Australian Society of
Exploration Geophysicists

APRIL 2018 • ISSUE 193
ABN 71 000 876 040 ISSN 1443-2471

PREVIEW

NEWS AND COMMENTARY

AEGC 2018: conference reflections, honours and awards

Computers vs the human brain

Vale David Leaman

FEATURE

Wave equation imaging and adjoint-state inversion for micro-seismic monitoring

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Data to Discovery

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PREVIEW

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FRONT COVER

Professor Jim MacNae (RMIT) in deep discussion with colleagues at AEGC 2018. Photo by Tim Pascoe Photography.

Preview is available online at
www.publish.csiro.au/journals/pv
ISSN: 1443-2471 eISSN: 1836-084X

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Editor's desk

This issue of *Preview* features an article written by Ben Witten and Jeffrey Shragge on 'Wave equation imaging and adjoint-state inversion for micro-seismic monitoring'. Ben recently completed his PhD thesis on 3D micro-seismic velocity analysis under the supervision of Professor Shragge. This work, which was supported by the ASEG Research Foundation, has been very well received and has already resulted in the publication of three papers in *Geophysics*. Ben and Jeffrey's article takes *Preview* readers right to the cutting edge of this subject.

This issue also features reflections on the first Australasian Exploration Geoscience Conference 2018 (AEGC 2018) by the Conference Organising Committee and also a number of our regular commentators. In addition, we honour the recipients of the ASEG awards that were made at the conference.

The decision by ASEG, PESA and AIG to create the AEGC by amalgamating the ASEG International Geophysical Conference and Exhibition, various PESA Basins Symposia and AIG meetings, is a reflection of the debate that has been going on for some years about the future of geoscience conferences nationally and globally (cf https://www.theguardian.com/higher-education-network/2017/aug/30/expensive-academic-conferences-give-us-old-ideas-and-no-new-faces).

It has been argued that, as the costs of mounting a conference have ballooned, conferences have to get bigger in order to survive. The conference 'industry' is partly responsible for these ballooning costs, and the offerings of this industry can be seductive – slick advertising, glittering venues, gourmet food and conference apps to personalise your conference experience (and the use of the data gleaned by those apps for future conference planning!). There is, however, a sting in the tail of many of these offerings. If a conference app is to be effective, for example, a high speed high capacity internet service is required, entailing more cost and limiting suitable venues, thereby driving up registration fees and, inevitably, resulting in further calls to broaden the conference appeal in order to increase the number of registrations etc.

Is bigger better? Apart from supporting the conference industry (a laudable objective but not necessarily the first priority of many ASEG Members) are big multi-disciplinary conferences effective at promoting cross-fertilisation between related disciplines (or sub-disciplines)?

I have found that this question keeps coming up amongst my friends and colleagues. We have all been to many (perhaps far too many) big multi-disciplinary conferences. The European Geosciences Union conference (EGU), for example, regularly attracts over 14 000 participants and can have over 50 parallel scientific sessions. Unfortunately, the number of parallel sessions and the geographic spread of those sessions over a large venue means that most participants are forced to narrow their focus on sessions within their area of expertise, and they do not stray into related sessions – however exciting and interesting they might sound. Occasionally I have strayed and found myself listening to a fascinating talk by a speaker who is alone in a huge theatre with me, the Chair, the AV aide and maybe a couple of the other scheduled speakers for that session. Hardly worth that speaker's time and effort in getting to the conference.

On the other hand, we have all found that the most exciting conferences in terms of fostering interactions between disciplines and/or sub disciplines and challenging the thinking of everyone involved (students and hardened professionals alike) are small conferences run on shoestring budgets in regional towns that may only be able to offer the equivalent of an RSL hall and catering by the CWA – Kalgoorlie for example (although the School of Mines does have a lovely conference venue) or Broken Hill. A single session forces all participants to sit through talks that they may have overlooked at a bigger conference, and the small town venue means that there are only a small number of places (pubs) in which conference participants can socialise – meaning that there is no excuse not to follow up on those burning questions!

The European Union has recognised the real value of these smaller scientific gatherings through its support of the COST Program (http://www.cost.eu/ – see also the Editor's Desk in *Preview* 185), as has the American Geophysical Union through its support of the AGU Chapman Conferences (https://chapman.agu.org/).

Something for the Federal Executive to consider as it plans for the future of the ASEG.

Lisa Worrall
Preview *Editor*
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President's piece

Twelve months have certainly flown by very quickly. Hard to believe that this will be my final President's piece in *Preview*. It has been a busy and rewarding year and the ASEG continued to grow from strength to strength. While our traditional ASEG activities have continued throughout the year, the ASEG FedEx has also been busy improving its governance framework. In light of this work, many outdated policies and procedures have been reviewed and updated; such as our Code of Ethics. It is important that as our membership continues to grow we remain proactive about how we manage our affairs internally and the external image that we portray. Our membership survey highlighted the increasing diversity we have within our Society and we must remain cognisant of how we manage the inclusivity of such diversity. This body of work will continue during 2018 as more policies and procedures get reviewed.

It was also a year of firsts, with the first combined conference, when we joined our sister societies, AIG and PESA, in Sydney in February. As I discussed in my opening address at the conference, the role of geophysics continues to be important in the exploration industry and is well recognised as such by the Australian Government. In a 2015 publication, developed for investors in minerals and petroleum industry, our government recognised its importance by stating: 'Modern exploration uses a multi-disciplinary approach drawing on advanced knowledge in geophysics, geochemistry and geology, and new exploration tools. New and adapted exploration technologies and techniques have been developed for exploring beneath the cover materials, which blanket extensive areas of the Australian continent. Chief amongst these has been the application of state-of-the-art geophysical surveys to define the distribution of rock types and structure at and beneath the surface, and to identify anomalies potentially related to the presence of mineralisation'.

The AEGC 2018 was a stepping stone in the continued promotion of an integrated approach to the exploration and development of our resources; mineral, petroleum and natural resources. Future conferences will continue to build on this platform and I encourage you to continue to show strong support for the next AEGC, to be held in Perth.

I would like to thank my current FedEx for the support and challenges they have provided during the past 12 months; it has been professionally rewarding and I have felt privileged to have been able to serve my Society in this capacity. I encourage you all to remain engaged with the 2018 FedEx and, if you have the ability to do so, please assist the ASEG in either a State Branch or FedEx capacity.

Andrea Rutley
ASEG President
president@aseg.org.au

Andrea Rutley, the outgoing ASEG President, addresses the opening ceremony of the AEGC 2018 in Sydney.

Welcome to new Members

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

First name	Last name	Organisation	State	Country	Membership type
Faisal Ur Rahman	Awan	Edith Cowan University	WA	Australia	Student
Kymren	Boelling-McDougall	Macquarie University	NSW	Australia	Student
Stuart	Clark	UNSW	NSW	Australia	Active
Tim	Dohey	Newmont Mining	WA	Australia	Active
Brodie	Klue	Golder Associates	QLD	Australia	Active
Drew	Lubiniecki	Adelaide University	SA	Australia	Student
Muhammad	Nizamani	Geological Survey of Pakistan	Sindh	Pakistan	Associate
Abdulwaheed	Ogunsami	Australian National University	ACT	Australia	Student
Madison	Page	Macquarie University	NSW	Australia	Student
James	Parslow	University of Newcastle	NSW	Australia	Student
Margarita	Pavlova	Lattice Energy	QLD	Australia	Active
Carolina	Pimentel	CGG Services Australia	WA	Australia	Active
Alicia	Pollett	University of South Australia	SA	Australia	Student
Luke	Smith	Macquarie University	NSW	Australia	Active
Peter	Staples	Cosmopolitan Minerals	WA	Australia	Active
Alastair	Stark	Adelaide University	SA	Australia	Student
Daniel	Thompson	Contractor	VIC	Australia	Active
Leo	Tsang	University of Queensland	QLD	Australia	Student

MinEx CRC bid successful!!

The Assistant Minister for Science, Jobs and Innovation, Zed Seselja, and Minister for Resources and Northern Australia, Matt Canavan, announced on Wednesday 23 March 2018 that $50 million of Australian Government funding was being awarded to the MinEx CRC bid.

'I welcome the MinEx CRC, which will create new mining opportunities', Minister Canavan said. 'This collaboration will provide new opportunities for mineral discovery in the resources sector and grow the Mining Equipment, Technology and Services sector.'

http://minister.industry.gov.au/ministers/canavan-seselja/media-releases/funding-exploration-and-research-secure-jobs-future

MinEx CRC is a major endeavour comprising:

- $50 m cash from the CRC Programme
- $41 m cash from geological surveys and from industry
- $49 m non-staff in-kind
- $78 m or 311 FTE staff in-kind
- TOTAL $218 m

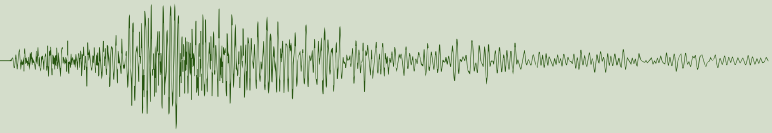
MinEx CRC's research will include:

- Developing more productive, safer and environmentally-friendly drilling methods to discover and drill-out deposits, including coiled tubing drilling technology.
- Developing new technologies for collecting data while drilling, bringing forward mine production.
- Implementation of a National Drilling Initiative (NDI) – a world-first collaboration of Geological Surveys, researchers and industry that will undertake drilling in under-explored areas of potential mineral wealth in Australia.

MinEx CRC's 34 current participants are:

Participants: Anglo American, Barrick Gold, BHP, South32, Atlas Copco, Geotec Boyles, HiSeis, Imdex, LKAB Wassara, McKay, Olympus, Sandvik, Geoscience Australia, Geological Surveys of NSW, SA and WA, Curtin University, Universities of Adelaide, Newcastle, South Australia and Western Australia, MRIWA and CSIRO.

Affiliates: Investigator, Minotaur, DataCode, Minalyze, Mudlogic, Southern Geoscience, Geological Surveys of NT, Queensland and Victoria, Mineral Resources Tasmania and the SA Department of State Development.



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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 March.

We would like to welcome the new members to the Federal Executive for 2018 – Leslie Atkinson (Membership), Kate Robertson (Communications) and Andrew Squelch. We would also like to thank those continuing in their roles for 2018. A big thank you to Marina Pervukhina who has taken on Education Committee Chair in addition to her role as State Branch Committee Chair.

We are pleased to announce the first ASEG newsletter coming 1 May. After feedback from last year's Membership Survey, the Communications Committee are working diligently to produce this publication. If you would like to contribute articles to the newsletter or *Preview*, contact Kate communications@aseg.org.au or Lisa previeweditor@aseg.org.au.

Finances

The Society's financial position at the end of February 2018:

Year to date income: $97 675

Year to date expenditure: $44 929

Net assets: $959 667

Membership

At the time of this report, the Society has 669 Members. This is down 32% from the same time last year and down 42% overall (Figure 1). Numbers are down similarly across most of the States with the least drop in Members being 36% in the ACT to a 45% drop in membership in the SA/NT Branch (Figure 2).

Retired and Honorary membership numbers have remained constant from last year, while there has been a 16% decrease in Active/Associate Members (Figures 3 and 4). There has also been significant decrease in the number of Student and Corporate Members (Figure 5).

To everyone who has renewed for 2018 – congratulations and a very big thank you! For those who haven't – what are you waiting for? Renew today!

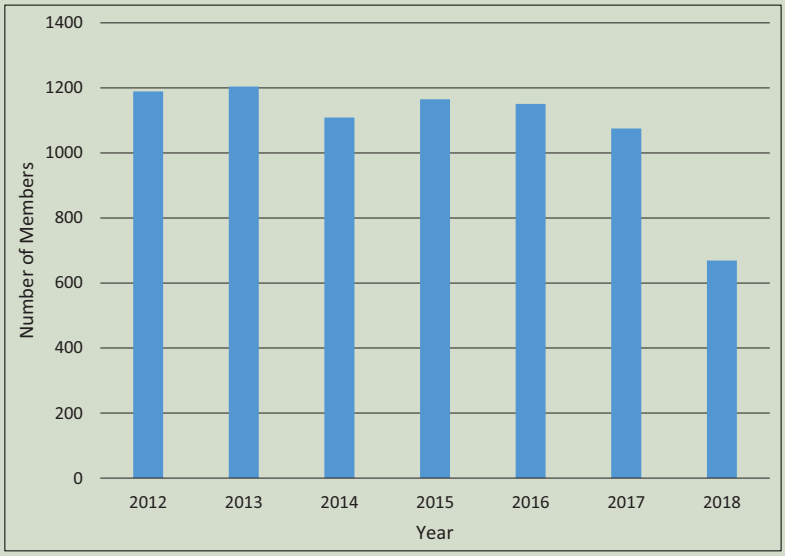

Figure 1. *ASEG membership numbers between 2012 and 2018.*

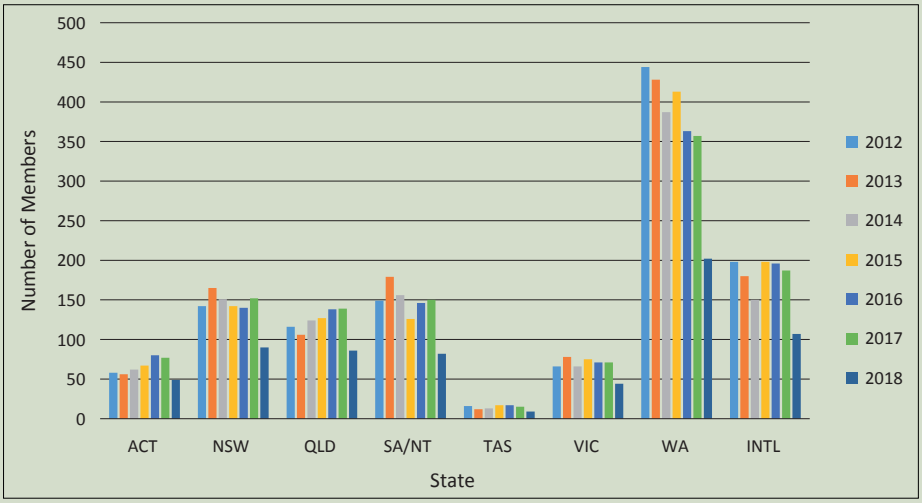

Figure 2. *ASEG membership numbers by State in 2018.*

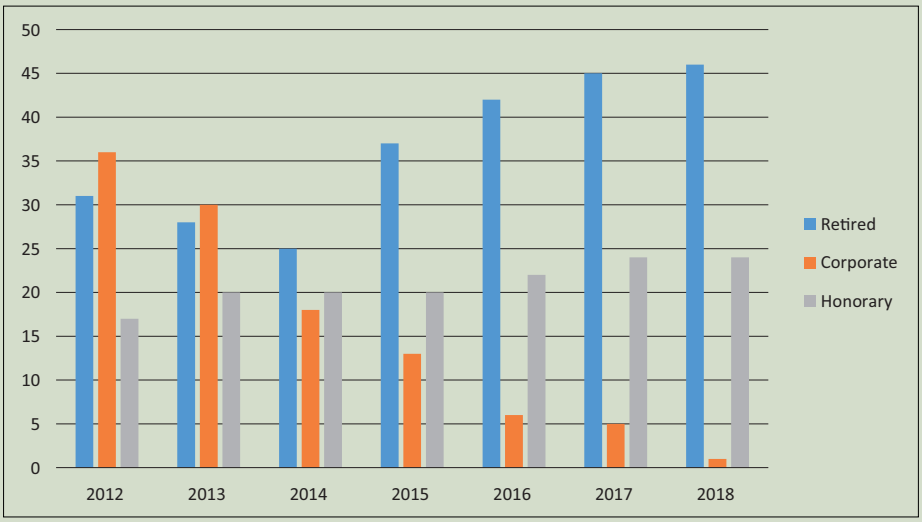

Figure 3. *Retired, corporate and honorary membership numbers between 2012 and 2018.*

