high signal-to-noise ratio that we can observe production-induced changes in the reservoir after months instead of years. This creates a demand for frequent seismic monitoring to better understand the dynamic behaviour of our fields. Increasing the frequency of seismic monitoring will have a proportionate cost implication, and a challenge is how to design a monitoring program that maximises the overall benefit to the field.

Reducing individual survey costs is important to enable frequent monitoring. Several techniques are considered for lowering these costs such as:

- Reducing the number of shots and/or receivers to minimise offshore vessel time. This includes shooting targeted (i4D-style) surveys on a frequent basis in between full-field surveys that are acquired infrequently.
- Use of smaller source arrays towed by less-expensive vessels.
- Semi-permanent ocean-bottom nodes that can be left on the seafloor for multiple on-demand surveys.
- Time-lapse VSPs that use permanent distributed acoustic sensors (DAS) in well bores.
- High-resolution 4D surveys that monitor shallow reservoirs cost effectively using low-cost vessels towing arrays of short-streamer cables (e.g. P-cable).

There is no single solution that works for every field, and we need to understand the pros/cons of the various technologies to select the best option for a specific field. Some results of applying these techniques to offshore fields will be discussed.

Biography

Paul Hatchell joined Shell in 1989 after receiving his PhD in theoretical physics from the University of Wisconsin. He began his career at Shell's Technology Center in Houston and worked on a variety of research topics including shear-wave logging, quantitative seismic amplitude analysis, and 3D AVO applications. Following a four-year oil and gas exploration assignment in Shell's New Orleans office, Paul returned to Shell's technology centres in Rijswijk and Houston where he is currently a member of the Areal Field Monitoring team and Shell's principal technical expert for 4D reservoir surveillance. His current activities include developing improved 4D seismic acquisition and interpretation techniques, seafloor deformation monitoring, and training the next generation of geoscientists.

Australian schedule:

3 April 2017	Perth	University of Western Australia
3 April 2017	Perth	ASEG WA Branch meeting

Environmental geophysics

Mike Hatch
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Welcome readers to this issue's column on geophysics applied to the environment. I was having trouble coming up with interesting material for this issue (think about thinking about this over the Christmas holidays) and thought that I would try to crowd-source some ideas from some of my friends and acquaintances in the field of environmental geophysics – my thought was to write about some of the holy grails…

One of those holy grails is what to do in highly saline environments to identify aquifers and characterise them. Most of the signal in any electrical survey just doesn't penetrate very far into highly conductive ground, and the contrasts between where there is water that is easy to extract and where it isn't can be is very subtle. Well, Dave Walsh of Vista Clara has been doing some testing in some areas that are pretty saline and has been finding that NMR can do a great job of separating the aquifers from the aquitards and characterising hydrogeologic properties in these challenging environments. Here is Dave's story.

Identifying and characterising aquifers in saline environments

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Motivation for this work lies in the fact that the world's groundwater supplies are getting more and more stretched, and there is increased need for non-potable water for industrial and commercial use. Additionally, *in situ* mining operations, where mineral resources dissolved in saline groundwater are extracted through production wells, are increasingly common worldwide (Beverley and Honeymoon are both examples of *in situ* uranium mines in South Australia). Important mineral resources that are commonly extracted through *in situ* mining include uranium, gold, lithium, potash and copper. In areas where freshwater resources are scarce, such as in the China Lake basin in the southern California desert, water managers are increasingly investigating deeply sourced brackish groundwater as a potential resource for domestic and industrial water supplies (https://gemcenter.stanford.edu/research/aquifer-characterisation-indian-wells-valley-california-using-geophysical-techniques). In all of these settings (most of which are likely to be high in TDS) it is important to know the properties and location of the aquifers – which is hard to visualise using standard geophysical techniques.

Geophysical methods based on nuclear magnetic resonance (NMR) are being tested and used for saline aquifer investigations because they can provide direct and reliable estimates of key aquifer properties, including how much of the water at a given location is tied up in fine grained material (i.e. is bound) and how much of it is mobile, leading to the ability to make high quality estimates of hydraulic conductivity, even in cases where the groundwater is very electrically conductive. NMR logging tools have been successfully employed in highly conductive brine and petroleum reservoirs by the oil and gas industry for decades; this ability is now being extended to use in groundwater surveying.

When a NMR logging tool is immersed in an electrically conductive fluid and porous medium, the transmitted and received RF fields are affected via electromagnetic skin effects (as are inductive techniques), resulting in some reduction in field intensity. This reduction, if unaccounted for, can lead to underestimation of water content and porosity measurements. For example, Table 1 shows the NMR water content measured by a typical small diameter NMR logging tool (Javelin JP238, Vista Clara Inc.) in fresh, brackish and saline water. The results indicate that using a fresh water calibration, there are negligible effect on detected water content in brackish water with electrical resistivity of 0.5 ohm-m (2000 mS/m). A moderate

Table 1. Experimentally measured effects of electrically conductive water on the NMR-estimated water content of a Javelin JP238 NMR logging tool. Values are derived using fresh water calibration values

		Water content measured by NMR		
Operating frequency	**Diameter of cylindrical NMR sensitive shell**	**Fresh water (160 ohm-m)**	**Brackish water (0.5 ohm-m)**	**Saline water (0.1 ohm-m)**
432 kHz	21 cm	100%	96%	75%
365 kHz	23 cm	100%	98%	75%
305 kHz	26 cm	100%	100%	73%
248 kHz	30 cm	100%	100%	79%

effect on estimated water content is observed in saline water at 0.1 ohm-m (~10 000 mS/m) – remember that the ocean is about 0.2 ohm-m (5000 mS/m). NMR relaxation times, used to determine pore size and permeability are generally unaffected by the increase in salinity.

In practice, the effect of conductive water in earth formations is lower than suggested by Table 1, because the electrically conductive water fills only a fraction of the volume between the tool

accurate inversion of water content and other aquifer properties can be realised

and the NMR sensitive zone, so the bulk electrical conductivity is much lower than for the fluid alone (Archie's Law). No conductivity corrections are applied to the data in Table 1 and the accuracy in very conductive formations can be further improved if necessary using a calibration of the tool in a brine tank.

It is also well known that an electrically conductive earth affects the depth of investigation for surface NMR measurements. Again, as long as the electrical conductivity structure of the subsurface is known (via electrical resistivity or induction surveys), the effect of the electrically conductive earth on the magnetic field patterns can be accurately modeled and accurate inversion of water content and other aquifer properties can be realised (Weichman, 2000).

An example of the use of NMR geophysical measurements to characterise a saline aquifer system was demonstrated at a groundwater investigation site at Leque Island, in western Washington, USA. This site is an agricultural field that was previously reclaimed from marshland, adjacent to Puget Sound (an inland saltwater body). The upper 20 m of the subsurface consists of interbedded, unconsolidated sediments, varying from sand and gravel to silt and clay. Groundwater samples obtained from shallow monitoring wells at the site ranged from relatively fresh to brackish, with electrical conductivity measurements on groundwater samples ranging from 250 mS/m (4 ohm-m) to 2500 mS/m (0.4 ohm-m). Figure 1 shows a collocated direct push EC measurement (Figure 1a) and direct push NMR measurement using a JP238 NMR logging probe (Figure 1b–e). The NMR measurement (Figure 1b) and the NMR derived aquifer properties (Figure 1c–e) clearly indicate three distinct high permeability zones corresponding to well sorted sands and gravels, denoted as zones 1, 2 and 3. The NMR data in these zones were used to derive quantitative estimates of hydraulic conductivity that compared well to direct hydrologic measurements (Knight et al., 2016). In contrast, the direct push EC log (Figure 1a) shows much less correlation with aquifer properties and permeable zones. The EC log does clearly show that the groundwater transitions from relatively fresh above 5m, to relatively saline below 5 m.

In addition, 2D surface electrical resistivity (ERT) and 1D and 2D surface NMR data sets were collected along two parallel transects at this site. The ERT inversion, shown in Figure 2, (the direct push EC and NMR measurements shown in Figure 1 were collected on this transect), shows that this site is quite conductive, with some correlation between the slightly higher resistivities at the surface and the uppermost permeable layer between 3 m and 7 m (if you really squint at the section). The 2D surface NMR inversion (Figure 3), collected along a transect 100 m south of the ERT line, indicates a clear and laterally continuous aquifer zone between depths of 3 m and 7 m, and a lower, laterally discontinuous aquifer zone at a depth of about 15 m.

There is no question that there are shortages of drinkable water worldwide and that we need to make better use of the various qualities of groundwater that are available to us. NMR may offer a method to better characterise and delineate those groundwater resources that have been previously considered to be less than desirable and are also (therefore) hard to delineate.

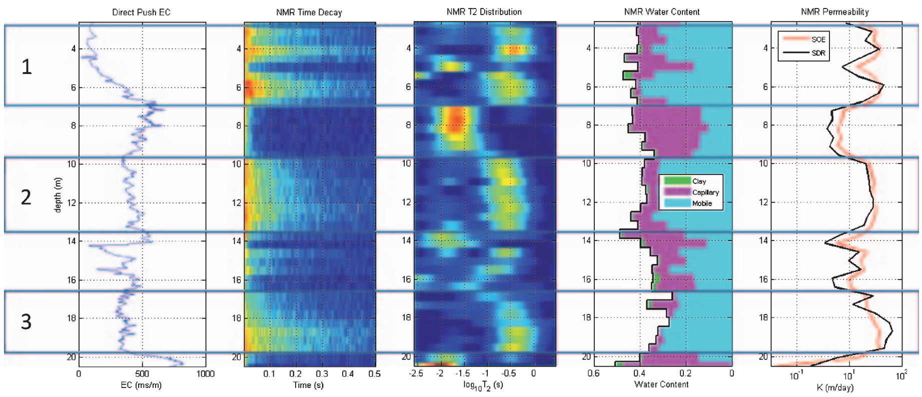

Figure 1. *Comparison of direct push electrical conductivity (a) and direct push NMR measured aquifer properties (b – e) at a site with brackish and saline groundwater, Leque Island Washington. The direct push EC log is dominated by the conductivity of the groundwater at this site, and hence provides little indication of the existence of the three high permeability zones. The direct push NMR log clearly indicates the presence and extent of three high permeability zones and provides quantified estimates of bound and mobile porosity and hydraulic conductivity.*

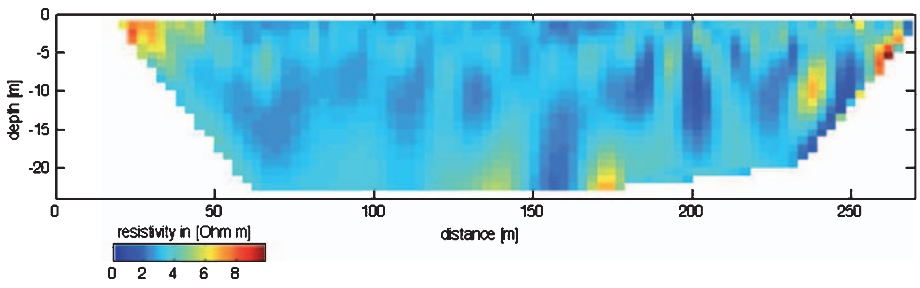

Figure 2. *2D electrical resistivity inversion, Leque Island Washington, USA, 2013. The electrical resistivity measurements are dominated by the conductivity of the groundwater below 5 m, and hence indicate little variability below 5 m.*

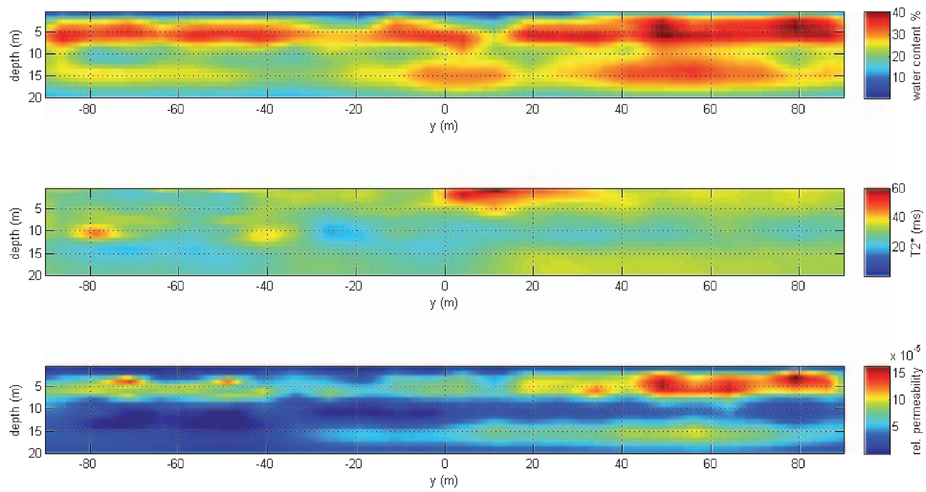

Figure 3. *2D surface NMR inversion, Leque Island Washington, USA, 2013. The 2D surface NMR inversion clearly indicates the presence of a laterally continuous upper aquifer at a depth of about 5 m, and a laterally discontinuous aquifer at a depth of about 15 m.*

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Minerals geophysics

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In 2016 CSIRO Mineral Resources completed the Uncover: Cloncurry project and formally presented their results. To me, the idea that systematic and multidisciplinary measurements on critically selected drill-core and hand specimen samples can be extrapolated to add to the understanding of district scale mineralising processes is one of the ways into the future for mineral geophysics.

Jim Austin and his colleagues at CSIRO have summarised some of their methodologies and findings (with an emphasis on mineral geophysics) for this edition of *Preview*. I invite you to read on.

Integrating knowledge from structural, geochemical and petrophysical analyses at sample to regional scales: new insights into the Mount Isa Eastern Succession

Jim Austin, Ben Patterson, John Walshe and Michael Gazley
CSIRO Mineral Resources

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Background

The Uncover: CLONCURRY project was funded in 2015 by Round 3 of the Queensland Government's Industry Priorities Initiative. The funds gave CSIRO Mineral Resources the opportunity to work with the Geological Survey of Queensland (GSQ) and industry partners, including: Minotaur, MIM-Glencore, Exco-Copperchem, CST, Sandfire, Hammer Metals, Red Metal and Chinova, in developing mineral systems based exploration in the Mount Isa Eastern Succession. The aim was to undertake integrated petrophysical and geochemical/mineralogical micro-characterisation of deposits across the Cloncurry District, and to use those data to better understand the structural, metasomatic and metallogenic processes that led to formation of the diverse styles of mineralisation of the Cloncurry District, within the architectural and geodynamic framework of the Mount Isa Eastern Succession.

The techniques utilised can be summarised in Figure 1, and include petrophysical analysis (e.g. density, remanent magnetisation, magnetic susceptibility, anisotropy of magnetic susceptibility (AMS)), and mineral mapping techniques (e.g. micro X-ray fluorescence (µXRF), rapid scanning electron microscopy (SEM) and micro X-ray computed tomography (µCT), and hyperspectral mineral mapping).

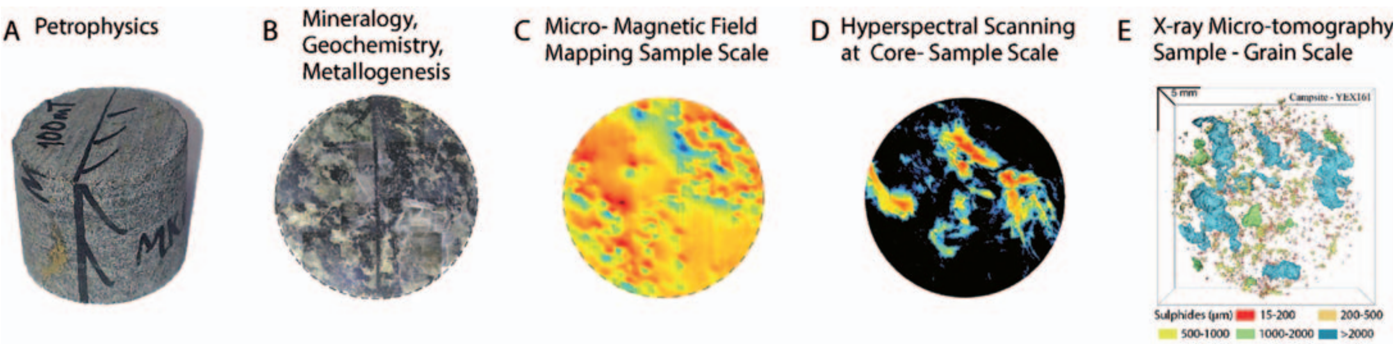

Figure 1. *Samples obtained for petrophysics were subjected to suite of geochemical and mineralogical analyses, and utilised for various mineral mapping techniques (e.g. micro-magnetic field mapping, hyperspectral mineral mapping and X-ray micro-tomography).*

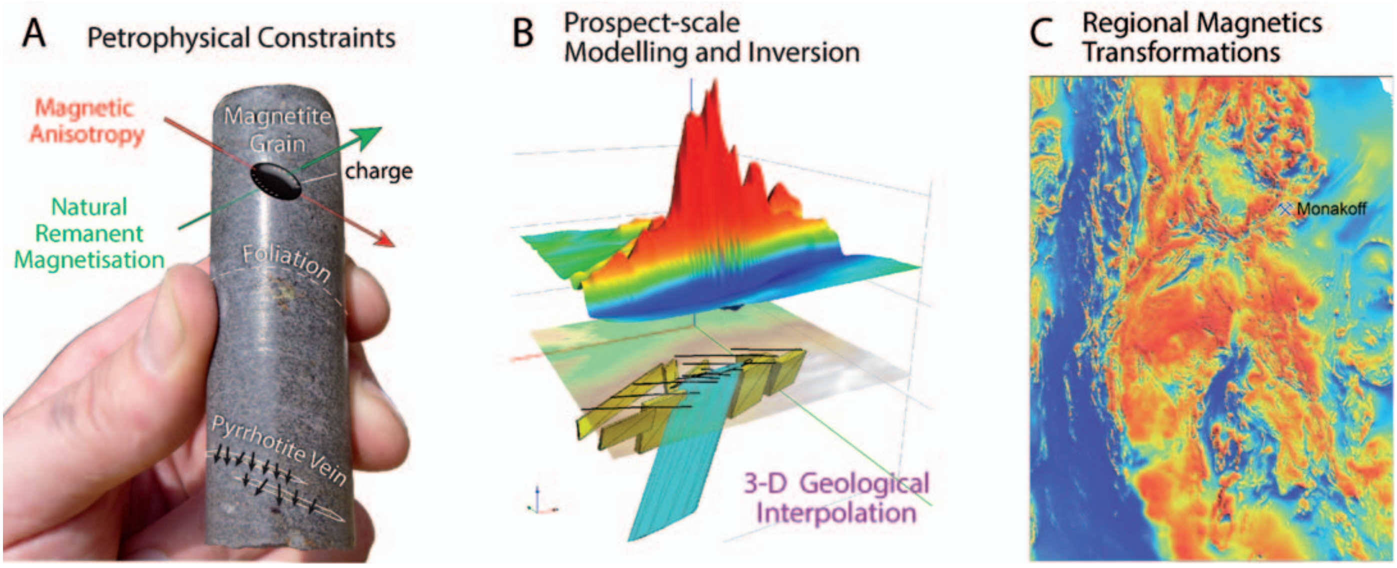

Figure 2. *Petrophysical analyses were used to constrain deposit/prospect scale modelling of specific mineralisation styles, and also to constrain transformations of the magnetic field.*

A strength of this integrated, multi-deposit approach is the creation of an internally-consistent dataset of samples analysed in a consistent manner. This facilitates direct comparisons between deposits, and enables application of insights gained at the deposit scale, resulting in a better understanding of the mineral system as whole (e.g. Figure 2).

AMS data were obtained for at least one specimen from almost every sample obtained from 17 deposits and prospects across the Cloncurry District, possibly constituting the only such dataset compiled across an entire mineral system ever collected.

AMS data are used to quantify structural fabrics within the mineral system, and are used to identify potential structural controls. In many cases it is possible to differentiate fabrics within different parts of the system, e.g. host rocks, mineralised zones, and overprinting relationships. It is also possible to identify fabrics caused by re-activation of pre-existing structures, as well as extensional fabrics. The structural insights provided by the AMS measurements provide a fundamental insight into both the spatial and temporal relationships between deformation, alteration and mineralisation, allowing us to temporally relate structural development to metasomatic and mineralising events across the Cloncurry District.

Integrated structural, metasomatic and metallogenic history of the Cloncurry District

Since the structural data provided by the AMS measurements provide fundamental insights into both the spatial and temporal relationships between alteration and mineralisation, the tectonic evolution of the Cloncurry District is considered in this context. These analyses illustrate that the Cloncurry mineral system is long-lived, comprising several mineralising, orogenic and metasomatic events that are often temporally inter-related, and which overprint each other in a variety of ways, to form disparate deposit styles. In the most simplistic terms, the mineral system was pre-conditioned by early (*ca* 1650 Ma) input of large volumes of Fe plus both Cu–Au and Pb–Zn-rich mineralisation in a syn-depositional exhalative setting. During D_2 (*ca* 1590–1570 Ma) peak temperature and strain conditions (e.g. 630 ± 50 °C and 8 ± 2 kbar at Artemis), there was some remobilisation of metal within the Cloncurry mineral system, via partial melting, metamorphic fluids and/or "skarn" formation. However, the relatively hot, ductile conditions prevented the formation of large-scale permeable fluid pathways, and this, together with a relative lack of magmatic fluid sources, was not conducive to the formation of hydrothermal deposits. Conditions became more favourable during the late history of the Isan Orogeny. During the later history (i.e. post-D_4), strain conditions transitioned from ductile to brittle, and the kinematics gradually switched from shortening ± transpression (D_2–D_4), to strike-slip (D_5) and then to post-Isan extension at *ca* 1500 Ma. This orogenic switch is coincident with intrusion of multiple voluminous phases of felsic magma (e.g. the Williams Batholith), and associated metasomatic events. The majority of hydrothermal mineral deposits formed from *ca* 1525 to 1500 Ma, in conjunction with several different metasomatic overprints, e.g. sodic-calcic (SWAN), magnetite-apatite (Canteen, E1), potassic (Ernest Henry), magnetite-barite-fluorite (Monakoff, E1), calcic (SWAN, Mt Colin), and chlorite-hematite-pyrite (Ernest Henry, Kalman, Merlin, Canteen). In many cases deposits show evidence of two or more styles of mineralisation, e.g. sedex + skarn (Maronan, Artemis), sodic-calcic + calcic (SWAN), sedex + magnetite-barite-fluorite (Monakoff, E1) and skarn + magnetite-apatite + chlorite-pyrite (Canteen).

Strain conditions, structures, magmatic systems, fluids and heat sources varied in magnitude and focus through time, and therefore interacted in different ways to form a range of different deposit styles (Figure 3).

Geophysical expressions of the Cloncurry Mineral System

The geophysical response of a mineral system is a function of the structural and the geochemical development within the system. In this case, since we have used techniques that mainly deal with magnetic properties, the main geochemical/mineralogical events/processes of interest pertain to the precipitation of magnetite and pyrrhotite, plus hematite and pyrite (due mainly to their high densities) and economic sulphides (e.g. chalcopyrite, sphalerite, galena). This is the first time

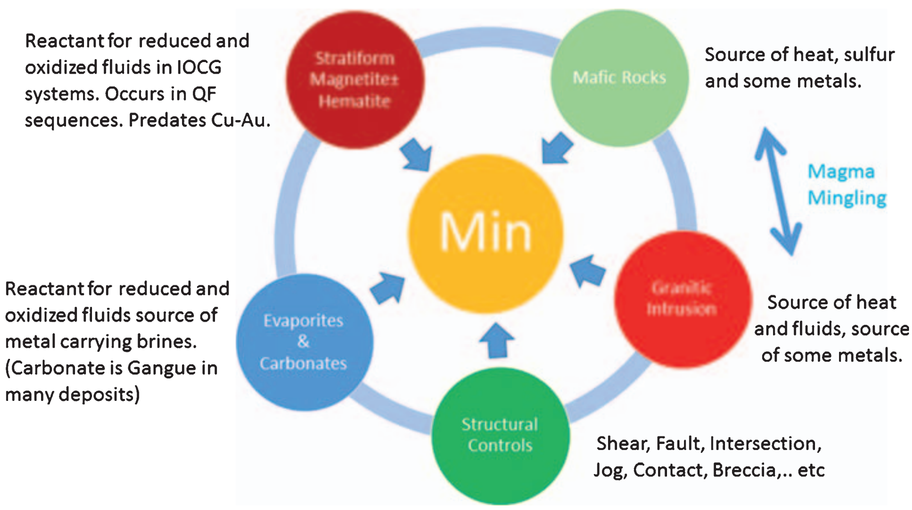

Figure 3. *Schematic highlighting the different ingredients of the Cloncurry mineral system, which combine in different ways to form a variety of different deposits styles across the district. IOCG = iron oxide copper-gold; QF = quartzofeldspathic.*

any study has brought together so much petrophysical data from so many different styles of mineralisation across a mineral district, and the results provide important constraints for future exploration for various styles of mineralisation undercover. The deposits studied have a wide variety of petrophysical properties, primarily dictated by the relative contents of magnetic minerals (e.g. magnetite, monoclinic pyrrhotite, hematite) and other non-magnetic minerals (e.g. hexagonal pyrrhotite, pyrite, galena, sphalerite, barite). Any combination of these minerals can be associated with high densities. High magnetic susceptibilities (and hence high amplitude magnetic anomalies) are invariably associated with coarse magnetite, whereas monoclinic pyrrhotite is associated with moderate magnetic susceptibility and high remanence (and potentially unusual magnetic anomalies). Hematite is only weakly magnetic.