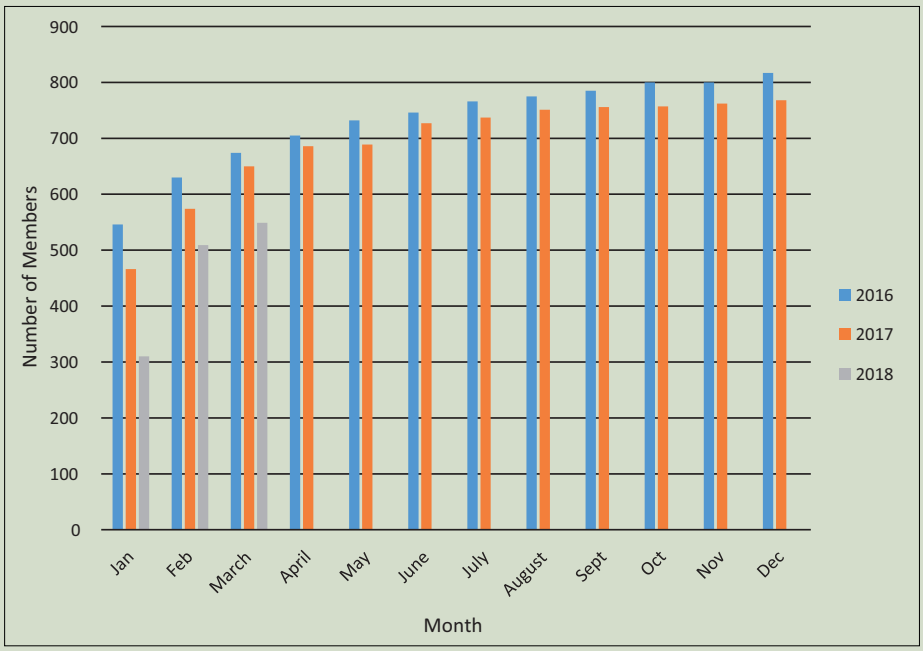

Figure 4. *Active and associate membership numbers by month between 2016 and 2018.*

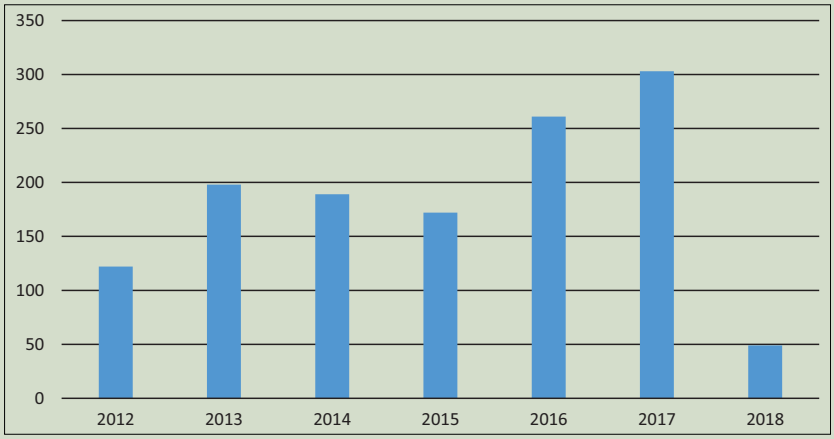

Figure 5. *ASEG Student membership numbers between 2012 and 2018.*

AEGC 2018

The 1st Australasian Exploration Geoscience Conference held in Sydney this February was a huge success with a final total of 922 delegates (including exhibitors, day, workshop only, and exhibitor passes). The final delegate split was 50:30:20 ASEG : PESA : AIG. A huge amount of effort was put in by the Sydney COC, there were 7–8 parallel sessions for 3 days, and we'd like to thank all involved for their contributions. By now you should have received a survey on the conference and we encourage you to provide feedback so that we and the Perth COC can strive to meet our Member's expectations.

Megan Nightingale
Secretary
fedsec@aseg.org.au

Marina Costelloe, ASEG President Elect, and David Denham, Preview *Associate Editor, at AEGC 2018.*

ASEG Young Professionals network

Joining forces: AEGC 2018

What a week it was in Sydney! The YP groups from ASEG, PESA and AIG joined forces for the first time to promote our networks in a collaborative way.

On display at the conference was our common mantra of 'training, mentoring, networking', with the focal point being the YP booth located alongside the society booths near the registration area.

YP recharge booth

The YP booth was designed as a recharging space, both literally and figuratively, and a meeting spot for YPs.

We distributed information about the YP contacts and activities in each society and also promoted the Frank Arnott Award (v2.0) and other training and mentoring opportunities.

Thanks to Fortescue Metals Group who provided 75 FMG branded power banks as booth giveaways. We expect the booth to feature again in a similar format at future joint conferences such as the AGCC and the AEGC 2019.

Presentation skills workshop

A presentation skills workshop ran on the Sunday prior to the conference. Although heavily promoted to YPs, the mixture of participants was about 50/50, which we feel helped to highlight the importance of the subject matter to the YPs.

Our instructor Doug Knight facilitated some excellent interaction on the day and genuine interest was shown in supporting the participants to build greater confidence around presenting their work.

It was great to then attend some of the subsequent conference presentations by the participants to see them put some of the ideas into practice.

Presentation skills coach Doug Knight in action at the YP booth.

From faxes to FaceTime

Ali Burston, an organisational psychologist from Metisphere, spoke at a free breakfast event early on the Tuesday morning on 'From faxes to FaceTime: building intergenerational relationships through networking and mentoring'.

Sadly this event was poorly attended and a recommendation for future conferences would be to ensure that at least one YP representative sits on the organising committee to improve communications.

Given the topic of this talk, some greater diversity on our organising committees also wouldn't go astray either.

YP Social @ Endeavour Tap Rooms

The YP networking drinks, held at the Endeavour Tap Rooms in the Rocks, sold out early during day one and with many disappointed YPs we sought some extra sponsorship. Thanks to Theo Aravanis of Rio Tinto, we were able to make some last minute adjustments at the venue to accommodate 80 YPs and representatives from our generous sponsors.

Yes, 80!!! Almost one-in-10 of the conference goers were there! It was a fantastic night and most people stayed well past the time we'd planned and hopefully made it to the conference bright and early the next day.

Thank you!

We wish to thank our sponsors again, namely: BHP, Fortescue Metals Group, Terrex Seismic, Bridgeport Energy, Gap Geophysics and Rio Tinto.

A fully sold-out YP networking drinks at the Endeavour Tap Rooms in the Rocks.

Dionne Olsen with some of the Victorian YP mentees after her engaging talk on communication skills.

We'd like to thank our many helpers with the booth design, decoration and setup, in particular Janelle Simpson, Mary Nguyen (PESA), and Michael Miller (AIG).

VIC seminar series 2018

The Victorian network (in conjunction with PESA) commenced its 2018 seminar series with a highly engaging talk by Dionne Olsen from the Nuffield Group on strategic and effective communication titled 'Figuring out the 'Why?''.

The core message was to understand 'why' your audience would want whatever it is that you are offering them.

With this in mind, it becomes possible to differentiate yourself and to better articulate your core strengths. Networking continued afterwards with some of our local mentors joining the group at a nearby bar.

YP network opportunities

Like all of the ASEG committees and specialist groups, the Young Professionals Network relies on the hard work and dedication of our volunteers to prosper.

We are always looking for vibrant and enthusiastic volunteers to assist us in reaching our goals of providing training, mentoring and networking opportunities to Young Professionals across Australia.

Contact the YP Network

To volunteer or join the Young Professionals Network please contact Megan Nightingale or Jarrod Dunne through ypadmin@aseg.org.au.

ASEG Branch news

New South Wales

In November, **Jim Austin** from CSIRO presented a talk composed of three courses:

Entrée: 'Magnetic properties of BIFs: The facts and the truth. A case study from the Capricorn Orogen, WA'.

Main Course: 'Understanding the complex magnetic signatures of magmatic Ni-PGE systems'.

Dessert: 'Geophysical signatures of IOCG & Sedex/BHT style mineralisation in the Cloncurry District, Qld'.

We all ate with gusto and 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, mostly non-geophysical, were asked and answered (well alright… mostly answered). A fun night and a good way to conduct our last meeting for the year.

In February, we held our AGM and two of the usual suspects (**Mark Lackie** and **Ben Patterson**) were elected to the roles of President and Treasurer. **Sherwyn Lye** retired as Secretary and that position was taken up by **Steph Kovach**.

For the technical meeting we invited two speakers who were going to present at AEGC 2018 to come along and give a 'dry run' of their talks. The speakers were **Clive Foss** and **Ben Patterson**, both from CSIRO. Clive spoke about 'Combined gravity and magnetic studies of satellite bodies associated with the giant Coompana reverse magnetic anomaly in South Australia', while Ben spoke about 'Constrained 3D modelling of and mineralogical analyses of the Horseshoe Range BIF, Western Australia'. Both speakers kept to conference time and answered many questions, which hopefully prepared them for their actual conference talks.

An invitation to attend NSW Branch meetings is extended to interstate and international visitors who happen to be in town at the time. Meetings are 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 will be holding their AGM in April. I will be resigning as Branch President after taking on the role in late 2010. I thank the Branch members for their support, particularly in the last few years. All official Branch positions will be up for election and there are currently nominations for President – **Ron Palmer**, Secretary – **James Alderman**, and Treasurer – **Henk van Paridon**. Any other nominations for these positions must be seconded and sent to the Queensland committee before the AGM.

We are currently looking for speakers to fill our calendar for 2018, if you'd like to volunteer a talk please contact qldpresident@aseg.org.au or qldsecretary@aseg.org.au.

An invitation to attend Queensland Branch meetings is extended to all ASEG Members and interested parties. Meetings are usually held monthly and details of all upcoming Queensland events can be found on the Qld Events tab on the ASEG website.

Fiona Duncan
qldpresident@aseg.org.au

South Australia & Northern Territory

The SA/NT Branch has had a relatively slow start to the year with the inaugural Australasian Exploration Geoscience Conference in full swing in Sydney during February. Since the conference we have held our first technical evening for 2018, in conjunction with our AGM, at which we were joined by **Ben Kay** and **Mike Reiger**, two students from the University of Adelaide's Geology & Geophysics Department and the Australian School of Petroleum respectively.

Ben and Mike presented on behalf of a group of 11 students from the University of Adelaide who called themselves 'Team On the Rocks' and who took part in the inaugural Frank Arnott Award (https://www.frankarnottaward.com), a competition with a focus on developing and proposing novel approaches to data integration and visualisation. The group, consisting of undergraduate students from 1st to 3rd year, put together a unique proposal in which they used various wavelet transformations to extract more information from their given datasets, and then alter 2D geophysical data sets to 3D by creating and combining 2D slices, finally projecting those data onto semi-transparent 3D printed surfaces created from additional datasets, primarily scaled topographic information. The whole process was achieved with minimal cost and using readily available open source software.

For their novel and easily accessible approach the team managed to claim the top prize in the Apprentice category, winning out over entries from Masters and PhD students from around Australia and the world, while also being invited to present at the Exploration '17 conference in Toronto. This was a truly impressive result for a team of geoscientists in such an early stage of their careers and a testament to the quality of work and attitude towards their education and career progression. Congratulations to Mike and Ben, as well as the rest of the team including **Larissa Collins**, **Angus Nixon**, **Sarah McDonald**, **Teagan Romyn**, **Kiryeong Lee**, **Melissa Stinear**, **Racheal Mahlknecht**, **Jianan Chen**, and **Jamieson Woolcock**.

Our state Branch AGM was held prior to the talk, with a vote held for the positions of the President, Secretary and Treasurer of the SA/NT Branch. I am happy to report that **Adam Davey** will remain our Treasurer and **Mike Hatch** our Secretary for 2018, and that **Kate Robertson** has been elected President for 2018. Kate has been an active member of our committee for several years and we are all looking forward to the different perspective and ideas she will bring to the committee in her new role. I would like to say thanks to all of our past and present committee members, secretaries and treasurers who have helped me over the past three years with every aspect of running the Branch, it is certainly most appreciated, without the generous contribution of your time we wouldn't be able to run as well as we have.

We would like to thank all of our 2017 sponsors, the Department of the Premier and Cabinet, Beach Energy, Minotaur Exploration, and Zonge. Without their support we would not be able to hold such full program of events for the local membership. We will be in touch with all our previous sponsors hoping they will return again for 2018. 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.

Please keep an eye out for further events in 2018 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. If you are interested in joining the committee please get in touch. 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 sa-ntpresident@aseg.org.au.

Josh Sage
joshua.sage@beachenergy.com.au

Tasmania

An invitation to attend Tasmanian Branch meetings is extended to all ASEG Members and interested parties. Meetings are usually held in the CODES Conference Room, University of Tasmania, Hobart. Meeting notices, details about venues and relevant contact details can be found on the Tasmanian Branch page on the ASEG website. As always, we encourage Members to also keep an eye on the seminar program at the University of Tasmania/CODES, which routinely includes presentations of a geophysical and computational nature as well as on a broad range of earth sciences topics.

Mark Duffett
taspresident@aseg.org.au

Victoria

The summer weather wasn't the only thing warming up the past couple of months as a flurry of events held in February cranked our 2018 Victorian Branch calendar into gear. We took off from pole position on the starting grid in first gear with a highly anticipated technical meeting night in early February. Mr **Adrien Bisset** of GeoTeric presented 'Quantitative interpretation of frequency decomposition blends using seismic forward modelling: a case study on Thebe gas discovery, offshore NW Australia', at the Kelvin Club.

For those audience members that were lucky enough to witness the commercially sensitive results presented from the study that evening, the application of the frequency composition blend technique was an excellent example of how effective the method can be in characterising gas bearing reservoirs. This innovative approach has the potential to aid subsequent appraisal and exploration drilling programs with a view to de-risking any future development plans as well. The rapid turn-around in generating these visually dazzling volumes could give traditional seismic inversion products a threatening run for their money. Thank you, Adrien, for educating the wider geophysics community by presenting results from this very detailed case study.

As we thundered around the first few corners through second and third gears, we once again took pleasure in jointly hosting the annual Summer Social with our Victorian sister branches of PESA and SPE at the delightfully accommodating venue of Henry and The Fox. In keeping with the summer theme, Melbourne endured one of its hottest evenings that night, with our outdoor bar succumbing to the heat! Despite the beer taps being turned off prematurely, the successful gathering was one of the best attended in recent memory. Thank you to everyone that joined alongside their fellow industry contemporaries, sweating in the heat yet gleefully sharing anecdotal musings which our fickle industry can sometimes offer. See you all at the next social gathering!

We finally powered into top gear and into the home straight of the summer with the inaugural Australasian Exploration Geoscience Conference that was held in Sydney recently. Your Victorian committee members were all in attendance and the opportunity to meet some of our fellow branch counterparts was indeed a pleasure. The conference was a tremendous success and brought some of the brightest minds in our industry with the brightest ideas to the one location, offering the opportunity of a lifetime to all those that attended.

In celebration as we stand upon the winner's podium, the Victorian Branch would like to extend an invitation to all Members, past, present and future, to re-connect with your Branch and peers by attending one of the many upcoming events on our calendar this year. We welcome all new Members to the ASEG and hope to make your acquaintance before long.

Seda Rouxel
vicpresident@aseg.org.au

Western Australia

It is with the greatest pleasure that I write this Branch report sitting in West Perth looking out at what might be the last summer storm for 2018. As a geologist and young professional I am honoured to have the opportunity to represent WA as the Branch President. One of my goals for 2018 is to provide new opportunities to WA Members, and I encourage any Member to approach either myself or the WA Branch Secretary with any feedback you may have on the Society's activities, as our goal is to ensure you receive value for your membership.

The WA Branch plans to host a range of professional development and networking events in 2018, including our regular monthly tech nights, young professional events, lunch time tech events in the CBD, a joint ASEG-PESA mentoring program, and closer collaboration with PESA and AIG particularly on technical events and workshops.

WA's first tech night of the year, on 14 February, kicked off our *Petroleum* stream with a presentation by **Anton Egorov** of Curtin University on 'Time-lapse full waveform inversion of vertical seismic profile data'. The following week saw Sydney host the first AEGC, which combined AIG, ASEG, and PESA members together under one roof to discuss Australian Geoscience and Exploration. The WA Branch is proud to announce that the next AEGC will be held in Perth in September 2019 and we are actively planning the event in close collaboration with AIG and PESA. Our first *Minerals* stream presentation of 2018 was very well attended and **Regis Neroni**

Anton Egorov (Curtin University).

Anton Egorov presenting to the February meeting of the WA Branch.

of Fortescue Metals Group gave a talk on the 'Application of the passive seismic Horizontal-to-Vertical Spectral Ratio (HVSR) technique for embankment integrity monitoring (and a bit more)'.

Upcoming WA events include:

- 11 April tech night – *Young Professionals* – Several short presentations by young professionals will be followed by an overview from **Jordan McGlew** (PESA WA – YP coordinator) on presentation tips and tricks, and the event will conclude with a short feedback session from peers. This event will be jointly hosted by PESA, and will hopefully be the first of several Young Professional events in WA throughout 2018.
- May tech night – *Petroleum* – SEG Honorary Lecturer **Mazin Farouki** – 'Dense sampling in marine seismic data: Efficiency in acquisition without compromising data quality'.

The WA Branch is currently populating its technical calendar for 2018. If you have any suggestions on presenters or material, please email either the WA Branch President or Secretary.

Our monthly WA Branch's tech nights are kindly sponsored by the following: Globe Claritas, First Quantum, Geosoft, GPX Surveys, HiSeis, NRG, Resource Potentials, Southern Geoscience, Teck, Western Geco, Atlas, CGG, ExploreGeo, NGI, and a private donation in in memoriam. We could not put together the Branch's wide range of technical activities without the support of our sponsors, and we look forward to maintaining strong partnerships with these companies. Sponsorships are due for renewal in May so if you are interested in sponsoring the Branch tech night please contact the Branch President on wapresident@aseg.org.au.

I hope that you all have a lovely autumn!

Heather Tompkins
wapresident@aseg.org.au

Australian Capital Territory

The ACT Branch had a fantastic start to the year, which continued with the ACT Branch Annual General Meeting on 15 March with guest speaker **Simon van der Wielen** presenting on 'SA3D – Multi-scale mineral systems maps'.

The Branch is also looking forward to a number of upcoming events. These include:

- 5–6 April: SEG workshop on 'Seismic anisotropy: basic theory and applications in exploration and reservoir characterisation presented by Professor **Ilya Tsvankin.**
- 18 April: Guest speaker Dr **Malcolm Sambridge** presenting on 'The story of nothing – geophysical inversion'
- SEG Honorary Lecturer **Mazin Farouki** presenting on 'Dense sampling in marine seismic: efficiency in acquisition without compromising data quality' (date TBA).

James Goodwin
actpresident@aseg.org.au

ASEG national calendar: technical meetings, courses and events

Date		Branch	Event	Presenter	Time	Venue
	Apr	ACT	SEG HL	Mazin Farouki	TBA	Sir Harold Raggatt Theatre, Geoscience Australia, Symonston, Canberra
	Apr	QLD	AGM	TBA	1730	XXXX Alehouse Black Street Milton
5–6	Apr	ACT	SEG workshop	Ilya Tsvankin	TBA	Sir Harold Raggatt Theatre, Geoscience Australia, Symonston, Canberra
11	Apr	WA	Tech night	Jordan McGlew	1730	TBA
18	Apr	ACT	ASEG AGM	Malcolm Sambridge	1600	Sir Harold Raggatt Theatre, Geoscience Australia, Symonston, Canberra
16	May	WA	SEG HL	Mazin Farouki	1730	TBA

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

Reminder: Annual General Meeting (AGM)

The 2018 AGM of the Australian Society of Exploration Geophysicists (ASEG) will be held at Geoscience Australia in Canberra on 18 April. The meeting will be hosted by the ACT Branch. Details to be supplied via email. Drinks will be available from 16:00 and the meeting will begin at 16:30.

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 2018.

The AGM will be proceeded by a scientific presentation. This year Professor Malcolm Sambridge will address the meeting on 'The Story of Nothing'. Professor Sambridge's research contributions have been in geophysical inverse theory and methods of inference from indirect observations, together with their application across the Earth Sciences. Specific research directions include the development and application of data inference techniques; theoretical seismology; imaging of the internal structure of Earth using seismic waves; robust inference and uncertainty estimation from Earth science data; Mathematical methods and numerical algorithms. He is currently Professor, Seismology and Mathematical Geophysics, Research School of Earth Sciences, Australian National University http://rses.anu.edu.au/~malcolm/index.php?p=bio.

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. Marina Costelloe was elected as President-Elect in 2017 and as such will stand for the position of President.

The following officers 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:

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

Nominations must have been received via post, fax or email no later than COB Tuesday 7 March 2018. 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.

Vale: Dr David Leaman (1943–2018)

Dr David Leaman

Tasmanian geoscience has lost one of its leading lights with the death of Dr David Leaman on 18 January 2018. A great champion of geophysics and its application to community concerns, he was also an assured geologist of remarkably broad expertise and interests.

Born in 1943, David grew up in humble circumstances in the northern Hobart suburb of Glenorchy – as he later recounted, on the rock that was to dominate his life's work: dolerite. The combination of mental acuity with extreme productivity and hard work that was to characterise his career saw him obtain scholarships without which he would not have been able to pursue higher education and his childhood ambitions of becoming a scientist. In February 1966, after graduating with Honours from the University of Tasmania, David was appointed as Groundwater and Engineering Geologist with the Geological Survey of Tasmania. His Honours thesis, titled 'Geophysics – Cygnet area including geological implications of the geophysical interpretation', marked the beginning of David's dedication to using geophysics to further geological knowledge. At the Geological Survey the projects he worked on included hydrogeology, basin studies, structural geology, engineering geology and geological mapping, with David applying geophysics in all these fields. During this period David also undertook and interpreted some of the first large area gravity surveys in the State to provide three-dimensional structural information for solving specific geological problems.

At this time David developed his life-long research interests in Jurassic dolerite, the relationship of water resources and land use, and the application of gravity and magnetic methods to solve geological problems. These interests were combined when David completed a PhD thesis on the mechanism of dolerite intrusions, titled 'Dolerite intrusion, Hobart district, Tasmania', under the supervision of Professor S Warren Carey AO. The thesis was undertaken whilst mapping for the Hobart 1:50 000 geology sheet and the interpretation was used to produce a perspex three-dimensional geological model of the greater Hobart area.

David also started an educational role which included groups as diverse as university students, exploration companies and mature-age groups, across equally diverse topics including tectonics, applied geophysics and geology for engineers. He held a part-time teaching and research role at the University of Tasmania from 1972 until 2001, supervising multiple generations of Honours and postgraduate students who have gone on to apply his methods and philosophy throughout the geoscientific world.

David was appointed to the newly created position of Principal Geophysicist with the Geological Survey in 1973. In addition to a wide variety of geophysical surveys for solving specific geological and technical problems, David started a programme of gravity data acquisition in key areas of the State to add detail to the 7 km- spaced 1973 Bureau of Mineral Resources state-wide gravity survey. Detailed three-dimensional interpretation of many of these surveys provided guidance for future Department of Mines drilling but remained isolated interpretations. In 1980 this work culminated in production of the first state-wide residual gravity anomaly maps, maps where the anomalies from large bodies, such as many of the granitoids, were clearly visible rather than obscured in the Bouguer Anomaly map by combination with anomalies from other sources. This regional-residual separation was progressively refined until the 1988 release of the Mantle88 Moho and water model that allowed quantitative interpretation of gravity data after removing a regional gravity field that was not data dependent. David recognised the crucial importance of the terrain correction for gravity observations in Tasmania, and undertook the mammoth task of calculating this for most of the stations in the State database.

David held his carefully-formed views very passionately and would not be swayed by political imperatives, which did not endear him to officialdom. In 1981, frustrated by bureaucratic controls and convinced that he had no future in the State Service, he resigned from the Survey to found Leaman Geophysics, however he continued to make major contributions to understanding of Tasmanian geology via geophysical methods in his new capacity. As an independent consultant he focused on undertaking challenging evaluations of geological structures using gravity and magnetic methods, undertaking assignments for mineral and hydrocarbon exploration companies in Tasmania, Bass Strait, the Mount Isa region and PNG. During the Department of Mines Mount Read Volcanics Project (1985–1988), David's modelling showed that there were Cambrian granite bodies embedded in the Mt Read Volcanics and concluded that these may well be associated with mineralisation. Other innovative Tasmanian crustal interpretations since 1981 have included a model of the major Tasmanian granitoids, recognition of major structures and pre-Carboniferous geology throughout Tasmania, interpretation of the magnetic and gravity data from the Western Tasmanian Regional Minerals Program (2001–2003), interpretation of the form of the King Island and eastern Tasmania granitoids,

and assessment of features from the 2007 aeromagnetic surveys of northeast Tasmania.

David has left behind an impressive compendium of his work and insights. He is senior or sole author of 10 geological maps and explanatory reports, sole author of 192 Geological Survey publications and records, and co-author of 38 other Survey publications and records. David is also sole author of 102 reports lodged with Mineral Resources Tasmania by exploration companies that are now open-file, and is author or co-author of 70 refereed papers. Among these are significant contributions to understanding the three dimensional architecture of the metallogenically prolific Mount Isa-McArthur Basin terranes of northern Australia. He was also the author and publisher of five books (one in its third edition) discussing Tasmanian geology or hydrology and interpreting Tasmanian geology for bushwalkers, as well as the extraordinary part scientific memoir, part treatise *The Rock Which Makes Tasmania*. These were a natural companion to his work bringing geology to the public through Adult Education, University of the Third Age, the Hobart Walking Club, history groups and community excursions. In recent years David applied geophysical and physical techniques to assessment and management of Tasmania's water resources, and consequently his advice was widely sought by community groups, farmers and land managers on matters of forestry, irrigation and land stability of subdivisions.

David Leaman was a member of several scientific societies including the ASEG, and twice president of the Royal Society of Tasmania. In 2015 he was awarded the Geological Society of Australia's Twelvetrees Medal 'for his exceptional contributions in the use of geophysics, with geological constraints, to elucidate the three-dimensional structure of the Tasmanian crust and also for his ongoing commitment to geoscience education.'