Many specimens contain mixtures of different Fe-oxide and sulphide phases, which are related to redox and/or overprinting. Assemblages within IOCGs in general sit on a spectrum, from highly reduced to highly oxidised (Figure 4). Oxidised assemblages contain hematite, no pyrrhotite, but typically pyrite and variable magnetite. Intermediate assemblages are typically magnetite-rich, and can contain pyrrhotite and/or pyrite. Reduced assemblages are typically pyrrhotite dominant, contain no hematite, but often do contain magnetite. Our observations suggest that hexagonal (non-magnetic) pyrrhotite is typically associated with galena and sphalerite (in sedex/BHT deposits), whereas magnetic pyrrhotite is more typically associated with Cu prospects (in hydrothermal deposits).

The deposits and prospects assessed by this study have a large range in magnetic susceptibility, from essentially negligible (e.g. 10^{-6} SI) to 2.1 SI (Figures 5, 6). In many cases high densities are correlated with high magnetic susceptibilities (e.g. Figure 5), and in most of these cases the dominant dense/susceptible mineral is magnetite. For the most part this is coarse grained, multi-domain magnetite, which does not retain significant, or stable remanence. High densities correlated with moderate susceptibilities are in many cases due to pyrrhotite. High densities and low susceptibilities are in many cases due to hematite and/or any of the

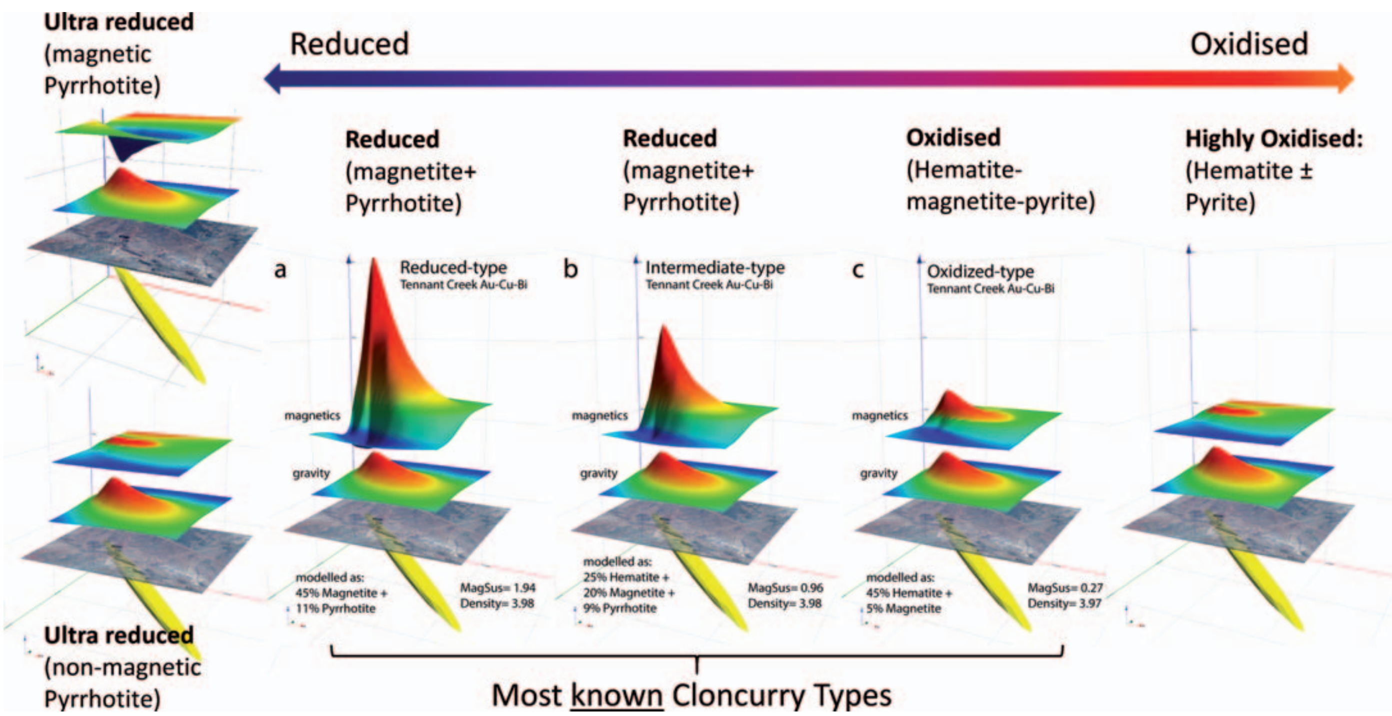

Figure 4. *Synthetic models of the El Dorado deposit, Tennant Creek (based on Austin and Foss, 2014), which contain different proportions of Fe-oxide and Fe-sulphide minerals, based on their Redox state. All the mineral assemblages have comparable density, but the different redox states have very different geophysical expressions.*

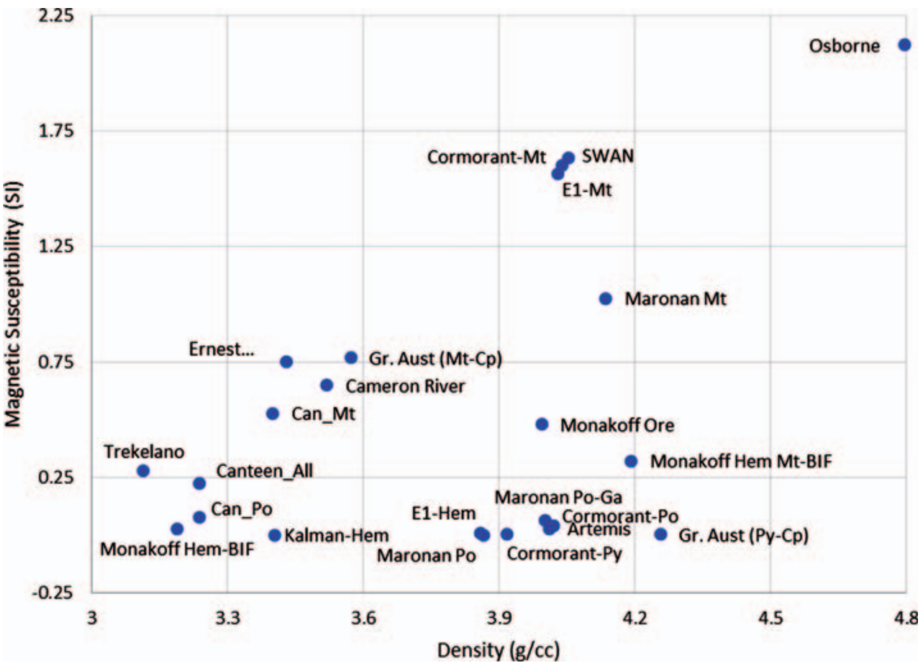

Figure 5. *Plot of magnetic susceptibility vs density for ore samples from deposits/prospects assessed in this study.*

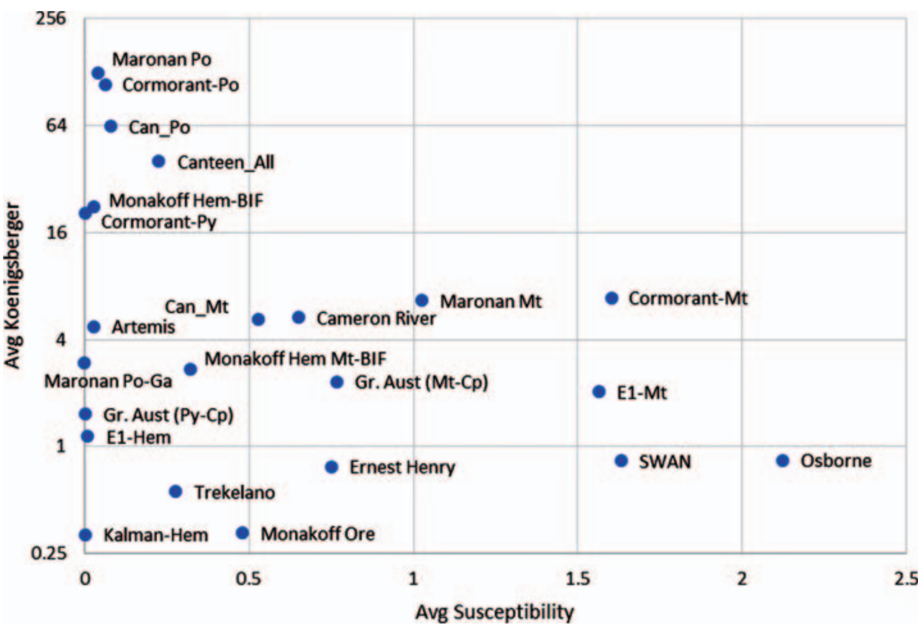

Figure 6. *Plot of the ratio of NEM to magnetic susceptibility (Q, Koenigsberger Ratio) vs magnetic susceptibility for ore samples from deposits/prospects assessed in this study.*

other sulphide minerals. The various deposits have a range of natural remanent magnetisation (NRM) intensities from negligible up to mean values of 450 A/m, with associated Koenigsberger ratios of up to 130 (Figure 6). Deposits that have high Koenigsberger ratios are usually dominated by monoclinic pyrrhotite as the magnetic phase. Where monoclinic pyrrhotite is the dominant phase it is possible that targets can be mis-modelled due to their magnetisation being different to the Earth's local magnetic field.

In terms of petrophysical properties there are several recognised associations:

1. Deposits with high density, high susceptibility, and low Q are dominated by coarse MD (multidomain) magnetite, e.g. Osborne, SWAN.
2. Deposits with high density, high susceptibility, and moderate Q are pseudo single-domain magnetite-rich (possibly indicative of sedimentary origin), e.g. Cormorant, Maronan.
3. Deposits with high density, low susceptibility, and high Q are rich in monoclinic pyrrhotite, e.g. Cormorant, Canteen.
4. Deposits with high density, low susceptibility, and moderate Q are rich in metamorphosed hematite, e.g. Monakoff West BIF.
5. Deposits with high density, low susceptibility, and low Q may contain hexagonal pyrrhotite and/or sphalerite, galena, pyrite and hematite, with a relative absence of magnetite.

Comprehensive reports are available for all 16 individual deposits and prospects across the district, as well as several summary documents. For further information contact james.austin@csiro.au or ben.patterson@csiro.au.

Reference

Austin, J. R., and Foss, C. A., 2014, Understanding iron oxide copper-gold (10CG) magnetic targets from the inside out: case studies from northern Australia: Annual Geoscience Exploration Seminar (AGES), 18–19 March 2014, Alice Springs.

Jim Austin is a structural geologist and geophysicist whose main interest is in the application of magnetic methods to mineral exploration. Prior to joining CSIRO he worked with the Predictive Mineral Discovery CRC, for the Encom-Mapinfo Geoscience Consulting Group, and also as an exploration geologist in Broken Hill, the Mount Isa Inlier, Papua New Guinea and the Thomson Orogen. In his current role at CSIRO he is focussed on understanding the geophysical properties of Iron Oxide Copper-Gold (IOCG), Sedex, BHT (Broken Hill Type), BIF (Banded Iron Formation) and Magmatic Ni-Au-PGE systems, partnering with exploration companies around Australia.

Seismic window

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More seismic attributes

A recent upgrade of my seismic interpretation software not only had the usual bug fixes or enhancements, it also came with a new seismic attribute calculator. 'Great' I thought, 'all I need is another attribute to add to the ever increasing list'. But this one was different because I had never come across it before and had no idea what it did or how it worked. Originally called 'tecva' this is a fairly old post stack attribute that was developed in Brazil in the early 1980s. The implementation I have now calls it 'pseudo – relief' and in an attempt to learn more about it I found a copy of a paper explaining how it is calculated (Bulhoes, 2005). It's not an easy paper to read because it's written in Portugese, but non Portugese speakers can get the general gist by feeding each paragraph into Google translator.

Pseudo-relief is really quite a simple attribute. I think it is essentially a RMS amplitude calculated over a small window (half a wavelength) of a quadrature trace, but my translation may be wrong. Figure 1 displays a pseudo-relief section alongside normal seismic and a RMS amplitude section. RMS tends to enhance high amplitudes and pseudo-relief certainly does that and it appears to have improved resolution. Figure 2 is a zoom into a channel-like feature visible on the pseudo-relief section showing the detail and multiple channel fill events.

Are there too many seismic attributes?

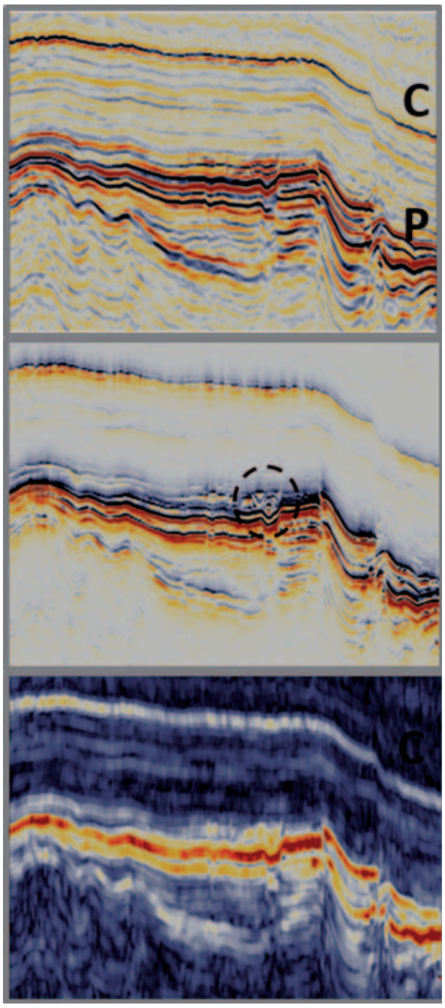


Figure 1. *Pseudo-relief (centre) compared to seismic data (left) and RMS amplitude (right) calculated over an 18 ms window. The pseudo-relief enhances the channel-like feature circled. The data are from the Jackson Field, Queensland.*

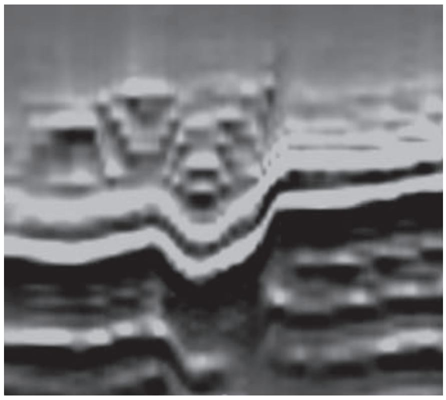


Figure 2. *Close up of the channel-like feature just above the strong P reflection that can be seen in Figure 1.*

Having reviewed this attribute two questions spring to mind:

Are there too many seismic attributes? Is this one any better than the others?

Being a fence sitter my answers are both yes and no. Yes, there are too many attributes to run them all on each dataset and no, this one is no better than the others. But it worked at the time and may be useful in particular situations, which is the case for most seismic attributes. Interpreters have access to many hundreds of seismic attributes on their desktops (Figure 3 is a compilation of just some of the edge detection attributes available). While we may not have time to use them all, an appropriate choice can make it easier to understand the geology and convey our ideas to work colleagues and management.

Reference

Bulhoes, E. M., 2005, Principio da SismoCamada Elemantar e sua aplicacao a Tecnica Volume de Amplitudes (tecVA). Ninth International Congress of the Brazilian Geophysical Society.

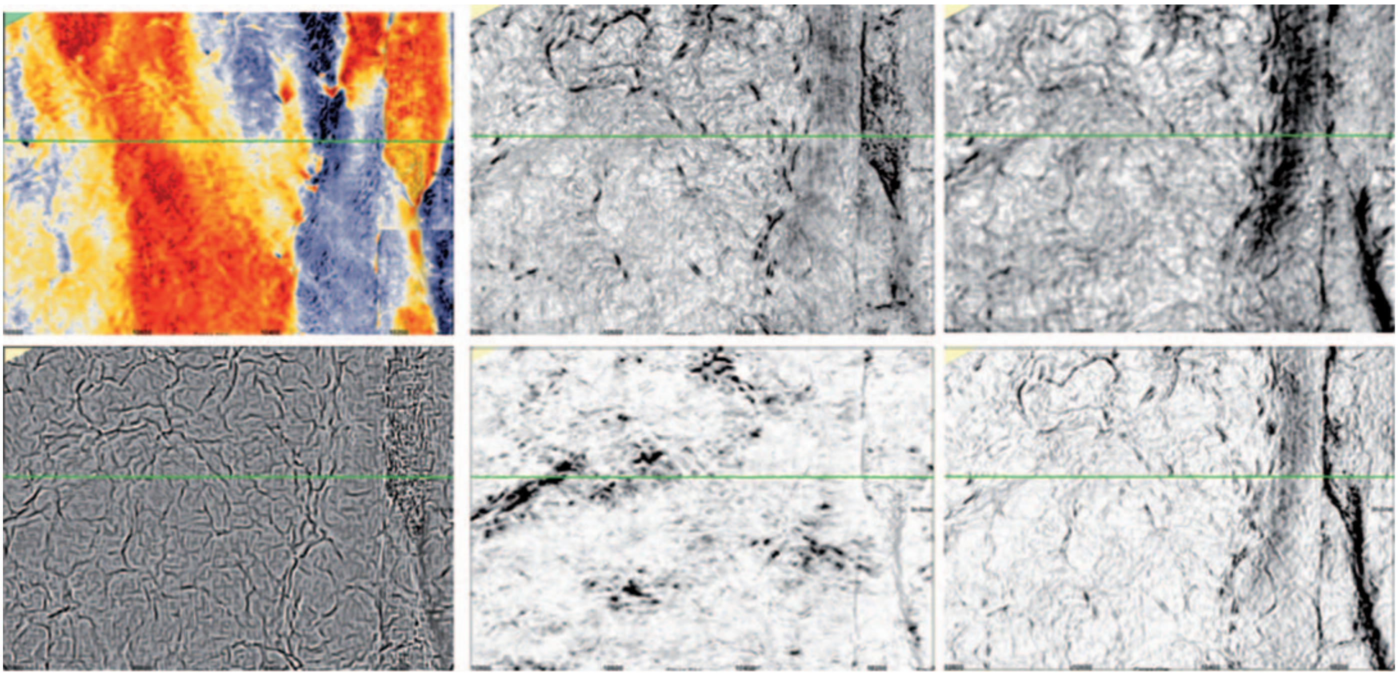
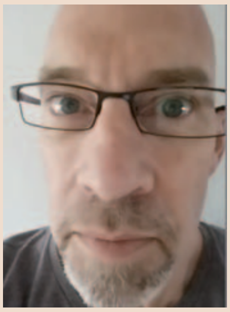


Figure 3. *A sample of the many edge detection attributes available. Clockwise from top left: seismic amplitude, similarity, dissimilarity, semblance, fault likelihood and maximum curvature. Attributes are calculated along the strong reflector near the top of Figure 1 (line location shown in green).*

This ***Askania magnetometer*** *from the ASEG virtual museum is probably the oldest item in the collection. It was generously donated by John Stanley, formerly lecturer at the University of New England and inventor. Such instruments were built in the late 1920s and 1930s by Askania Werke of Berlin, Germany, and only measure only the vertical component of the field. A separate version measured the horizontal component. The resolution of 2 nT was considered to be very sensitive when first available and it superseded the use of dip needles with a 1000 times improvement in sensitivity.*

Operation of this variometer first required levelling the instrument on its tripod using two spirit levels. Instrument temperature was recorded from an internal mercury thermometer for the purpose of applying a compensation correction. The relative vertical magnetic force was measured off a graduated scale viewed through a microscope. Calibration scale and temperature compensation factors are not known for this instrument. Setup and measurement time at each station is estimated to be one minute for an experienced operator.

Webwaves



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Consolidating changes to the ASEG website

The start of another year, and what better way to crash back to reality than a *Preview* column? Members may be relieved to know that there are no major plans for the website this year. They may also be pleased to discover that two of the major tests of the site viz. the wine offer and membership renewal were passed, largely without drama. Some niggling issues remain, and these are being addressed, but it is safe to say that the site is likely to remain essentially unchanged for the next 12–18 months – before the process of renewing the site begins afresh. Some areas of the website that will be refined include the history section, the contractor's database and Special Interest Groups (SIG). The process of augmenting the contractor's data base with information such as the geophysical method(s) they employ and where they operate has begun.

Currently, only one SIG is listed on the website. The 'Young Professionals' SIG (YPSIG) is a vibrant group of young professionals who want to champion the interests of young employees in the profession of geophysics. They have a background or interest in geophysics and are Members of the Australian Society of Exploration Geophysics (ASEG). There is no age limit, but the group is intended for people aged under 35, or those new to the profession. Interested Members may contact the group at ypadmin@aseg.org.au.

One other SIG, the Near Surface Group, has yet to obtain the same level of activity as the YPSIG. This is despite the long history of involvement of ASEG Members with near surface geophysics. ASEG Members, or non-members, who are interested in this group should contact the group at nsgadmin@aseg.org.au for more information.

A third category of SIGs is those that do not yet exist. The need for such groups might be established during conferences or Branch meetings, and an SIG may serve interested parties better than current avenues. An example of such a group would be one dedicated to drones, as was suggested on the segmin (http://lyris.geosoft.com/read/?forum=segmin) newsgroup last year, and there are likely to be others. SIGs can be formed with a minor amount of effort. ASEG Members interested in starting a SIG should contact the Secretariat (secretary@aseg.org.au) for more information.

Echoing themes from *Preview* 185 and the current issue, photos and brief descriptions of magnetometers provided by John Stanley have been converted to exhibits in the online Equipment Museum (https://www.aseg.org.au/equipment-museum). These instruments cover over 70 years of instrument development from the 1930s.

Figure 1 plots the user age (as determined from Google Analytics) vs number of site sessions between 9 December 2016 and 8 January 2017. Even accounting for the nature of these statistics, the large number of users between 25 and 34 is especially encouraging. However, the age distribution of site users is clearly biased towards older users. As the science of geophysics ages along with its practitioners, so too will the tools that are employed. Some of these are superseded by modern versions, while others fall out of favour as more modern instruments are developed. This leads to questions about what to do with the legacy data. Re-surveying with modern instruments may not be possible (nor even necessary for high-quality data) for a variety of reasons, and while the measurement and its location can often be determined from a data plot, they may not be particularly usable without metadata such as filter settings, times, transmitter currents, etc. Some of these metadata are included in the reports that may accompany the data. In cases where they do not, it may be instructive to refer to original operator's manuals. To this end, the Web Committee has undertaken to upload older manuals to the website (https://www.aseg.org.au/equipment-manuals-brochures). Manuals are organised primarily by method, although the search box at the top right of the site can be used as well. Manuals, mostly as PDFs, currently on the site were kindly provided by Kim Frankcombe. Contributions from ASEG members with similar collections are always welcome.

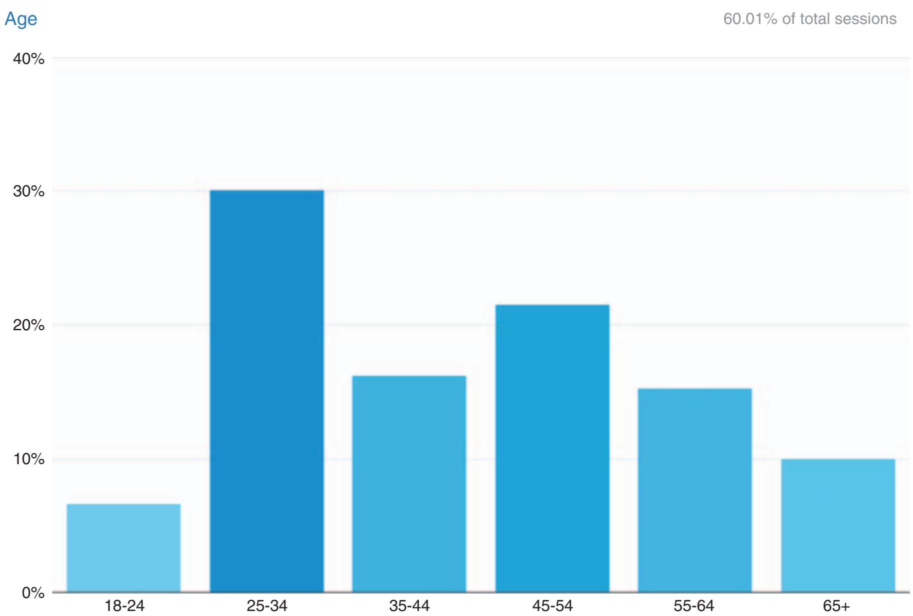

Figure 1. *User age (as determined from Google Analytics) vs number of site sessions between 9 December 2016 and 8 January 2017.*

Data trends

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My digital twin

I decided to kick-off 2017 by not going to work anymore. I mean who needs it? Plus I suspect that the team at work would not miss me – well not the actual me anyway. So over the holiday period I created a digital twin that could take my place.