David Leaman was an enormously productive contributor to Tasmanian geology and geophysics over 50 years, with major contributions in modelling geological domains using gravity and magnetic surveys, determining the three-dimensional form of Tasmanian granitoids, clarifying Jurassic dolerite structure and deep crustal structures across Tasmania, the nature of groundwater aquifers, the management of our water resources, and many more. His approach was fearless and sometimes controversial, but stimulated geological discussion and challenged accepted dogmas to the betterment of our understanding. As such he was a mighty proponent of the great intellectual tradition originally established by his mentor Prof Carey in the Geology Department at the University of Tasmania. His legacy of educating and informing students, explorationists and the general public in the fields of geology, geophysics and the rocks of Tasmania will continue to loom large for many decades after his passing.

He is survived by former wife Diana, their daughters Sarah and Jenny and three grandchildren, and also by Marcia, his partner for his last 23 years.

Bob Richardson, Keith Corbett, David Duncan and Mark Duffett

AEGC 2018: Reflections

The First Australasian Exploration Geoscience Conference (AEGC 2018), which incorporated the 26th ASEG Geophysical Conference and Exhibition and the PESA Basins Symposia, was held at the newly renovated International Convention Centre in Sydney in February 2018. The conference was jointly hosted by the AIG, ASEG and PESA.

Here are some statistics from the conference:

- 960 delegates
- 90 exhibitors
- 18 conference sponsors
- 15 keynote presentations
- 270 regular oral presentations
- 90 posters
- 8 workshops
- 7 official social events.

Sydney's February weather behaved itself and, after a couple of days of workshops and a geological tour of the Blue Mountains, the conference began with opening drinks in the exhibition area on the Sunday afternoon.

The conference theme 'Exploration • Innovation • Integration' reflected the broad subject of the conference: exploration, be that for petroleum, minerals or groundwater resources, and innovation and integration in terms of what needs to be done to best explore for resources. The large technical program, exhibition, and workshops allowed delegates to experience what is new and best in the exploration for resources.

Some highlights of the conference were:

- Peter Botten's plenary address.
- Phil Cooney coming from behind to win the 'quiz' at the dinner.
- The 'buzz' in the Exhibition Gallery.
- The quality of the technical sessions.

The Conference Organising Committee have received much praise for the conference, which has been greatly appreciated. The post-conference survey indicated that the vast majority of delegates and exhibitors were very pleased with how the event went. Thank you to everyone involved in organising this major conference and exhibition, it just cannot be done without all the volunteer help. An extra thanks to all those reviewers of small and extended abstracts who reviewed all those abstracts with severe time limitations. As well, thanks to the Chairpersons who made the technical program run smoothly.

We hand the baton to the WA branches of the AIG, ASEG, and PESA and wish them all the best of luck for the Perth Conference in September 2019. While the AEGC will evolve, registrants can be assured that all the aspects of the ASEG-PESA-AIG conference that they love will still be there, whether it be catching up with colleagues, clients and contractors, seeing the latest geophysical innovations in the exhibition hall or the technical geophysical presentations at the oral sessions.

On behalf of the 2018 Conference Organising Committee
Mark Lackie and Max Williamson (Co-chairs)

The 2018 Conference Organising Committee on stage during the closing plenary.

AEGC 2018: conference and exhibition awards

Laric Hawkins Award: For the most innovative use of a geophysical technique from a paper presented at the (ASEG) conference

Malcolm Cattach, Christopher Parker and Russell Mortimer

Sub-audio magnetics (SAM) – ground-based and HELISAM FLEM trials at the Forrestania EM test range

Best oral paper – minerals

Kate Hine

Woodlawn revitalised by DHEM

Best oral paper – minerals

Daniel Sattel

Passive EM processing of MEGATEM and HELITEM data

Best oral paper – energy

David Long

The Ungani Oil Field, Canning Basin - evaluation of a dolomite reservoir

Best oral paper – Near-surface and groundwater

Regis Neroni

Application of the passive seismic Horizontal-to-Vertical Spectral Ratio (HVSR) technique for embankment integrity monitoring.

Best student oral paper – minerals

Tasman Gillfeather-Clark

Self-organising maps – a case study of Broken Hill

Best student oral paper – energy

Natalie Debenham

The influence of reverse-reactivated normal faults on porosity and permeability in sandstones: a case study at Castle Cove, Otway Basin

Best poster paper – minerals

David Clark

Borehole measurements within highly magnetic bodies – corrections of measured magnetic fields and gradients

Best poster paper – energy

Tim Dean

The seismic signature of rain

Best poster paper – near-surface and groundwater

Shigeo Akuma, Masahiko Makino, Ayumu Miyakawa, Tadashi Nakatsuka, Yoshiharu Otsuka, Shunsuke Kudo, Makoto Yanagida, Toshinori Sasaki and Tatsuji Sugimori

Magnetic imaging of ultramafic bodies on the site of the Ohi nuclear power station, central Japan

Best student poster paper – minerals

Harrison Jones

Geophysical signature of the southern Gurubang base metal occurrence in south eastern NSW

Best student poster paper – energy

Victorien Paumard, Julien Bourget, Benjamin Durot, Sébastien Lacaze and Tom Wilson

Full-volume interpretation methods: applications for quantitative seismic stratigraphy and geomorphology of the Lower Barrow Group, Northwest Australia

Best student poster paper – near-surface and groundwater

Bibirabea Sedaghat, Ralf Schaa, Brett Harris, Andrew Pethick, Alex Costall, Jingming Duan and Wenping Jiang

Magnetotelluric, basin structure and hydrodynamics; south west of Western Australia

Best small exhibitor

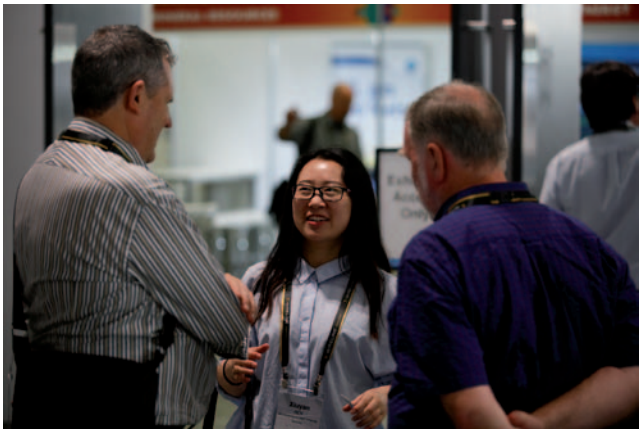
Terrex

Best large exhibitor

Oil Search

The conference awards for best paper were sponsored by First Quantum Minerals and all winners were also presented with a gold coin.


AEGC2018



AEGC 2018: ASEG honours and awards

ASEG Gold Medal: Robert (Bob) Smith

The ASEG Gold Medal is awarded from time to time for exceptional and highly distinguished contributions to the science and practice of geophysics by a Member, resulting in wide recognition within the geoscientific community. The ASEG President announced at the ASEG awards ceremony held at the AEGC in Sydney in February that the ASEG Gold Medal has been awarded in 2018 to Bob Smith, a Member of the ASEG since its formation in 1970.

This award specifically recognises Bob's distinguished service to the profession, both in Australia and overseas, through his contributions to industry, research and education over a 50-year period, and his outstanding work and support for the ASEG and other professional bodies.

After graduating from the University of Melbourne in 1960 with a BSc (Hons) majoring in physics, Bob embarked on a geophysical career in 1961 with the Bureau of Mineral Resources, based in Melbourne and later Canberra. In 1968, he moved to Adelaide to take up the position of Chief Geophysicist with McPhar Geophysics P/L, managing McPhar's geophysical contracting services in Australasia. In 1973, he built up and managed a successful consulting practice in mineral exploration.

In 1977, Bob was appointed to the role of Chief Geophysicist for CRA Exploration Pty. Ltd (CRAE), where he was charged with leading and developing the acceptance and application of geophysics and related technology within CRA. The role included representing CRAE on various government committees and industry professional groups. Bob led the introduction and development of modern geophysical methods during a period of unprecedented expansion in CRA. CRAE soon became recognised as an industry leader in geophysical applications in mineral exploration.

Bob was instrumental in recruiting and training geophysical staff to develop an integrated role within what became the world's largest mining company, with the most extensive exploration program seen to date. He provided technical support to all geophysical operations in CRAE's exploration activities, resulting in several discoveries which could be directly attributed to the geophysical input.

Bob Smith receiving his award from ASEG President Andrea Rutley.

During his two decades with CRA (which merged with Rio Tinto in 1995), Bob became an active supporter and initiator of a wide range of research projects, many through AMIRA and others within CRAE. The developments in TEM and IP in Australia at that time were part of a broad-based cooperative program, with CSIRO at the centre and most exploration companies contributing both funds and expert input. Bob's input and leadership were major ingredients in the success of these collaborative programs.

As part of this drive for innovation and problem solving, Bob developed and maintained strong links with the geophysical community worldwide, and visits to Australia by many 'world experts' resulted. Through this co-operation and sharing of expertise, Bob and mineral geophysics in Australia achieved wide international recognition.

During his time at CRAE/Rio Tinto, Bob built a formidable geophysical team, many starting as young, green graduates and progressing under Bob's guidance to make their mark within and outside that group as innovators, leaders and discoverers in their own right. Bob's legacy remains strong within the Rio Tinto group but also industry wide where geophysicists mentored by him have subsequently made their mark in exploration applications and discoveries worldwide.

Bob's promotion of the integration of geology and geophysics in exploration was no better exemplified than his initiation and implementation, in partnership with the late Prof David Boyd and other industry geophysicists, of the AMF course 'Geophysics for geologists'. This long running course was attended by over 600 geologists in Australia and overseas over three decades, and has arguably helped to create a special 'Australian brand' of close cooperation between geophysicists and their geological colleagues.

Bob's contributions to ASEG have been outstanding, having been a Member since the Society's inception, and an active supporter and contributor to the present day. He served as Federal President in 1987-88 and was the founding Chairman of the ASEG Research Foundation in 1990. Bob was a member of the ASEG-PESA Conference Organising Committee in Melbourne 2013, and an organiser of Airborne Gravity and Natural Fields EM Workshops held in conjunction with ASEG conferences in 2004, 2010, 2012, and 2016. He has attended and had an

active participation in every ASEG conference since the first meeting in Adelaide in1979. Bob was awarded Honorary Membership of the ASEG in 1997 for his outstanding contribution to the ASEG and the profession to that time.

He has also had an active role in other professional organisations, including the SEG (Associate Editor, conference technical chairman), the AusIMM (Geoscience Society Committee member, and representative on AGC). He was also a member of the Technical Advisory Committee for the Australian Mineral Exploration Technologies CRC from 1995–2000 and a similar role at AGSO during the 1990s. He has been an invited speaker at several Australian and international conferences and has authored or co-authored many published papers including state-of-the-art papers on geophysical technology development and the role of geophysical methods in mineral exploration.

A flow on effect of Bob's professionalism throughout his career was, and is, still a firm focus on quality control in contractor-acquired data. The Australian contracting industry has benefited and owes much to Bob's sharp eye for quality data.

Since retiring from Rio Tinto in 1999, Bob has continued practicing as a consultant and has remained very active in the ASEG and the ASEG Research Foundation. One of his main achievements has been the advancement of the University of WA Airborne Gravity Gradiometer (AGG) project to the stage where it was ready for funding to completion by a third party. Since 2000, he has served on a management committee overseeing the project and monitoring development of the system. The RJ Smith Airborne Gravity Gradiometry test range near Kauring (WA) is named in honour of his efforts in the field of AGG.

Wider recognition of his services to the industry have come in the form of the Australian Centenary Medal Award in 2003 'for service to Australian society in geophysics and mineral exploration', and the AusIMM Branch & Society Service Award in 2014. In later years as he nears retirement, he has become a State Emergency Service (Victoria) volunteer, and a keen golfer.

It is only fitting that his positive influence on the science and on many members of the profession, his distinguished career spanning over 50 years, and his on-going contributions to the ASEG and the professional development of its Members should now be recognised with the award of the ASEG Gold Medal.

Lindsay Ingall Memorial Award: Andrew Sloot

The Lindsay Ingall Memorial Award is intended for an Australian resident or former resident for the promotion of geophysics within the non-geophysical community, including geologists, geochemists, engineers, managers, politicians, the media or the general public. The award honours the memory of an ASEG founder, past President and Honorary Member, the late Lindsay Ingall, for his capacity to cross geoscience boundaries, his ability to relate technically and effectively with other professionals, regardless of their own understanding of the principles of geophysics, and for his enduring commitment to assist geoscientists across Australia. It is awarded to an individual who has actively promoted geophysics to the wider community.

The award in 2018 is made to Andrew Sloot, a Sydney-based ASEG Member who is well known to mineral industry geophysicists and the broader geological and corporate community as a passionate advocate and promoter of geophysics and the resources industry. His nomination for this award has been strongly supported and endorsed by many company geologists and exploration managers.

Andrew is an experienced geophysicist with expertise in the implementation of numerous geophysical technologies to provide beneficial information for a range of resource projects. His detailed knowledge of a wide range of geophysical methods and his unassuming manner facilitate his very successful communication with geoscientists, exploration executives, landholders, and community stakeholders.

He is recognised for his capacity to communicate effectively in a non-technical manner, his good understanding of exploration methods and geological objectives, and for his clear presentation and discussion of geophysical exploration data. He encourages and fosters respectful communication with landowners and community representatives, to explain the activities and processes that are used in the exploration work, and to respect and work around the farming activities that may be temporarily affected by the work. Feedback from the landowners suggests they are impressed with Andrew's professionalism and understanding of their needs, as well as providing them with an insight into the practical uses of geophysics for applications outside of mineral exploration.

Andrew also is an enthusiastic mentor and supporter of early career geoscientists. He maintains a policy of offering employment to graduates to gain vital early career experience, and assist them make the progression from university to the real world of exploration. He has been a positive mentor for young people for many years.

He has also provided assistance to undergraduates contemplating a career in geophysics by recounting his early professional experiences to students at AIG Careers Nights. He actively encourages students and young professionals to attend society meetings to acquire knowledge and develop professional networks.