Initially I was not sure that my digital twin (or DT, as I like to call him/her/it) could go to work for me. I mean I do a lot of complex stuff and attend meetings where I am sure I am indispensable. Could my DT actually make it all work?

To test drive it, I sent DT to my son's soccer game to see how he/her/it would handle the situation. I watched myself from a distance as DT stood on the sideline issuing lines of support to my/his son and providing in depth analysis on player positioning and goal tender weaknesses that could be exploited. I watched as DT whispered under my/his/her/its breath at some of the calls the referee was making. I stood in complete astonishment as DT spoke to one of the soccer moms on the sideline complimenting her on her new haircut and asking if she had been working out. I started to sweat a little while I was watching this all unfold, so my DT kicked off a fan to cool me/itself down. My twin was no twin at all – it was better than me!

Everything I was seeing led me to believe that my DT was fit and ready for work – but was work ready for DT? At the soccer game DT had displayed restraint, expertise, social skills and self-preservation in a difficult situation, all the while checking its emails, sports scores and Facebook status without missing a beat. It was efficient, truthful and worked to a rigid schedule. What could possibly go wrong in the workplace?

So on the Monday when I/he/she/it came into the office, DT noticed that the coffee machine was not working. DT being my digital twin was mechanically inept and rather than look to fix the coffee machine, prepared itself/me to buy everyone a coffee from the local café (instead of just turning on the coffee machine at the wall which had been turned off over the holiday period). DT's proposed offer to buy everyone coffee was an act of generosity that would surprise everyone, including myself and in return DT. The thought of spending $40 on coffee where I knew only half of the people (at best) would thank me/DT for it, created a downward spiralling loop in the code that made DT a little dizzy.

As the Internet of Things industry expands, so will the growth of the digital twin industry.

I knew that when someone gave me a gift that the response was a 'thank you', but I did not programme DT with code on what to do if a thank you never came in from the person receiving the gift. If DT said 'you're welcome' to someone who had not even thanked him in the first place, then DT would seem sarcastic – which is not at all like me. If DT asked them to say thank you before it would give them the coffee, DT would seem like a workplace bully – a little more like me. If DT used his logic to only buy people coffee that were likely to thank him, he would seem stingy – totally like me.

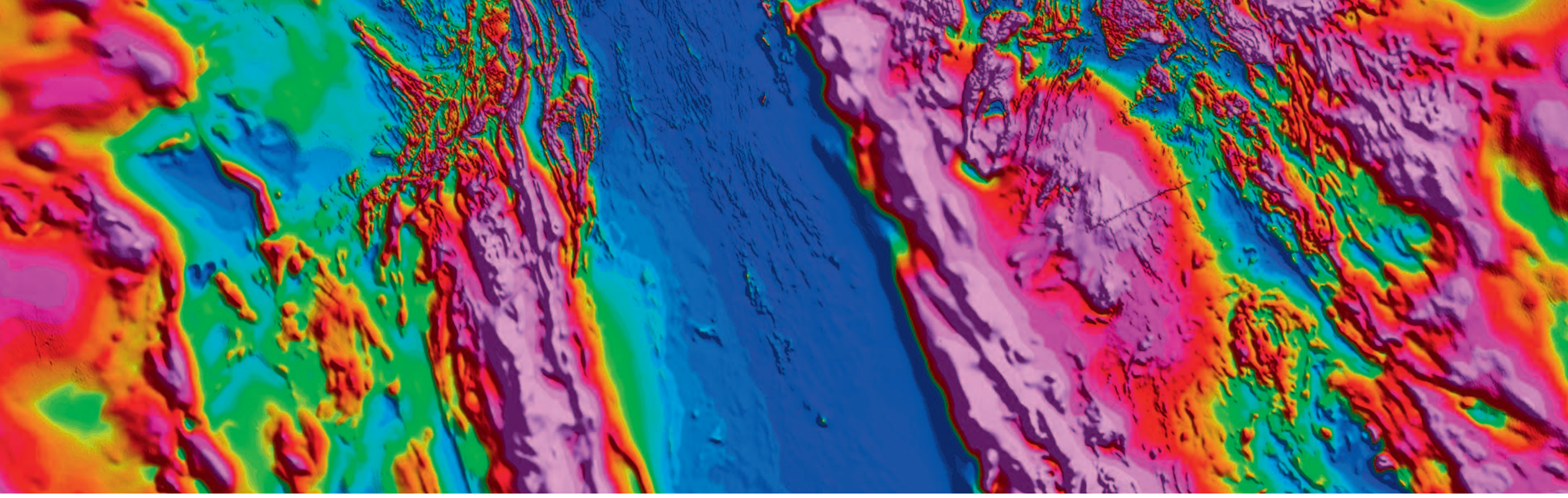
So, within 5 minutes of getting into the office, DT had been faced with social, economic and technical issues that it simply could not handle – my digital twin was more like me than I could ever have imagined.

It is expected that in the next 3–5 years, digital twins will be a multi-billion dollar industry. Despite the digital twin industry being built around the creation of digital versions of physical objects (not humans) – it is very interesting technology nonetheless.

As an example of what a digital twin might be like, imagine a roller coaster at your favourite theme park. If the seatbelt on the ride does not function correctly, the ride needs to be shut down until the belts are fixed. This shutdown can cost the theme park thousands of dollars an hour.

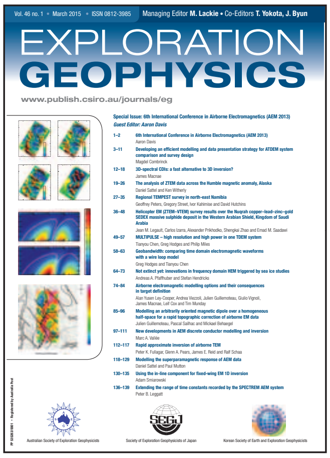
Imagine now that a digital version (digital twin) of that ride existed in software running on a machine in the theme park, and sensors on the physical ride were sending real time feedback to the digital twin. By using the data from the sensors, the digital twin could have told the mechanical team at the theme park that the belts were going to fail many hours or days in advance. This, in turn, would have allowed mechanics to take corrective actions or perform preventative maintenance before the fault actually occurred, potentially saving the park thousands of dollars.

As the Internet of Things (IoT) industry expands, so will the growth of the digital twin industry. It won't be long before digital twins are deployed in oil refineries, seismic acquisition vessels and on the escalator in the international terminal in Sydney that takes you to the airline club lounges. DT hates stairs – I think it is because he has no legs.



Exploration Geophysics

The Journal of the Australian Society of Exploration Geophysicists



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The Magazine of the Australian Society of Exploration Geophysicists

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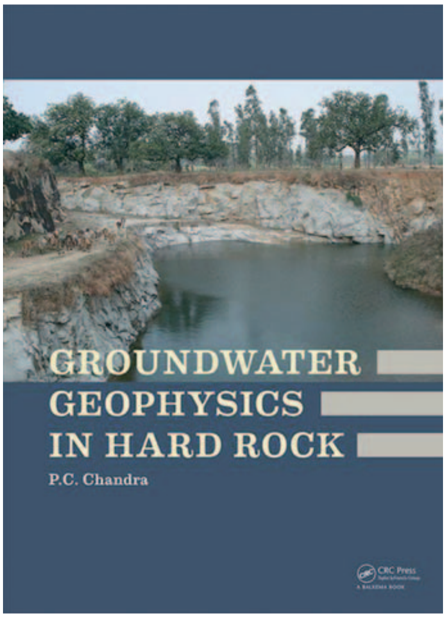
Groundwater geophysics in hard rock

By Prabhat Chandra Chandra



Publisher: CRC press, 2015, 384 pp.
RRP: £66.99 (hardback); £46.89 (eBook)
ISBN: 978-0-415-66463-9

This book sets out to address the specific problem of using geophysical techniques in hard rock environments. It offers case studies that range from the local to regional scale. The initial section is composed of four chapters; in the first two the reader is introduced to different aquifer types and the hydrogeology of hard rock environments. This section also provides some facts on trends in the use of groundwater from a global perspective.

In chapters three and four the use of geophysics, planning of surveys and what information can be expected as deliverables from these surveys is discussed. The author suggests information such as aquifer thickness, bedrock delineation, location of fracture zones, and lateral continuity, (amongst others) are products extractable from the geophysical data.

The core of the book is concentrated in the next eight chapters (five to twelve). These explain, in some detail, the basic principles, field-procedures and interpretations of different geophysical methods such as magnetics, resistivity, self-potential, electromagnetics, and variations of these techniques.

An important part of planning a geophysical survey is setting realistic expectations of what the employed technique can and cannot deliver; this is not always possible to foresee and most of the time this insightfulness comes only through experience. Most readers, as I was, would be familiar to some extent with the majority of geophysical techniques presented in the book, however individual levels of understanding will vary according to personal interest or exposure to the particular methods. I was particularly interested in the two chapters on the Mise-A-La-Masse and the Self Potential methods, both of which are not commonly employed techniques. The book is also a good guide to the strengths and weaknesses of the geophysical methods discussed.

There is enough detail in these middle eight chapters for readers to understand the essence of different geophysical techniques and what they can be used to achieve. The book also provides sufficient references to the literature for a more in-depth immersion, if that it is what is sought.

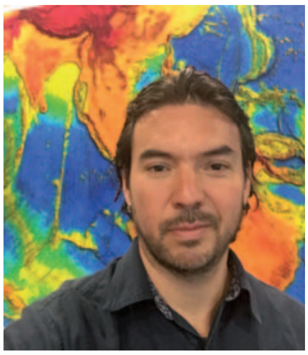
For most of the geophysical methods reviewed case studies from the subcontinent are presented. Through these case studies the author portrays different aspects of conducting geophysical surveys in hard rock environments.

In the closing two chapters the author advocates strongly for the integration of different geophysical methods, by which quantitative parameters such as the thickness and extent of the saturated/unsaturated zones can be determined. He explains how these parameters can assist in characterisation and delineation of the architecture of hard rock aquifers. The author further separates activities and research on hard rock geophysical methods into two domains 1) where the methods are grouped as quantitative measuring tools, and 2) where the measurements and their by-products are transformed into hydrogeologically meaningful outputs.

Dealing with the problem of scale is also discussed. Geophysical surveys are used for two reasons in ground water studies: (1) to determine the suitability of previously selected sites; or (2) for reconnaissance and selection of suitable sites from a larger, more regional area. The author suggests which methodologies might optimally address regional, local and detailed targets. He reviews a range of techniques from satellite, airborne and ground to borehole scale studies. There is also mention, and a brief explanation, of methods such as seismic, ground penetrating radar and nuclear magnetic resonance, and a discussion about how these methods can complement other geophysical techniques explained in greater detail earlier in the book.

The final chapter has been reserved for showcasing the role of geophysics in managed aquifer recharge and for monitoring groundwater contamination. A concluding summary on the broader topic of groundwater geophysics in hard rock environments may have been more appropriate, but I believe that consideration of these applications was placed in the final chapter to demonstrate how geophysical methods can inform hydrogeological knowledge of an area, enhance it, and then be transformed into a tangible product.

Several of the topics covered in this book are clearly applicable beyond the hard rock environment, particularly the suggested approaches on integration and transformation of geophysical measurements to hydrogeologically meaningful products. The book does a good job in reviewing some of the existing geophysical methods used for groundwater exploration and provides the reader with enough information to study when selecting a geophysical method to answer hydrogeological questions.



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The development of optically pumped magnetometer systems and their applications in Australia Part 2

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Diversifying the application of optically pumped magnetometers

a. 'High Definition' and 'Broad Spectrum' magnetic mapping

When the first optically pumped magnetometer was developed it was immediately recognised that if the very fast measurement rate attribute could be exploited through automatic recording and the provision of an odometer system for automatically determining the location of each measurement, magnetic mapping would be revolutionised. With these combined developments instead of acquiring magnetic measurements at 20 m intervals or even greater, as was previously the standard, it became practical to record magnetic profiles at sub-metre sample intervals. This could now be done while travelling faster than an operator could walk, and even up to 40 kph with a vehicle-borne platform.

According to sampling theory, a given sample interval can only enable wavelengths of twice that interval, or longer, to be properly defined. Shorter wavelengths, if present, will be under-sampled and will constitute 'magnetic noise'. As a rule of thumb, the shortest wavelength component of a magnetic anomaly will be a wavelength approximately twice the depth to its source below the sensor. It follows that for any given sample interval only magnetic sources originating at greater than that distance below the sensor will be properly defined, while sources closer to the sensor will contribute magnetic noise to the profile.

The consequence of sampling at 20 m intervals (or greater as was more common) at ground level was that all magnetic sources within 20 m (or more) of the ground surface contributed only noise on the magnetic profile. Decreasing the sample interval from 20 m to 0.2 m delivered access to magnetic information in the 0.4 m to 40 m wavelength band, and this is the band that includes anomaly sources occurring between the ground surface and 20 m depth. Instead of magnetic surveys being low-pass limited beyond 40 m wavelength, data acquisition became available covering the entire spectrum arising from surface as well as subsurface sources. The terms 'Broad Spectrum profiles' and 'High Definition imaging' were used to describe the closely sampled data acquired with the magnetometers developed at the Geophysical Research Institute (GRI). The importance of this development to magnetic exploration beneath and within the regolith in Australia cannot be overstated, as our regolith is characterised by accumulations of intensely magnetic, near surface, iron-rich minerals. Only if the magnetic response from such sources can be properly sampled can it be effectively filtered.

Some classic applications of Broad Spectrum profiles to sub-surface mapping include:

- Mafic sills intruding coal seams (Figure 1).
- Thin dykes intruding coal-bearing sediments (Figure 2).
- Deep source exploration beneath a maghemitic regolith (Figure 3).

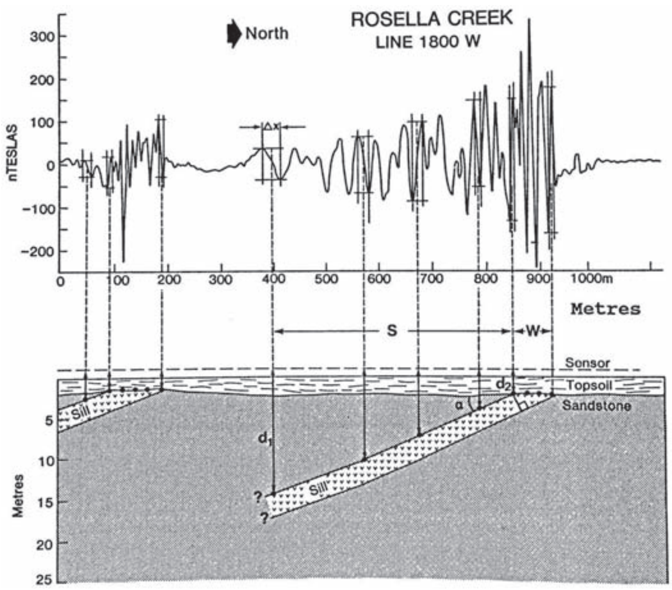


Figure 1. *This profile, recorded across a shallow thin sill, epitomises the significance of Broad Spectrum data acquisition. In close proximity to the surface of a mafic intrusion, magnetic minerals present contribute to a high amplitude 'white noise' spectrum. As the sill dips to greater depth 'upward continuation' progressively low pass filters the white spectrum and in this profile this process can be seen to both decrease the peak-to-peak amplitude of the profile and to increase the wavelength between adjacent peaks. In fact, dividing the distance between adjacent peaks (ΔX) by the tangent of the Earth's magnetic inclination provides a good estimate of the depth to the sill at that point. From two such measurements distance S apart, the dip angle of the sill can be deduced.*

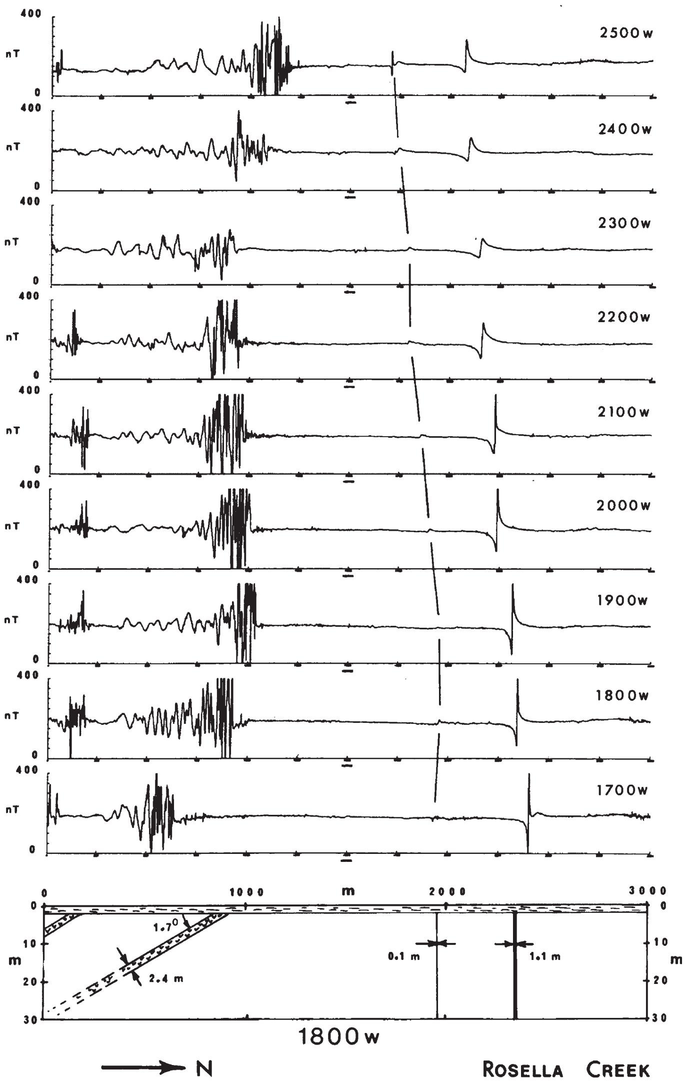


Figure 2. *Even very thin dykes can pose an expensive problem to longwall mining if their presence is not expected. This series of broad spectrum profiles clearly identifies near surface dykes down to 0.1 m in thickness. A pair of thin sills can also be recognised from this data.*

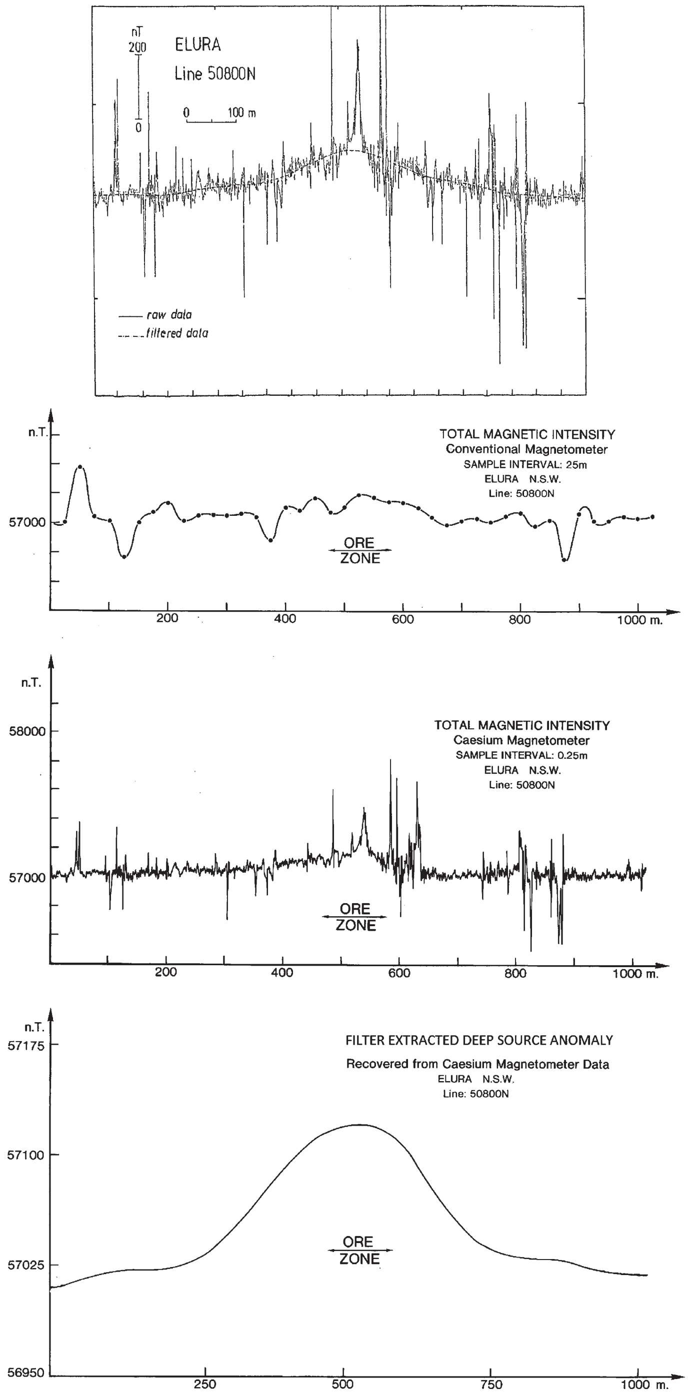


Figure 3. *The Elura Ag/Pb/Zn orebody consists of siliceous, pyritic and pyrrhotitic materials weathered to a depth of approximately 100 m. Overlying this orebody is a maghemitic layer rich in intensely dipolar magnetic gravels. Only after properly sampling the full spectrum of the magnetic noise profile from these gravels could it be effectively filtered and a quality profile representing the magnetic response of the deep orebody extracted.*

Classic examples of High Definition imaging include:

- Magnetic signatures of sandstone and conglomerate (Figure 4).
- A magnetic image of an intrusive pipe, ring dykes, uplifted stratigraphy, streambed alluvials and even buried 76 mm artillery projectiles (Figure 5).

These examples were documented in detail by Stanley and Cattach (1990) and Stanley et al. (1992, 2005).

b. The upgrade to TM-4

In 1988, after a period working in industry, Stephen Lee returned to the GRI and developed a new concept in period counters based upon the statistical analysis of a large number of overlapping, short duration, windows of the Larmor period using Programmable Logic Array technology. The result was a count resolution of 0.005 nT at approximately 40 Hz sampling, or 0.1 nT resolution at approximately 400 Hz sampling. This counter formed the basis of a new magnetometer system, the TM-4 (Figure 6).