Andrew has been an enthusiastic supporter of the ASEG over many years and has participated as an exhibitor in numerous ASEG-PESA Conferences. He is a regular geophysical exhibitor at AIG and SMEDG events, always being available to talk to geologists about the role of geophysics in mineral exploration. He is an active member of the SMEDG Organising Committee, has chaired SMEDG meetings, and has helped to coordinate speakers for various SMEDG talks.

He has also been an active participant on the Technical Committee of the ASEG Ground Geophysical Survey Safety Association, established in 2011 to advance safety procedures for the benefit of non-technical crew-members and the general public.

Andrew Sloot has been described as a 'credible and worthy ambassador for the

Andrew Sloot receiving his award from ASEG President Andrea Rutley.

discipline of geophysics'. The Lindsay Ingall Memorial Award is therefore an appropriate recognition of Andrew's achievements in actively promoting geophysics to the wider community over many years.

Shanti Rajagopalan Memorial Award: Shaun Strong

The Shanti Rajagopalan Memorial Award, inaugurated in 2013, is presented for the best paper published by a Student Member in *Exploration Geophysics* in the period prior to each ASEG Conference.

The award is named in memory of the late Dr Shanti Rajagopalan, who passed away in 2010 at the prime of her career. Shanti was one of the best known and respected members of the ASEG, and was well known for her outstanding contributions to the geophysical profession.

Shanti was also a major contributor to the ASEG. She was a great supporter of her local branch, served as Victorian Branch President, and was actively involved in the organisation of ASEG conferences in Hobart and Melbourne. She was also Editor of *Exploration Geophysics* in 2000 and 2001.

But it is most noteworthy in the context of this award that, in 1987, as a student Member, Shanti received the inaugural Laric Hawkins Award for the most innovative use of a geophysical technique from a paper presented at the ASEG Conference. It is therefore very appropriate that an award to encourage technical excellence by our Student Members is named in honour of Shanti.

The winner and recipient of the Shanti Rajagopalan Memorial Award for 2018 is Shaun Strong, for his paper co-authored with Steve Hearn entitled 'Statics correction methods for 3D converted-wave seismic reflection'. The paper was published in *Exploration Geophysics*, Vol. 48, pp. 237–245.

Shaun Strong receiving the Shanti Rajagopalan Memorial Award from ASEG President Andrea Rutley.

Shaun completed his PhD at Queensland University in December 2016. He is currently working for Velseis in Brisbane as a geophysicist with responsibilities in both the research and acquisition departments.

Honorary membership of the ASEG: John Denham

ASEG honorary membership has been conferred upon long-standing NSW Branch member John Denham, in recognition of his distinguished service to the petroleum exploration industry in a career spanning more than five decades, and for his most valuable contributions to the ASEG over many years.

John was born in Parramatta in 1941, and after graduating with a BSc in geology and geophysics from Sydney University in 1962, he started working for Austral Geo Prospectors (later United Geophysical) as a 'Computer' on seismic field crews in Queensland. By 1965 he was Party Chief of a seismic crew in the Simpson Desert, later in Queensland and PNG, gaining experience in conventional land seismic operations, desert and jungle operations.

In 1971 he joined BHP Petroleum in Melbourne as a Senior Geophysicist, remaining there until late 1993, filling a variety of roles, including that of Chief Geophysicist, involving BHPP operations worldwide. This involved field operations, processing and interpretation of both land and marine data. He pushed and oversaw the introduction of digital technology into BHPP from the early 1970s, including one of the first interactive interpretation systems in Australia in 1983.

During this time, he published papers in APEA, ASEG, AusIMM and SEG journals on subjects as diverse as depth conversion, case histories, field techniques, interactive interpretation, processing, geophysics education, and geophysics history. John's professional career has been characterised by an enquiring mind, and a pragmatic approach to improving seismic methodologies.

After over two decades with BHPP, John continued his career for some years as a consultant, doing a number of relatively small jobs in Australia and the USA.

During his career John has made an exceptional contribution to the ASEG, again focusing on scientific rigour and advancement. A member of ASEG since 1971, he initiated a petroleum geophysics conference in Melbourne, was technical co-chairman of the 1989 ASEG conference in Melbourne, and served as Editor of Exploration Geophysics from 1994 to 1999.

At the inception of the ASEG Research Foundation in 1989, John volunteered to serve on the committee, and was appointed Chair of the Petroleum sub-committee. He has retained this role to the present, each year vetting applications to ensure that supported research projects are both scientifically sound and practically worthwhile. John maintains an interest in graduates who have been supported by the Foundation, and can often be found at ASEG conferences mentoring the next generation of geophysicists.

John was awarded an ASEG Service Certificate in 2003 in recognition of his significant contributions to the Society at that time. He has continued to support the Society, and has been a regular attendee and contributor at almost all ASEG conferences since the inaugural meeting in 1979. John is also an important member of the History Committee due to his knowledge of the society from its early days.

John has managed to fit in many other leisure activities during his busy career. He has held a Private Pilot's licence since 1967, and has also been involved in sailing since the mid-sixties, building an 11 m schooner in 1979, which he twice sailed from Melbourne to North Queensland and back. In retirement, John lives on a farm, which he has owned since 1983, at Elong Elong near Dubbo in Central West NSW. 'John from Elong' is well known in his local community as a long standing radio quiz champion where his expertise ranges far from geophysics, fuelled by decades of reading. He has also served as a volunteer with the local Rural Fire Service brigade.

It is very fitting that the ASEG now recognises John's outstanding contributions over many years to the ASEG and to the geophysics profession, with the award of honorary membership of the ASEG.

John Denham receiving his award from ASEG President Andrea Rutley.

Honorary membership of the ASEG: Andrew Long

ASEG honorary membership has been awarded to Western Australian Branch Member Dr Andrew Long, in recognition of his outstanding contribution and leadership in petroleum geoscience spanning 30 years, and for his valuable contributions to the ASEG over many years.

Andrew is a graduate from the University of Melbourne (BSc, 1985), Curtin University (Post Graduate Diploma in Petroleum Geophysics, 1986), and the University of Western Australia (PhD, 1996). In 1993, he was awarded the Alumni Medal by Curtin University.

Early in his career he applied his land seismic acquisition and processing experience to satellite altimeter data used for oceanic gravimetry while working part-time at World Geoscience during his PhD studies. The small team he led introduced the first commercial satellite gravity solutions to the Asia-Pacific region in 1993, and the results received best petroleum presentation at the 1994 ASEG conference in Perth.

This work also attracted the attention of Prof Jon Claerbout from Stanford University, and culminated in Andrew working as a Post-Doctoral Research Affiliate with both the Stanford Exploration Project (SEP consortium) and the Crustal Geophysics Group after completing his PhD in 1996. He later returned to Stanford in 2001 as a Visiting Scholar with the Stanford Rock Physics and Borehole Geophysics Group whilst working for PGS. His Stanford experiences heavily influenced how he has embraced the value of academic partnerships with industry since, and his enthusiasm for the promotion of technology at international forums.

He is currently Chief Scientist with the Sales & Service division of PGS, and actively promotes geophysical technologies within PGS - an international company with about 2000 employees - and the wider geophysics community via regular publications in many journals. At PGS he also administers their sponsorship and participation in 13 international university consortia.

Andrew has been an ASEG Member since 1991 and has presented over 20 papers at ASEG conferences, including three efforts where he presented four papers at the same conference (2004, 2006 and 2013). He has variously been awarded best oral presentation (single author), best written paper (as a co-author), and presenter (for a colleague) of the paper awarded the Laric Hawkins prize in 2006. He has also won presentation awards from APPEA, IPA, and the SEG.

Andrew is highly active within the SEG and EAGE organisations, being the inaugural SEG Honorary Lecturer for the Pacific South region in 2009, and a presenter of several SEG and EAGE courses. A regular speaker at various Australian and International universities, as well as ASEG and PESA state chapters, he is an active member of ASEG, SEG, EAGE, PESA and SEAPEX.

Andrew actively seeks to engage with, encourage and mentor young geoscientists across the Australian and International oil and gas industry. He is a great supporter of geophysical innovation in the industry, and encourages others through his regular participation and presentations at conferences, publication of his work, and refereeing the work of other Australian and international geophysicists.

Andrew has been a great supporter and contributor to ASEG-PESA Conferences over many years. The 2015 ASEG-PESA conference line-up of international petroleum keynote speakers, which he had a major role in assembling, reflects the strength of his industry and academic contacts. His dedication to research and thirst for excellence in his projects was evident in the early days of his career, and are qualities he has taken with him through his 30-year geophysical career.

Andrew is an extraordinary contributor to the geophysical community in both a technical sense and as a community volunteer. To acknowledge these outstanding contributions to the profession and the ASEG over many years, the ASEG is pleased to confer the award of honorary membership to Andrew Long.

Andrew Long receiving his award from ASEG President Andrea Rutley.

ASEG Service Certificate: Yuzuru Ashida

Professor Yuzuru Ashida has been awarded an ASEG Service Certificate for his distinguished role in promoting international co-operation between the ASEG and SEG Japan, and in enhancing the international status of ASEG publications.

Professor Ashida graduated from Kyoto University in 1967 and received his doctorate from Tokyo University in 1985. After 20 years in Japan Petroleum Exploration Co Ltd, he joined the Faculty of Engineering of Kyoto University as a lecturer, and progressed to Associate Professor in 1988, then Professor in 1996. He has served the SEGJ as a member of various committees and on the SEGJ Board, and was elected President for the period 2002-2004. He was awarded the Best Distinguished Paper in 1980 and 1990, a Service Certificate in 1998, and an Honorary Membership of the SEGJ in 2014.

Since 1995, Professor Ashida has been a supporter and regular attendee at ASEG conferences. He became an ASEG Member in 2003. His active contribution to the ASEG commenced in September 2000 with his role in establishing the ASEG's first association agreement with an international geophysical society – the SEGJ. Since then, the ASEG has concluded association agreements with eight international societies. The SEGJ is now a regular participant in ASEG Conferences and the ASEG has been invited to the International Symposia organised by the SEGJ.

News

The tie between ASEG and the international associations has also been enhanced by Professor Ashida's leading role in initiating the joint publication of *Exploration Geophysics* between ASEG and SEGJ. He also proposed the inclusion of the Korean SEG as contributors to the joint journal. Lindsay Thomas, the Managing Editor of *Exploration Geophysics* at the time, was convinced by Professor Ashida's arguments for the joint-journal concept, and was also appreciative of his assistance in some aspects of the implementation of the new development.

These initiatives have increased the quality and quantity of the articles in the journal, leading to improvement of the international ranking of the journal, and raising the prominence and status of the ASEG in the world geophysics community. *Exploration Geophysics* now enjoys an increased international reputation within the profession, due to the greater diversity of content that has resulted from Professor Ashida's initiative.

The ASEG is pleased to recognise Professor Ashida's achievements and significant contributions to both the ASEG and its associate international societies, with this award of the ASEG Service Certificate.

Yuzuru Ashida receiving his award from ASEG President Andrea Rutley.

ASEG Service Medal: David Robson

The ASEG Service Medal awarded for outstanding and distinguished service to the ASEG over many years. The recipient in 2018 is David (Dave) Robson, a member of the NSW Branch and ASEG Member since 1972.

Following his graduation with a BSc and a Post Graduate Diploma of Applied Geophysics from the University of NSW in 1972, David gained valuable experience in the contracting industry with Scintrex Pty Ltd before joining the BMR (now Geoscience Australia) in 1974, where he utilised geophysical technology to characterise known ore bodies, and to assist with regional geological mapping programs in northern Australia. In 1980, he joined WMC as senior geophysicist based in Melbourne and Kalgoorlie. In 1994, he joined the Geological Survey of New South Wales (GSNSW) in the role of Chief Geophysicist, a role he held for over 20 years, until his retirement in 2014.

As Manager of the Regional Mapping Group and Chief Geophysicist at GSNSW, David was responsible for a team of geologists and geophysicists that maintained, updated and interpreted NSW geological, geophysical and other datasets. This included government surveys, and the collation and archiving of private company surveys for release as open file data. Quality control and standardised formats were key issues for Dave in his custodian role for GSNSW, and he acted to implement processes and protocols that would benefit future data users. He actively promoted geophysical surveys to the government, secured substantial budget allocations for airborne and ground geophysics, and scrupulously managed contract data acquisition and processing. He was determined to provide the best possible public datasets, not just for NSW but to ensure compatibility across Australia.

The award of the ASEG Service Medal is largely in recognition of David's outstanding service to the ASEG over many years, through involvement in and contribution to State Branch Committees, Conference Organising Committees, the ASEG Technical Standards Committee, and the ASEG Federal Executive.

David made significant contributions to the 2004 and 2010 ASEG-PESA Conferences held in Sydney. In 2004, he was co-chair of the Technical Workshops Committee, organising and facilitating an impressive program of workshops in the fields of minerals, petroleum and finance. In 2010, he was the Honorary Secretary, and chair of the Workshops Committee, arranging eleven workshops in a variety of fields. His diligence resulted in a significant net surplus for workshops at this conference.

David was also an integral member of the 2018 AEGC Sydney Conference Organising Committee as Honorary Secretary, contributing to overall organisation, workshops and communications. David's efforts have greatly assisted the NSW branch in achieving excellent technical and financial outcomes for the Society.

David's contribution as chairman of the ASEG Technical Standards Committee from 2009 to 2015 has helped ensure that standards for geophysical data acquisition, processing and delivery were developed to benefit all in the geoscience community. Through David's leadership, the ASEG developed and published standards that will ensure that geophysical surveys are conducted to a consistent standard for use in the exploration and research sectors.

In addition, David has also made significant committee contributions to the local ASEG branches in Victoria and NSW (Branch Secretary from 1995 to 1998), and to the ASEG Federal Executive, where he served with distinction as Federal Honorary Secretary from 1999 to 2001.

Throughout his career, David has consistently promoted geophysics and the ASEG, always encouraging younger members to get involved and contribute to local branch meetings and conferences. His dedicated support for the Society for over four decades, in particular his willingness to contribute much time and energy to key roles on Conference Committees and the Federal Executive, and his deep respect for the scientific value of the ASEG and the people who contribute to it, have made a positive impression on many other geoscientists.