The upgrade from TM-3 to TM-4 in 1989 was significant in many ways that would influence new applications. It had an interface with a DGPS for both data positioning and navigation functions, and its frequency counting specifications were improved over the TM-3 by a factor of 20 for resolution and a factor of 40 for sample rate. Up to four Cs magnetometer sensors could be logged simultaneously. The period counter and data logging functions required the power of a new Motorola 68030 CPU with a 68881 co-processor. Data were logged on a

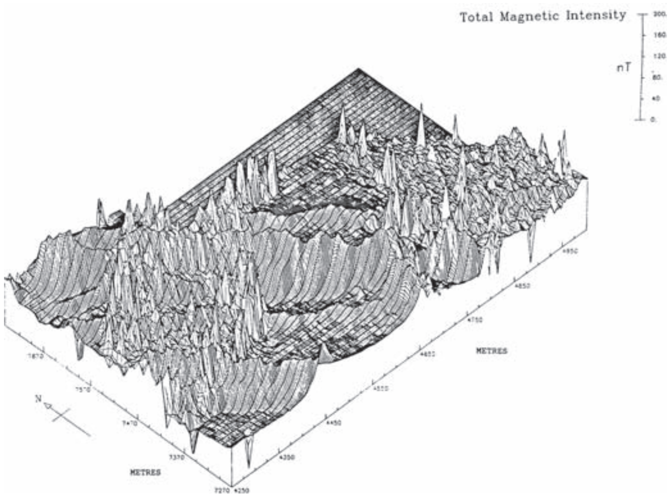


Figure 4. *An isometric image of high definition magnetic data in this location defines the distinctly different magnetic signature of a relatively iron rich conglomerate interbedded between horizons of sandstone. Four linear features reveal the location of thin intrusive dykes that effectively prohibited longwall mining of the underlying coal seam.*

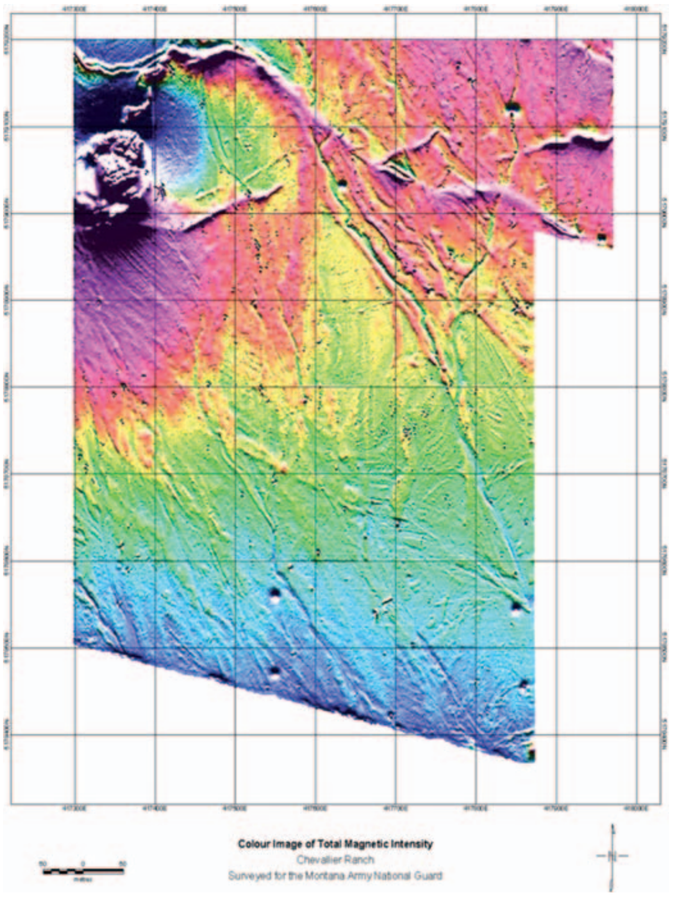


Figure 5. *This high definition magnetic image represents 9 million, DGPS positioned measurements of the Total Magnetic Intensity covering a 45 ha area. Data acquisition using a hand-held, quad-sensor TM-4 magnetometer took 20 crew days. Interpretable from this data are an intrusive pipe, ring dykes, uplifted sedimentary stratigraphy and alluvial drainage. Small speckles revealed the presence of buried unexploded ordnance, predominantly 76 mm artillery projectiles. The four circular features in the lower section were each due to a steel fence post.*

Figure 6. *The TM-4 magnetometer with odometer attached. Seen also in quad-sensor application in the search for unexploded ordnance 2000 m above the Missouri valley in Montana.*

battery-backed RAM. In 2016, after 25 years of service, a TM-4 remains in use at Comenius University for archaeological and environmental investigations.

In 1989, differential GPS using a local base station delivered an absolute positional accuracy of around 1.5 m. In Broad Spectrum survey applications requiring precise relative sample interval accuracy a cotton thread type odometer was still used to control the sample interval along line, while the DGPS was used to position the course of the survey line and to facilitate navigation within a survey area. A vehicle-borne system using a quad-cycle was built for mineral exploration applications and this combined the relative accuracy of a digital odometer to control sample intervals along line with the absolute position of survey transects and navigation aids being controlled using DGPS.

c. Sub audio magnetics for simultaneous electrical and magnetic mapping

The significance of 'High Definition' magnetic mapping for resolving great detail in near surface geological structures was recognised from the early vehicle-borne magnetic profiles and various archaeological investigations. It left a significant impression. This immediately raised the question as to what might be the benefits for the exploration industry if similar spatial resolution could be economically achieved measuring other useful parameters such as electrical conductivity, electromagnetic coupling, induced polarisation and even gravity. Malcolm Cattach joined the GRI team in 1980 and with sponsorship and access to the latest instruments provided by Newmont Exploration, Mal commenced a Master's program to evaluate, compare and perhaps suggest improvements to, the current state-of-the-art induced polarisation receivers. He explored means to increase the speed with which closely spaced measurements might be acquired, but remained frustrated by the inherent fact that if the depth of exploration was to be maintained then the electrode spacing had to be large. With a large receiver electrode separation measurements could only reflect an average current flow through the large volume of ground between the electrodes and this would prohibit high spatial resolution. But, important seeds were sown; there had to be a better way.

The benefits of high definition magnetic mapping and the desire to expand this to include other parameters of geophysical mapping remained at the forefront of John's and now Mal's minds. Mal proposed: 'can we use a magnetometer to measure the electromagnetic response of a time-varying current in the ground? If we can, then we should be able to filter between the spatially varying magnetic field and the time varying electromagnetic field.' It sounded too good to be true. 'If it were possible then someone would surely have already done it'. Then one day in 1988, John and Mal were using a TM-3 in an area also being investigated using CSAMT and there, visible on the TM-3 signal, was the CSAMT waveform. This convinced Mal to commence a PhD program under John's supervision to investigate this new application (it is beside the point, but what was actually observed was the primary field from the wires feeding the CSAMT electrodes, not the ground response. But that is the luck of the draw in research, and Mal was convinced to pursue his conviction.)

The concept was quite simple. If a fast-sampling magnetometer was operated one metre above the ground surface, where the shortest wavelength of the spatially varying magnetic field is about two metres, at a walking speed of up to say 2 m/s (7.2 kph), then the spatially varying field would be observed in time as frequencies lower than 1 Hz. If a time varying current were introduced to the ground by either a galvanic source or an electromagnetic loop using a square wave generating source at a frequency greater than 1 Hz, then the spatially and time varying components of the magnetic field could be separated by filtering. Naturally occurring temporal changes in the magnetic field could be removed by reference to a base-station magnetometer. It was envisaged that the current source would deliver a bi-polar, square wave in the 5 Hz to 200 Hz range and hence the name Sub Audio Magnetics (SAM) was proposed (Cattach et al., 1993).

Hypothetically, if current were applied using grounded electrodes, four total field parameters could be extracted. These were:

- The spatially varying magnetic field intensity (TMI)
- Magnetometric electrical resistivity (TFMMR) acquired during the 'ON' time
- Magnetometric induced polarisation (TFMMIP) acquired during the 'OFF' time
- Electromagnetic response (TFEM) acquired during the 'OFF' time, where in this case the EM source was the current in the wire feeding the electrodes

Alternatively, if the excitation source used was a closed wire loop, then an enhanced electromagnetic response could be measured at the expense of the resistivity and induced polarisation parameters.

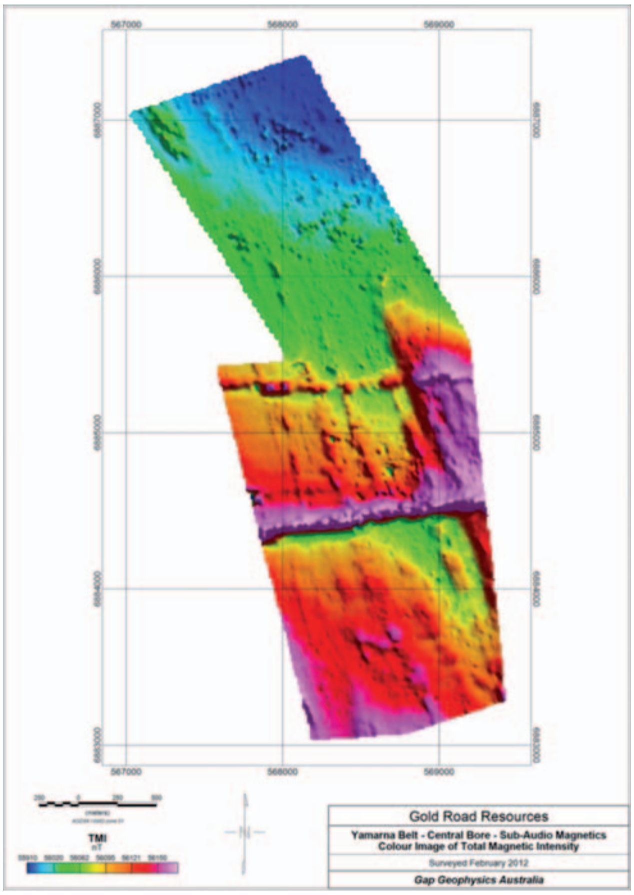
During the course of his PhD research into the SAM method, Mal focused on the use of the TM-4 magnetometer with a galvanic source where several amperes of current were introduced through electrodes initially separated by 1000 m. Mal diligently applied the laws of physics to calculate corrections that would be necessary if the electrical response due to changes in sub-surface conductivity properties were to be isolated. These included the subtraction of the primary field due to the current in the wire feeding the electrodes and subtraction of the normal field that would occur if the ground were homogeneous.

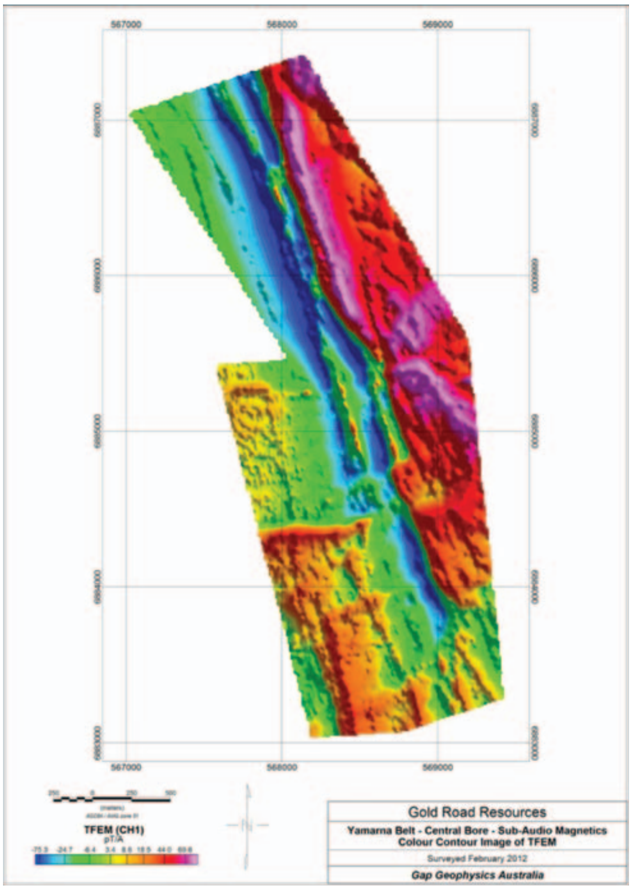
Malcolm achieved his goal using a galvanic source with resounding success and the simultaneous acquisition of high definition TMI and TFMMR was quickly adopted by the exploration industry. Under the supervision of Malcom Cattach and John Stanley, David Boggs, in his own PhD research, used TM-4 data to confirm the predicted viability of also acquiring the transient decay signal from an electromagnetic source (Figure 7). From this it was inferred that the transient decay from an induced polarisation source would also be measurable (Boggs et al., 1998).

The TM-4 and its application to SAM earned Malcolm Cattach and John Stanley the 1995 ASEG Grahame Sands Award for Innovation in Applied Geoscience.

d. SAM to provide discrimination between UXO and Non UXO

David Boggs' feasibility assessment, confirming that high definition transient electromagnetic data could be acquired simultaneously with spatially varying TMI and TFMMR data using the SAM technology principles, led to the recognition of specific desired enhancements to the TM-4 performance. Driven by these results development of the first specialised SAM receiver, the TM-6, was commenced in 2002. Ron Bradbury engineered an upgrade to the Steve Lee statistical period counter making it now a true frequency counter with a precisely regular count rate. He was also able to raise its performance to 0.005 nT @ 120 Hz and 0.04 nT at 2400 Hz. Each measurement was able to be time tagged to 10 µS precision synchronised with GPS time. Up to four Cs magnetometer sensors cold be logged simultaneously. Unlike the TM-4, which had its own display screen and keyboard, the interface with theTM-6 was via a Bluetooth connection with an off-the-shelf, hand-held device.