It is most fitting that David's distinguished contribution to the ASEG and the profession over many years has been recognised with the award of the ASEG Service Medal.

David Robson receiving his medal from ASEG President Andrea Rutley.

Update on geophysical survey progress from Geoscience Australia and the Geological Surveys of Western Australia, South Australia, Northern Territory, Queensland, New South Wales, Victoria and Tasmania (information current on 8 March 2018)

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
Andamooka	GSSA	GA	Sander Geophysics	23 Feb 2017	81 396	200 m 60 m E–W	14 560	6 Jun 2017	Final data QA/QC in progress	183: Aug 2016 p. 34	TBA
Barton	GSSA	GA	Thomson Aviation	22 Jan 2017	111 758	200 m 60 m E–W	20 560	11 May 2017	Final radiometric data QA/QC in progress	183: Aug 2016 p. 34	TBA
Fowler	GSSA	GA	Thomson Aviation	18 Feb 2017	95 009	200 m 60 m E–W	17 360	2 Jun 2017	Final radiometric data QA/QC in progress	183: Aug 2016 p. 34	TBA
Torrens	GSSA	GA	Sander Geophysics	4 Mar 2017	79 990	200 m 60 m E–W	14 800	15 Jun 2017	Final data QA/QC in progress	183: Aug 2016 p. 34	TBA
Tasmanian Tiers	MRT	GA	TBA	TBA	Up to an estimated 66 000	200 m 60 m N–S or E–W	11 000	TBA	TBA	TBA	National Collaborative Framework Agreement between GA and MRT is being updated. The survey has been deferred to occur between Oct 2017 and Mar 2018
Isa Region	GSQ	GA	GPX	3 Jul 2017	120 062	100 m 50 m E–W	11 000	5 Nov 2017	Preliminary final gridded data made available to GA on 13 Feb 2018	188: Jun 2017 p. 21	TBA
Tallaringa N (1A)	GSSA	GA	TBA	26 Oct 2017	97 762	200 m 60 m E–W	17 320	85.7%	TBA	190: Oct 2017 p. 26	TBA
Tallaringa S (1B)	GSSA	GA	TBA	26 Sep 2017	145 042	200 m 60 m E–W	26 010	70.8%	TBA	190: Oct 2017 p. 26	TBA
Coober Pedy (8A)	GSSA	GA	TBA	18 Sep 2017	90 627	200 m 60 m N–S	16 140	21 Dec 2017	TBA	190: Oct 2017 p. 26	TBA
Billa Kalina (8B)	GSSA	GA	TBA	10 Oct 2017	90 625	200 m 60 m N–S	16 140	18 Dec 2017	TBA	190: Oct 2017 p. 26	TBA
Childara (9A)	GSSA	GA	TBA	5 Nov 2017	135 021	200 m 60 m N–S	23 910	62.0%	TBA	190: Oct 2017 p. 26	TBA
Lake Eyre (10)	GSSA	GA	TBA	2 Oct 2017	91 800	200 m 60 m E–W	16 180	93.6%	TBA	190: Oct 2017 p. 26	TBA

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
Tanami-Kimberley	GSWA	GA	Thomson Aviation	16 Jun 2017	49 825	2500 m line spacing	110 000	31 Oct 2017	Preliminary final data made available to GA on 27 Feb 2018	The survey area covers the Billiluna (all), and parts of the Lucas, Cornish, Mount Bannerman, Mount Ramsay, Noonkanbah, Lansdowne, Lennard River, Derby, Charnley and Yampi 1:250 k standard map sheets	TBA
Kidson Sub-basin	GSWA	GA	CGG Aviation (Australia)	14 Jul 2017	72 933	2500 m line spacing	155 000	TBA	81.2%	The survey area covers the Anketell, Joanna Spring, Dummer, Paterson Range, Sahara, Percival, Helena, Rudall, Tabletop, Ural, Wilson, Runton, Morris and Ryan 1:250 k standard map sheet areas	TBA

TBA, to be advised.

Table 3. AEM surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
East Kimberley	GA	GA	SkyTEM Australia	26 May 2017	13 723	Variable	N/A	24 Aug 2017	Nov 2017	TBA	TBA
AusAEM (Year 1)	GA	GA	CGG	TBA	59 349	20 km with areas of infill	TBA	TBA	45.8%	186: Feb 2017 p. 18	TBA
Surat-Galilee Basins QLD	GA	GA	SkyTEM Australia	2 Jul 2017	4627	Variable	Traverses	23 Jul 2017	Nov 2017	188: Jun 2017 p. 21	TBA
Stuart Corridor, NT	GA	GA	SkyTEM Australia	6 Jul 2017	9832	Variable	Traverses	12 Aug 2017	Nov 2017	188: Jun 2017 p. 22	TBA
Olympic Domain	GSSA	GA	SkyTEM Australia	14 Nov 2017	3181	1.5 & 3 km E–W	33 200	21 Nov 2017	Raw edited data to GA in Dec 2017	190: Oct 2017 p. 27	TBA
Fowler Domain	GSSA	GA	SkyTEM Australia	Early Dec 2017	3057	5 km NW–SE	15 000	5 Dec 2017	Raw edited data to GA in Dec 2017	190: Oct 2017 p. 27	TBA

TBA, to be advised.

Table 4. Magnetotelluric (MT) surveys

Location	State	Survey name	Total number of MT stations deployed	Spacing	Technique	Comments
Northern Australia	Qld/NT	Exploring for the Future – AusLAMP	150 stations deployed in 2017	50 km	Long period MT	The survey covers the area between Tennant Creek and Mount Isa. The next field season resumes in mid-April 2018.
AusLAMP NSW	NSW	AusLAMP NSW	25 stations deployed in 2018	50 km	Long period MT	Covering the state of NSW with long period MT stations at approximately 50 km spacing

Table 5 Seismic reflection surveys

Location	State	Survey name	Line km	Geophone interval	VP/SP interval	Record length	Technique	Comments
Northern Australia	Qld/ NT	South Nicholson Basin	1100	20 m	40 m	20 seconds	2D – Deep Crustal Seismic Reflection	The survey covers the region between the southern McArthur Basin to the Mt Isa western succession, crossing the South Nicholson Basin and Murphy Province. The data acquisition phase of the survey started on 23 May and was completed in Aug 2017. Raw data were released in Mar 2018.
South East Lachlan	Vic/ NSW	SE Lachlan	Approx. 450	10 m	40 m	20 seconds	2D – Deep Crustal Seismic Reflection	The survey covers the South East Lachlan Orogen crossing the Victorian–New South Wales border. The data acquisition phase of the survey commenced on 5 Mar 2018 near Benalla in Victoria. The survey will complete data acquisition south of Eden in NSW.

Geological Survey of South Australia: National Regolith Conference, Wallaroo, Yorke Peninsula

Dr Carmen Krapf from 'Characterising the Cover' program at GSSA is the organiser of the 5th Australian Regolith Geoscientists Association (ARGA) conference to be held from 8–11 April 2018 at Wallaroo on the Yorke Peninsula, South Australia. Two days of technical presentations will be combined with pre-, post- and mid-conference field trips that include the influence of bedrock on the soils and vines of the Clare Valley, aspects of transported and *in situ* regolith of the Yorke Peninsula, and the influence on metal dispersion and choice of effective surface techniques for mineral exploration. Members of the GSSA are involved in organising and leading the field excursions and will present on aspects of geochemistry and mineralogy of the cover within the context of informing the national UNCOVER initiative.

Technical presentations include keynotes by Ignacio González-Álvarez (CSIRO) on 'Insights on the paradigms applied for mineral exploration in deeply weathered landscapes' and Allan Chivas (University of Wollongong) on 'Oxygen isotope dating the Australian regolith'. A wide range of regolith-related topics will be covered by some 20 talks and 8 posters that include aspects of regolith geochemistry, passive seismic surveys for estimating regolith thickness, regolith mineralogy and hydrogeology, and aeolian regolith from New Zealand, northern Himalayas and Namibia.

Further information is available at http://regolith.org.au/conference2018.html.

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Canberra observed

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The 1st AEGC Conference in Sydney

I don't know what other attendees thought, but I reckon the organisers did a wonderful job in delivering a high quality technical program of talks and poster sessions.

The First Australasian Exploration Geoscience Conference put an end to our series of 25 International Geophysical Conferences and Exhibitions and delivered a broader-based meeting with more multidisciplinary presentations. This is an inevitable trend in the exploration business because to find new mineral and petroleum resources we will be relying more on teams that are able to harness specialist technical skills.

We still need specialists to provide the right skills and people who can identify these skills. For each exploration target we probably need the same core of expertise, but we might need other skills not in common use. For example, when the search is under regolith cover, we might need EM information and analysis as well as shallow seismic, gravimetry and geochemistry. But there may be other techniques that have not been used previously that will be critical. We must be alert to new developments.

There were two issues that impressed me. The first was the number of multi-disciplinary papers both as posters as well as oral presentations, and the second the increased focus on outcomes, rather than process. The second issue is very important. We should never be shy to ask 'why?'

Finally, I would like to congratulate Lisa Worrall for compiling the Conference *Previe*w Handbook. The Handbook was essential for choosing which sessions to attend and for finding out about the author. I know that this information was available on one's smart phone, but it's much easier to have everything in the hard-copy handbook that's properly indexed than on a phone with a small screen. Future conferences should publish similar handbooks.

Exploration investment in 2017 better for minerals than petroleum

Minerals

Investment in mineral exploration continues to increase, according to the mineral and petroleum exploration data for the final quarter of 2017, released on 5 March 2018 by the Australian Bureau of Statistics (http://www.abs.gov.au/ausstats/abs@.nsf/mf/8412). Figure 1 summarises the exploration investment from 2005–2017, adjusted for the CPI.

The trend-estimate for total mineral exploration expenditure increased 2.3% ($10.4 m) to $457.1 m in the December quarter 2017 (Figure 2). The largest contributor to the increase in the trend estimate this quarter was New South Wales (up 7.0% to $57.6 m). However, NSW is still only 11% of the total of $496.1 m.

In original terms, mineral exploration expenditure rose 6.2% ($23.6 m) to $403.1 m. It is now at similar levels to what it was in the June quarter 2006, but well below the peak of $1163 m in the June 2012 quarter (see Figure 1). Western Australia with a $298.5m investment in the December 2017 quarter, continues to dominate at 60% of the Australian total.

In terms of commodities, gold continues to dwarf all other commodities and an estimated $209 m was invested in the search for gold in the December 2017

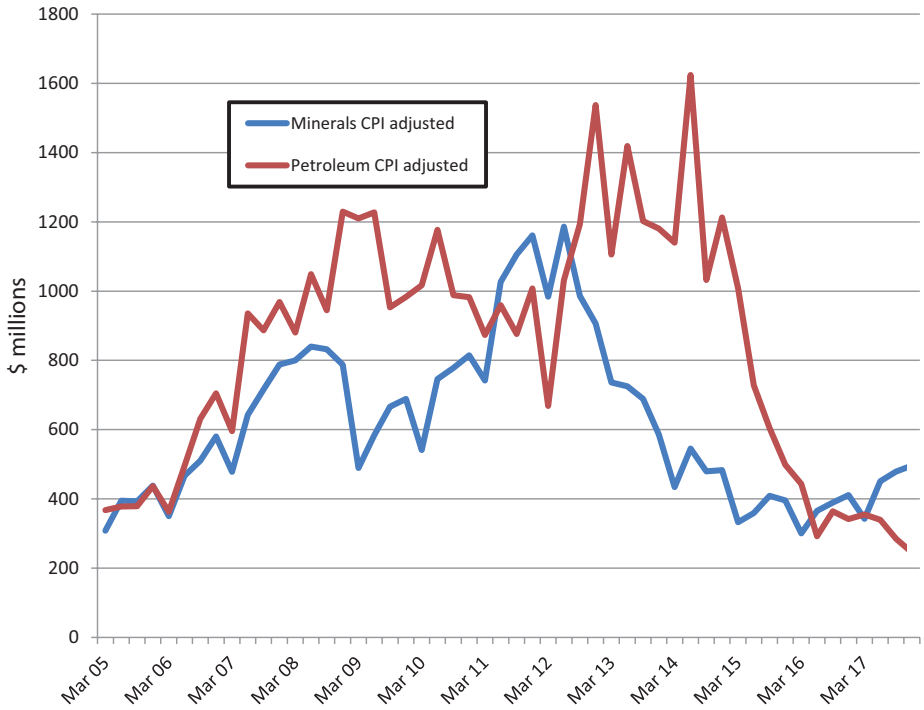

Figure 1. *Quarterly minerals and petroleum exploration investment, CPI adjusted, for the period 2005–2017.*

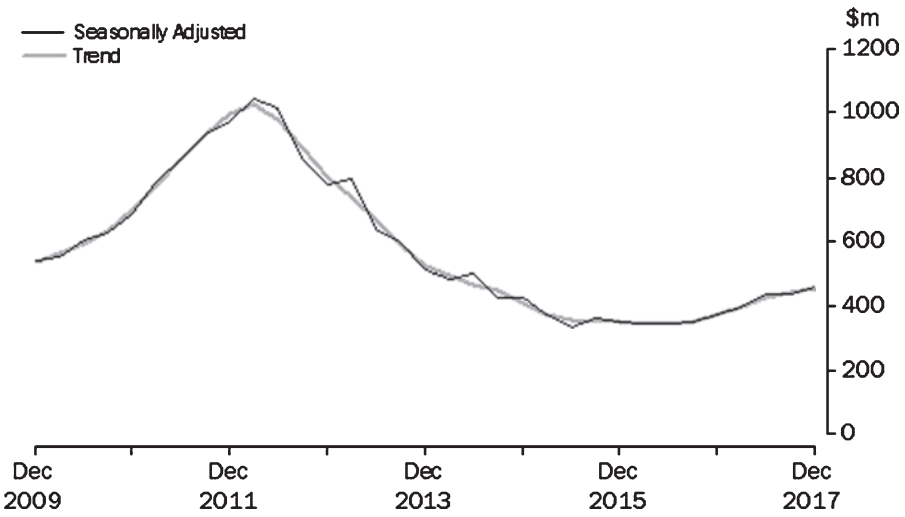

Figure 2. *Mineral exploration, seasonally adjusted and trend 2009–2017.*

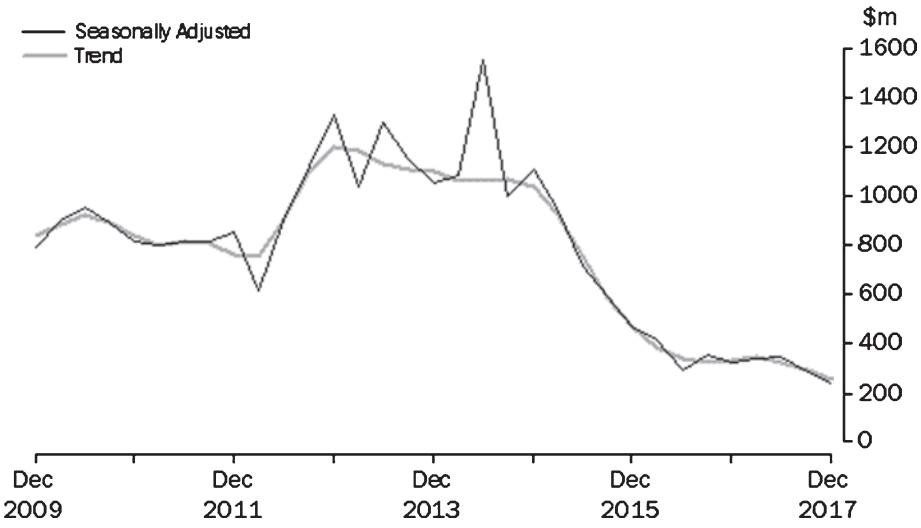

Figure 3. *Petroleum exploration, seasonally adjusted and trend 2009–2017.*

quarter. Iron ore was second at about $69 m.