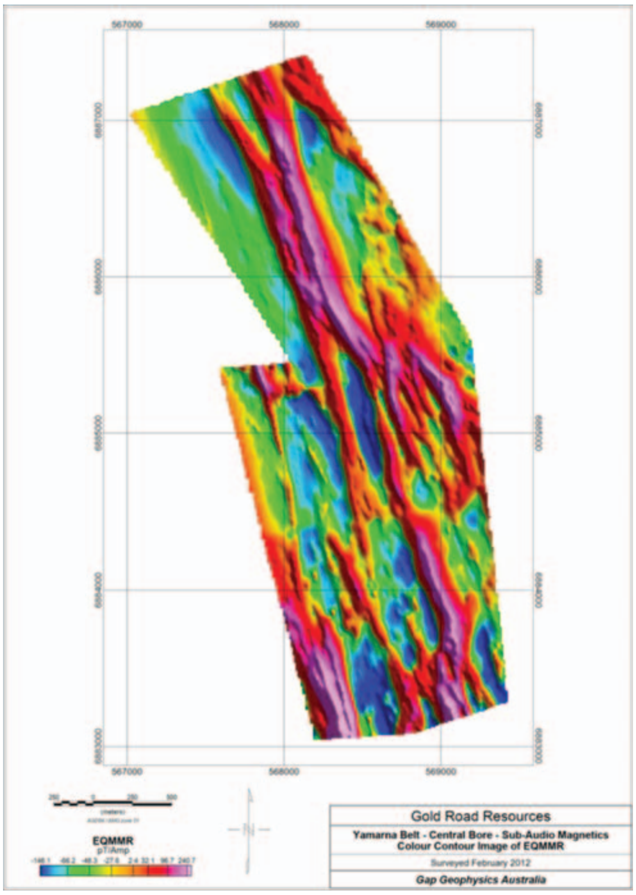


Figure 7. *Images of TMI, TFMMR and TFEM acquired simultaneously with a TM-7 magnetometer using SAM.*

This enabled the TM-6 to be more conveniently carried in a backpack, leaving the operators hands free (Figure 8). With DGPS now capable of delivering cm positional accuracy, the requirement for an odometer system was overcome in even the most demanding sampling applications. The processing power and storage capacity were also increased permitting the use of real-time navigation aids, real-time signal stacking where required and digital recording at very high data rates.

Figure 8. *The TM-6 magnetometer system with ports for up to four Cs sensors and a frequency counter capable of delivering measurements to 0.04 nT resolution 2400 times per second with each measurement time tagged to 10 µS precision synchronised to GPS time. Data positioning with cm accuracy and survey navigation aids was provided by DGPS. On-board signal stacking delivered a noise floor of just 0.05 pT for electromagnetic exploration applications.*

At the time of the TM-6 development the major cost in remediating contaminated military sites was recognised as arising from the labour intensive investigation of false alarm sources. Magnetic field mapping was effective in detecting ferrous items to a depth in most environments beyond the expected penetration depth. But highly remnant magnetised fragmentation could not be distinguished reliably from dangerous UXO items. Electromagnetic metal detectors were relatively cumbersome to use but were more discriminating against fragmentation as they responded in a manner more proportional to the target dimensions. Electromagnetic detectors also had an advantage in being capable of detecting non-ferrous items. However, electromagnetic systems deploying a small, roving coil transmitter were inherently limited in their detection depth. The energising signal decreased nominally with the inverse cube of the depth to target and the induced signal also diminished with an approximate inverse cube relationship with distance back to the receiver. Consequently, detection depth using a small coil energising source decreases with nominally an inverse 6th power. A magnetometer achieves a greater detection depth primarily because the source is passive and its response decreases only with a nominal inverse cube relationship. SAM technology was seen as a viable solution for both reducing the false alarm rate and for increasing the electromagnetic detection depth. Not only could the magnetic and the electromagnetic response be acquired simultaneously with a single sensor, but the energising field could be applied using a very large loop surrounding, for example, a whole ha. From such a source the energising field remains constant beyond the depth of concern and so the electromagnetic response follows just the inverse cube law instead of the inverse 6^{th} power experienced with a roving coil transmitter. Using SAM the detection depth of both magnetic and electromagnetic responses would be equivalent, both measurements would be precisely co-located and in combination would deliver enhanced discrimination capability.

The TM-6 specification was defined such that it would enable a large loop SAM system to detect UXO targets as small as a 20 mm projectile (approximately 20 mm diameter, 100 mm length). In order to meet this specification a current transmitter had to be designed and built capable of driving up to 350 Amp current through a square loop of dimension 110 m surrounding a 1 ha search area. Keith Matthews brought his experience with high power, fast shutoff transmitter technologies to the team and the result was the MPTX-500 transmitter (Figure 9). Calculation of the transient electromagnetic response from a 20 mm projectile in the energising field produced from such a loop revealed that the TM-6 magnetometer frequency counter now had the performance to detect the transient response from a source as small as the 20 mm projectile target. The predicted performance of SAM in this application was confirmed during an evaluation program sponsored by the US Environmental Security Technology Certification Program (ESTCP, 2003).

Figure 9. *The MPTX-500 transmitter was developed as an EM source capable of delivering up to 350 Amp current through an energising square loop of 110 m x 110 m. When such a loop surrounded a 1 ha search area SAM technology, using a TM-6 magnetometer, was capable of detecting UXO targets down to 20 mm projectile size.*

e. Identifying induced polarisation using SAM

The simultaneous measurement of Total Field Magnetometric Induced Polarisation together with TFMMR and TMI was always specified in the hypothetical concept of SAM. But it was not until the TM-6 technology had evolved that an induced polarisation signal could be confidently distinguished from electromagnetic coupling. Recent case studies by Gap Geophysics have confirmed David Boggs' prediction that all four parameters could in practice be simultaneously measured with a single, Cs magnetometer sensor.

f. SAMSON for deep penetration electromagnetic surveys

The successful application of the TM-6 magnetometer and MPTX-500 transmitter to electromagnetic detection of UXO targets was the precursor to the next stage of SAM development for mineral exploration applications. In 2005 Malcolm Cattach brought together a development team under the new organisation of Gap Geophysics. During the years 2006 to 2008, the TM-6 magnetometer/SAM receiver underwent ongoing development, evolving into the TM-7, with significant enhancements to acquisition electronics and firmware as well as processing software (Figure 10).

Total Field Electromagnetic measurement became practical as an offspring of the SAM concept. In 2007, SAMSON ('Son of SAM') was developed as a collaboration between Gap Geophysics and ElectroMagnetic Imaging Technology (EMIT). The distinguishing feature of SAMSON was the use of stationary measurements and real-time signal stacking in order to enhance the signal-to-noise ratio of weak transient responses from very deep sources. In the application of SAMSON to very deep exploration it is practical to achieve late time noise levels of 0.05 pT with a typical measurement station occupation time of 5 minutes. But while the measurement time might now be relatively long, the requirements of deep source exploration can be met with measurement stations 50 m apart. This is a distinctly different application of the Cs magnetometer sensor to those previously focused upon the high definition mapping of near surface sources. Such is the diversity in applications of the Cs sensor. SAMSON earned for Andrew Duncan, Malcolm Cattach and Steven Griffin the 2007 ASEG Laric Hawkins Award for the most innovative use of a geophysical technique from a paper presented at the ASEG Conference (Duncan et al., 2007).

Figure 10. *The TM-7 magnetometer system is the current generation. Its performance is similar to that of the TM-6 but advantage has been taken of advanced acquisition electronic components, firmware and processing software.*

g. High-power transmitters to support SAM technologies

When using the TM-7 magnetometer SAMSON methodology was able to achieve a measurement sensitivity that was well within ambient noise when transmitters available at the time were used. It soon became clear that further improvements to sensitivity would not improve the signal-to-noise ratio. However, if higher powered transmitters could be made available then improvement in signal-to-noise using the TM-7 could be expected.

Gap GeoPak (GeoPak) was established in 2007 as a joint venture between Australian companies Gap Geophysics Pty Ltd and Kayar Pty Ltd (engineering company).The objective in establishing the company was to develop a range of high performance geophysical transmitters that would:

- Significantly exceed the performance and reliability of commercially available transmitters
- Optimise the signal-to-noise ratios achievable by Gap Geophysics proprietary and non-proprietary survey techniques.
- Significantly increase the depth of exploration for electrical techniques.
- Reduce station occupation time thereby increasing survey efficiency.
- Incorporate enhanced safety features which meet and exceed the more stringent requirements of today's mining exploration industry.

Gap GeoPak's flagship products are the HPTX-70/80 range of high power transmitters. With the ability to achieve up to 350A and power output up to 80kW, these transmitters have pioneered high power, deep penetrating EM surveying in Australia (Figure 11).

The GeoPak HPTX-70 earned Malcolm Cattach, Keith Mathews, Ed Campbell and Symon Bouwman the 2012 ASEG Grahame Sands Award for Innovation in Applied Geoscience.

Figure 11. *The HPTX-80 transmitter is capable of delivering 80 kW of electrical power to either a galvanic source, where electrodes may be separated by several km, or to an electromagnetic loop of several square km area. With such a transmitter, and the TM-7 magnetometer, very deep electromagnetic exploration can be achieved using SAMSON technology or the survey efficiency of a helicopter-borne platform can be applied to TMI and TFMMR exploration using SAM technology.*

h. HeliSAM

The development of high powered transmitters such as the HPTX-80 has made feasible the supply of high current to galvanic electrodes that are separated by several km. The area between these electrodes that can be explored using TMI and TFMMR maybe several square km, and the use of a towed bird sensor can deliver excellent spatial resolution in a fast and economic manner. Similarly, the use of a large area electromagnetic loop to energise the ground can make available a large prospective area capable of benefitting from the efficiency and speed of airborne data acquisition measuring TMI and TFEM.

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February	**2017**		
22–24	Third AAPG/EAGE/MGS Myanmar Oil and Gas Conference Exciting Evolution: Myanmar's petroleum systems, plays and field developments http://www.eage.org/event/	Yangon	Myanmar
22–24	Oil, Gas & Mines Africa Conference http://www.eage.org/event/	Nairobi	Kenya
March	**2017**		
12–14	Full Waveform Inversion: What are we getting?	Manama	Bahrain
27–30	77th Annual Meeting of the German Geophysical Society (DGG) http://dgg2017.dgg-tagung.de/	Potsdam	Germany
31	EAGE/DGG Workshop on Fibre Optics Technology in Geophysics http://www.eage.org/event/	Potsdam	Germany
April	**2017**		
2–5	AAPG Annual Meeting	Houston	USA
10–14	70th Geological Congress of Turkey www.jmo.org.tr	Ankara	Turkey
17–20	2017 CGS/SEG International Geophysical Conference: Geophysical Challenges and Prosperous Development	Qingdao	China
23–28	European Geosciences Union (EGU) General Assembly 2017 http://www.egu2017.eu/	Vienna	Austria
24–28	Engineering Geophysics 2017 Conference and Exhibition http:/eage.org.ru	Kislovodsk	Russia
June	**2017**		
12–15	79th EAGE Conference and Exhibition 2017 http://www.eage.org/	Paris	France
July	**2017**		
31 Jul–3 Aug	15th International Congress of the Brazilian Geophysical Society and the EXPOGEf 2017 http://sys2.sbgf.org.br/congresso/	Rio de Janeiro	Brazil
September	**2017**		
3–7	23rd European Meeting of Environmental and Engineering Geophysics Near Surface Geoscience 2017 http://www.eage.org/event/	Malmö	Sweden
3–7	Second European Airborne Electromagnetics Conference Near Surface Geoscience 2017	Malmö	Sweden
10–13	SAGA 2017 15th Biennial Conference and Exhibition www.sagaconference.co.za	Cape Town	South Africa
12–14	Offshore Site Investigation and Geotechnics Committee (Society for Underwater Technologies) 8th International Conference http://www.sut.org/specialist-interest-group/osig-offshore-site-investigation-and-geotechnics/	London	UK
24–27	SEG International Exhibition and 87th Annual Meeting http://www.seg.org	Houston	USA
October	**2017**		
8–12	International Conference on Engineering Geophysics (ICEG)	Al Ain	UAE
15–18	AAPG/SEG International Conference and Exhibition http://www.aapg.org/events/conferences/ice/announcement/articleid/5666/aapg-seg-2017-international-conference-exhibition	London	UK
21–25	Exploration '17 http://www.exploration17.com/	Toronto	Canada
22–25	Geological Society of America (GSA) Annual Meeting 2017 http://www.geosociety.org/meetings/2017/	Seattle	USA
24–26	OTC Brazil	Rio de Janeiro	Brazil
December	**2017**		
7–9	SEG Microseismic Technology and Applications Workshop	Beijing or Hefei	China

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