Petroleum

The situation for petroleum is becoming critical. The trend estimate for total petroleum exploration expenditure fell by 13.2% (–$38.8 m) to $254.3 m in the December quarter 2017 (Figure 3). Expenditure on production leases fell 4.2% (–$2.3 m) and exploration expenditure on all other areas fell 13.2% (–$31.4 m). This is the lowest level of investment since 2004.

The largest contributor to the decrease in the trend estimate was Northern Territory (–42.7%, –$31.3 m) and the largest contributor to the fall in the seasonally adjusted estimate was Western Australia (–12.5%, –$18.1 m).

Onshore investment fell from $101 m to $78 m and offshore from $293.1 to $178 m. These numbers are really bad, and it is not obvious what the government can do to help boost the oil search.

Education matters

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Congratulations to all the students who won awards at AEGC 2018. They are:

- Tasman Gillfeather-Clark (Macquarie University, best student oral paper in the minerals stream for his presentation entitled 'Self-organising maps – a case study of Broken Hill'
- Natalie Debenham (University of Adelaide), best student oral paper in the energy stream for her presentation entitled 'The influence of reverse-reactivated normal faults on porosity and permeability in sandstones: a case study at Castle Cove, Otway Basin'
- Harrison Jones (Macquarie University), best student poster in the minerals stream His poster was entitled 'Geophysical signature of the southern Gurubang base metal occurrence in south eastern NSW'
- Victorien Paumard (University of Western Australia) and his co-authors; Julien Bourget, Benjamin Durot, Sébastien Lacaze and Tom Wilson, best student poster in the energy stream. Their poster was entitled 'Full-volume interpretation methods: applications for quantitative seismic stratigraphy and geomorphology of the Lower Barrow Group, Northwest Australia'
- Bibirabea Sedaghat (Curtin University), Ralf Schaa, Brett Harris, Andrew Pethick, Alex Costall, Jingming Duan and Wenping Jiang, best student poster in the near-surface and groundwater stream. Their poster was entitled 'Magnetotelluric, basin structure and hydrodynamics; south west of Western Australia'

Not only did these student collect framed certificates, they were also given a gold coin by the award sponsor, First Quantum Minerals.

Introducing Marina Pervukhina: the new Chair of the ASEG Education Committee

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Marina Pervukhina was born in the Urals, on the boundary between Europe and Asia. She obtained her BS and MS in physics and engineering from Moscow Institute of Physics and Technology (State University now), which is famous for the fact that two legendary Russian physicists Lev Landau and Pyotr Kapitsa were giving lectures there. Marina worked at the State Institute of Oceanography and then at the Nuclear Safety Institute of the Russian Academy of Science. Later her family moved to Japan where she got a research position at the Geological Survey of Japan. She was granted her PhD in geophysics in 2006 by Kyoto University for her research in rock physics of seismogenic zones.

Marina joined CSIRO in 2007 and since that time she has been working on rock physics and petrophysical properties of seal and organic-rich shales. She joined the ASEG FedEx in 2017 as the Branch Representative and soon realised that the ASEG Education Committee needs to be collaborating with the branches closely and directly. She was very excited to be asked to lead the Education Committee. She believes that the Professional Development courses that ASEG promotes in Australia offer great opportunities to learn new skills that are equally valuable for both young professionals and for experienced geoscientists. She also sees these events as great networking occasions.

Education courses planned for this year

This year the ASEG is planning to bring a couple of SEG courses to Australia. Professor Ilya Tsvankin gave a course on 'Seismic anisotropy: basic theory and applications in exploration and reservoir characterisation' in Canberra between the 5th and 6th of April. Dr Kurt Marfurt is coming to Australia in July with his DISC 'Seismic attributes as the framework for data integration throughout the oilfield life cycle'. In addition, the ASEG plans to promote EAGE education courses in Australia, since EAGE offers more than 60 courses in geophysics, geology, petrophysics, near-surface, engineering and training and development. These courses are sponsored and thus are generally more affordable for self-employed geoscientists and consultants. Finally, Marina believes that the educational courses should not necessarily be 'imported'. A number of famous geoscientists work and live in Australia. She is planning to promote their lectures and/or courses nationally and worldwide.

If you have any suggestions for an OzStep or OzLeap program in 2018–19 please contact Marina directly. OzStep is a light, short introductory type of workshop organised by your local Branch. OzLeap is more in-depth and may run over a couple of days. Marina would also like feedback on what skills you would like to develop, as the ASEG may be able to help organise an educational event for you.

SEG short course presenter Professor Ilya Tsvankin: a specialist in seismic anisotropy

Professor Tsvankin is Co-Leader of the Center for Wave Phenomena at Colorado School of Mines. Professor Tsvankin is known for his research in seismic anisotropy, elastic wave propagation, and characterisation of fractured reservoirs. His monograph 'Seismic signatures and analysis of reflection data in anisotropic media' is comprehensive text covering both basic and applied aspects of seismic anisotropy. Professor Tsvankin has been teaching his popular two day SEG course 'Seismic anisotropy: basic theory and applications in exploration and reservoir characterisation', together with Dr Vladimir Grechka for many years. Professor Tsvankin taught this course in Canberra on the 5th and 6th of April this year.

In February and March, prior to giving the course in Canberra, Professor Tsvankin visited CSIRO and Curtin University in Perth.

Professor Boris Gurevich (Curtin) (left), Dr Marina Pervukhina (CSIRO) (centre) and Professor Ilya Tsvankin (CSM) (right) in front of Australian Resources Research Centre in Perth.

Travel grant to the EGU for Alison Kelsey

Alison Kelsey

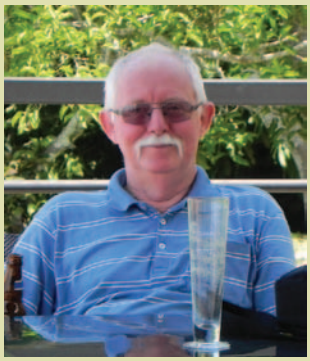
Alison Kelsey, PhD graduate of the University of Queensland School of Earth and Environmental Sciences, has been awarded a $3000 travel grant by the Australian Environmental Foundation. Alison will present her work in a paper at the annual meeting of the European Geosciences Union, in Vienna, during April 2018.

The AEF Board has awarded the grant from its Bob Carter Memorial Fund, a fund set up to commemorate the life and work of the late Professor Bob Carter, a world-renowned geologist and marine scientist who passed away in January 2016.

Alison's PhD thesis investigated and demonstrated an astronomical mechanism as the cause of cycles of natural climate change of around 1500 years in length. Her research was based on an analysis of the palaeoclimatic record of Fraser Island in Queensland and other Australian regional records. The memorial association with Bob Carter's work is apt; Bob was variously Chairman of an Australian Research Grants panel and Chairman of the Department of Earth Sciences at James Cook University from 1998 to 2005 and a visiting research professor in geology and geophysics at the University of Adelaide from 2001 to 2005. Bob was well known as a 'climate contrarian' who in the fullness of time will be proven right, wrong, or some position in-between. He debated marine geology and climate issues in public with courtesy and objectivity – he would be advising the same approach by Alison Kelsey and all recent graduates.

A call for papers by the EGU for a special session on natural cycles in climate change brought about 12 papers on the subject (cycles from decadal to multi-millennial) of which Alison's contribution is but one. I look forward to sharing some perspectives from this set of papers, in the next issue of *Preview*.

Minerals geophysics



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AEGC 2018: goldilocks and cautious optimism

When the expanded sponsorship for the Sydney conference was announced at the 2016 ASEG Adelaide conference I must admit I had reservations, which were shared by some of my colleagues. We had concerns that 'our' geophysical conference would be swamped by the other geo-scientific disciplines, particularly geology.

I've long thought that the format for the ASEG conferences was just right – not too short and not too long, with a strong emphasis on technical quality in presentations and posters, and a physical focus around the exhibitors' hall. Serving lunches and having end-of-day drink sessions amongst the exhibitors was always a master-stroke, greatly expanding the potential for interaction between conference participants and exhibitors. The very idea of continuing business over a few drinks after work is a quintessentially Australian mineral industry tradition. The ASEG conference is an excellent vehicle for catching up with fellow geoscientists, finding out the latest developments in geophysical techniques and doing business.

We needn't have worried! To my mind, from a mineral geophysics viewpoint, the Sydney conference was a great success. There was strength and depth in presentations, posters and exhibitors, and we benefited from the significant presence of geoscientists from other disciplines. Did I imagine it, or was there more geology in the geophysical presentations? A geologist colleague reported that many of the geological presentations included geophysical aspects. Anything that fosters cross-pollination between the earth science disciplines has got to be good. And yes, I did go to geological and geochemical presentations when I could fit them in. There was so much on offer that I completely missed out on the Coal, Near Surface and Groundwater streams.

I've discussed a few of my highlights from the Mineral Geophysics streams below. I've omitted any specific references – abstracts for all papers may be found in the conference issue of *Preview* (February 2018, issue 192).

Each conference seems to highlight particular aspects of mineral geophysics. In 2016 it was passive seismics; in 2018 IP from EM struck me as one of the hot topics in mineral geophysics. A better understanding of what have been called IP effects in EM data could lead to practical applications. More broadly, the EM stream, as usual, delivered a range of papers with contractors elaborating on their latest developments and success stories. Multiple papers on the same data set provided interesting and differing viewpoints, with comparisons between the results from 1D and 2D inversions sparking debate amongst practitioners. Geoscience Australia updated information on their modelling and inversion of airborne electromagnetic data in 1D software. The paper on deep GPR performance sounded a timely warning on over-enthusiastic depth of investigation claims – another blow against 'voodoo geophysics'.

For something new and different, the two papers on the biased heterodyne technique sparked a lot of interest. What a great story: government and industry consultants and contractors working together to develop a new geophysical technique using the results of research published in a university thesis in 1974.

In the natural fields realm, using existing global lightning networks to relate sferics to individual lightning strikes and then applying this to AMT data corrections is a step in a new direction. New airborne gravity instrumentation was reported on, and existing systems compared in detail – always useful information when assessing airborne gravity.

There was an excellent range of case history papers. Revitalisation of the Woodlawn mine through DHEM was inspirational; to have an ore lens named after you speaks volumes on the impact of the work. The theme of characterising cover materials and their effects was also evident in many papers.

Walking around the exhibitors' hall, many geophysical contractors at the conference reported an increase in enquiries and exploration activity; their mood appeared to be one of cautious optimism, which is good news for the exploration industry. We've been through some pretty tough times.

Finally, congratulations are due to the successful participants in the Frank Arnott Award 'Collaborative Challenge Supporting Innovation in Visualisation and Data Integration'. Teams from Australia secured third place in the 'Experienced' category, and first and third places in the 'Apprentice' category. We will present their stories in a future edition of *Preview*.

Seismic window

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AEGC 2018: the 26th or the 1st?

Was the recent conference in Sydney the 26th ASEG conference or the first AEG Conference? I'll let you make up your minds on that but here are a number of observations:

There were many minor but noticeable shortcomings at the recent AEGC in Sydney that the ASEG conference manual would have sorted out years ago. Do the other societies know about the detailed conference planning documents in the ASEG files?

Many people referred to the conference as the PESA conference – surely a sign of the changing of the guard.

While there were hundreds of conference bags left over, most of the copies of *Preview* were snatched up (I only get it to read the articles!).

Although there was nothing ground breaking for me, I thought the AEGC put together a good technical programme with some interesting geological and geophysical papers. I would like to see some more big announcements at our conference, but the larger conferences like SEG and AAPG seem to be where new technologies are revealed. They seem old hat by the time the Australian conference comes around.

Now a more serious look at what makes a good conference – the promotional giveaways in the Exhibition area (Figure 1). I didn't see them all, but here's what my sampling has come up with:

Best popular – the laughing Kookaburra (Pawsey)

Best useful – large tape measure (Zonge)

Best fit – Down Underwear (DUG)

Tastiest – 30 cm stick of Welsh rock (Robertson)

Flashback – colour pencils (Velseis)

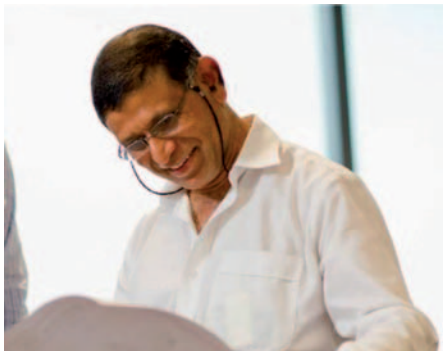
Purplest – shopping bag (Shearwater)

Most variety – notepads, power adaptors, first aid kits, pens etc. (CGG)

Figure 1. *A sample of AEGC promotional items.*

The article that follows was sent to me for comment and I thought it might start some good discussion in this forum. It deals with artificial intelligence, ageing and the loss of skills in our industry caused by a lack of mentoring. Do we still think like geologists? Anyway, take it away Bala.

Computers and the human brain in our business: questions to consider



Balakrishnan Kunjan
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What drives success in our industry? ***Where do computers stand vis-à-vis the human brain****?* There is no question about the role of computing power in our business. And today, there is the reality and promise of Big Data and Artificial Intelligence (AI) driven techniques and technologies. What and where is the role of the human mind? Is it a clear cut answer or is it context dependent?

From observation of practices in our industry over many years and in different settings, ***it appears that computers do not yet completely run the show.*** They may, eventually, but it could take a long while to get there – completely. At least in our lifetime, I expect that much of the necessary creativity will still be generated by the human computer.

When Exxon beta tested their ISIS (Interactive Seismic Interpretation System) in our Esso Kuala Lumpur office in the mid-80s, there was much excitement. It felt amazing that you could interpret seismic horizons, erase horizons, tie lines, change your mind, easily redisplay in different scales, use colour and make maps by-passing the Drafting Department. No more posting values on maps and getting them drafted in sepia. No more using your ears as holders for Derwent colour pencils and Staedtler erasers. And erasing paper seismic sections until there were holes in them!!

There is no doubt that we have made huge strides in productivity since those days. But in all of this, having observed many of our computer savvy practitioners of the art going about the business of building exploration and production geological models, I am left feeling uneasy about over-reliance on the magic of computing, and the less than critical acceptance of the outputs. Don't get me wrong, I love my interpretation and mapping systems and I am an active interpreter using software.

The fundamental issue is that computer processes work best where there is very good data, e.g. good 3D seismic data.

High density well control also helps greatly. Most of our interpretation is about extrapolating from known well control into the unknown. If you work in areas of poor seismic imaging and/or limited well control where there is still great petroleum potential, ***much of the work is in the mind of the interpreter.*** And a geologically oriented interpreter ***uses the power of computing to 'shape an interpretation' instead of accepting the shape of the interpretation provided by the computer.***

There are several issues in the way that the power of computing has affected thinking and action in our business. There is the undeniable power of computing that makes processes easier and faster. ***However, over the decades, there appears to be an aura that has developed around computing that has had an effect of separating the computing from the actual geology under study***. In the early days, geological principles were top in the mind when you took a pencil to either contour a time structure map or a sand isopach map. ***You had to stop and think about the structural style.*** How do we expect the faults to link, relay, step out etc.? Given the 2D seismic line spacing of at best half a kilometre if not 2 km, there was a great deal of gap to fill. The gap was shaped by the structural model in the mind of the interpreter. If the fault is listric in section, how do you shape the structure contours? If the section shows a compressional 'flower structure', how do you link the faults and shape the contours? And as for isopachs, how do contours of a fluvial channel sand look compared to a distributary mouth bar system? And can you recognise the difference by looking at log patterns and the succession of facies before you contour the isopach? Are you thinking palaeogeography?

I am sure that there are many experienced interpreters who have come across work that with better geological thinking could be improved greatly. There are many examples of poor interpretations leading to expensive dry holes that could either have been avoided or achieved better overall outcomes. It is possible that future computer learning systems will capture the essence of an experienced geological mind in improving interpretation outcomes, even under less than ideal data quality and quantity situations. In the meantime, from my perspective, ***it is important that managers in our business recognise these challenges and that better training and mentoring programs be put in place, so that while computer processes are being enhanced, geological interpretations do not suffer and lead to avoidable expensive mistakes in our business.***

I submit these observations from my background and experience, as a way to add to the discussion on optimal usage of computers vis-à-vis the human brain in our business. I am sure that there are diverse views on this subject and am happy for an open exchange.

Wishing all of you continued success in your work regardless of where you are in the spectrum of using the combined power of computing and the human brain.

From Melbourne

Bala

Webwaves

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New content and some thoughts about accessibility

It has been a busy year thus far. One conference. Two editions of *Preview*. And although this column will be read in the fourth month of 2018, it was written in the third.

The Web Committee could be forgiven for feeling weary, but it has already acted on one suggestion made at the recent AEGC conference – which was to create a page through which users could access open-source software. Most likely some users have such pages saved as bookmarks. However, in the spirit of assisting the wider community, the Web Committee has undertaken to provide a series of pages offering open-source geophysical software. We envisage these pages being laid out much like the section of the website dedicated to equipment manuals. As with old equipment manuals, the Web Committee is eager to take suggestions from the community and add to this page.

Members may also be interested to read that the book 'Geological Interpretation of Aeromagnetic Data' (Isles and Rankin, 2013) is now available for download as a PDF file. Although the ebook is still available as a CD, the ASEG, and regular readers of Guy Holmes' Data Trends column, recognise that media preferences change reasonably regularly. Unlike a CD, which may be lost, damaged or left behind, digital media is generally more portable. Accordingly, readers who prefer to be unencumbered by material items such as physical distribution media, may find the relatively instant gratification of a digital download irresistible. The main PDF is around 40 Mb while the accompanying high-resolution appendices are around 510 Mb.

Usually, mention of digital download would be countered with claims of poor service. Figure 1, which shows National Broadband Network (NBN) roll-out over Australia, suggests that outside (and sometimes within) capital cities, coverage is poor. However, Figure 2, which shows signal strength of the mobile phone network paints a slightly different picture. Although not as good as

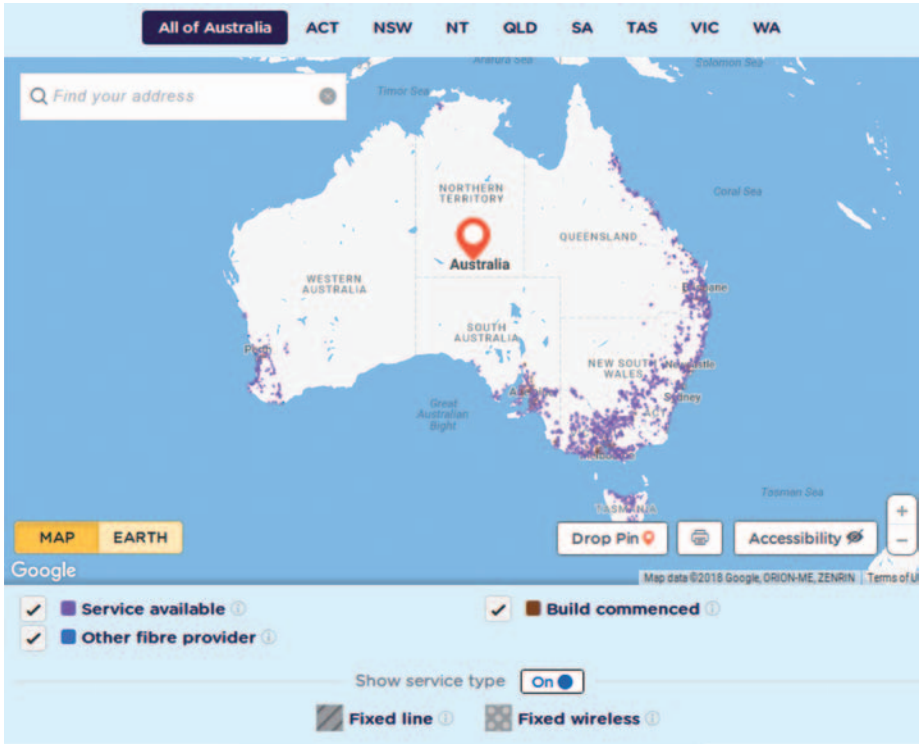

Figure 1. *NBN Rollout map (NBN Rollout Map, 2018). Coverage is so far centred around capital cities. And in central Victoria.*

Figure 2. *Mobile-phone signal coverage for Australia, New Zealand and parts of Indonesia and Papua New Guinea (Global Cell Coverage Maps, 2018). Coverage is strongest on the east coast, near capital cities and along roads near towns. And in Indonesia.*

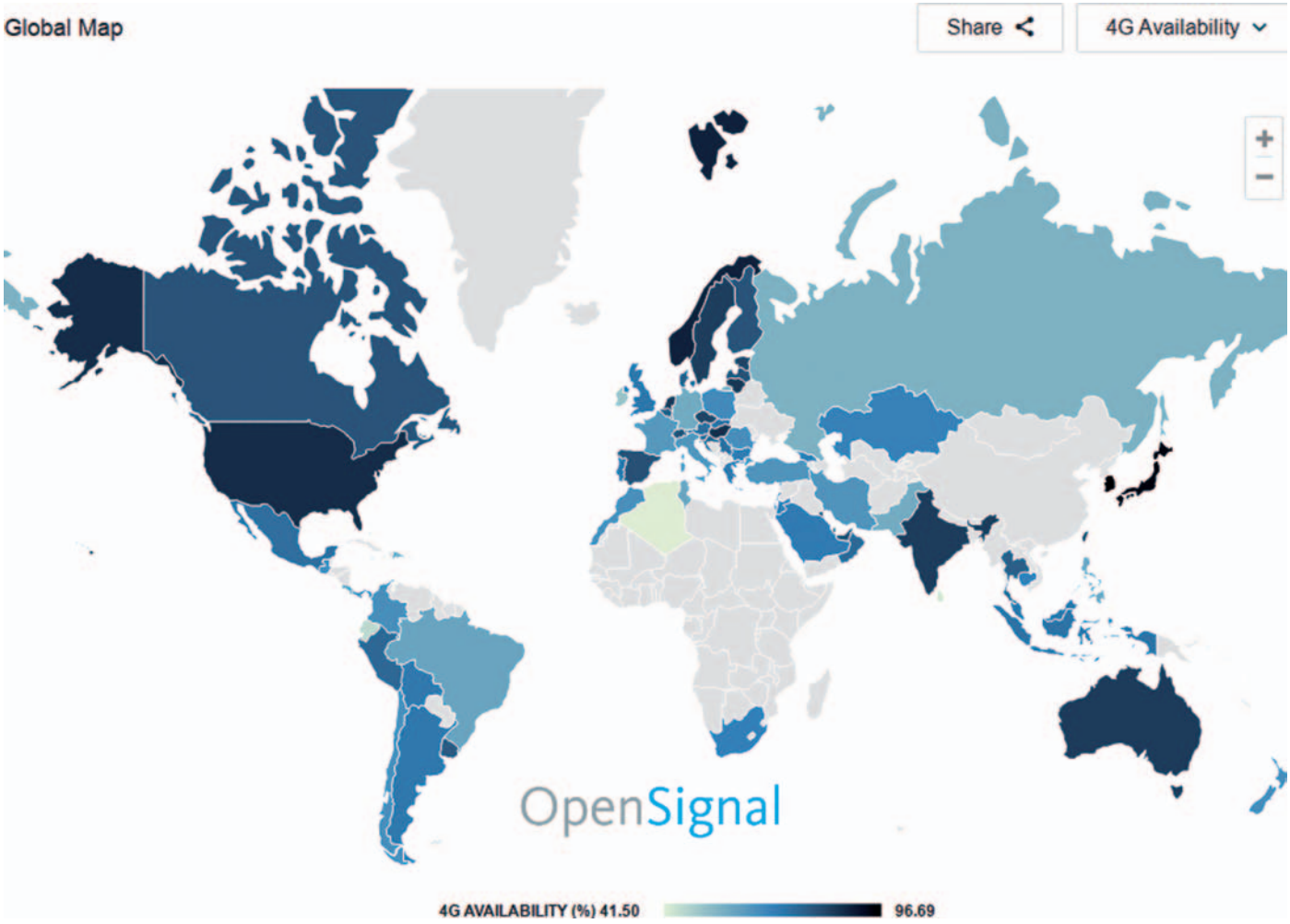

Figure 3. *World-wide distribution of 4G mobile availability (The State of LTE, 2017). By world standards, 4G availability in Australia is very good.*

Indonesia, Figure 2 suggests that download speeds may be reasonable around the coast, along main roads or in Victoria. Indeed, Figure 3, which compares 4G download speeds over the world, suggests that when coverage is present, it is very good by world standards. Generally speaking.

All of which suggests that 'Geological Interpretation of Aeromagnetic Data' can easily downloaded in the office to a mobile device, and read in the field!

References

Global Cell Coverage Maps, 2018, www.opensignal.com/networks (accessed 8 March 2018).

Isles, D., and Rankin, L. 2013, Geological interpretation of aeromagnetic data, https://www.aseg.org.au/ebook-download-geological-interpretation-aeromagnetic-data-david-isles-and-leigh-rankine

NBN Rollout Map, 2018, www.iinet.net.au/internet-products/broadband/nbn/coverage (accessed 8 March 2018).

The State of LTE, 2017, www.opensignal.com/reports/2017/11/state-of-lte (accessed 8 March 2018).

Wave equation imaging and adjoint-state inversion for micro-seismic monitoring

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Introduction

Human activities within the top few kilometres of the crust can induce significant changes in the Earth's stress field. Such activities include fluid injection for enhanced oil/gas recovery, wastewater disposal, CO_2 sequestration, or hydraulic fracturing purposes. Fluid injection can cause changes to the local and distal stress fields that may induce irreversible changes to the rock and cause earthquakes (Committee on Induced Seismicity Potential in Energy Technologies, 2013). One can monitor the Earth for the (micro-) seismic signals to detect potential earthquakes and, through data processing, estimate the earthquake location. The spatial and temporal distribution of the detected seismicity provides insight into how the injection is affecting the subsurface.

Understanding the distribution of earthquakes is crucial for a number of reasons, primarily hazard assessment and risk mitigation. Traditionally, seismic event studies have focused on naturally occurring, larger magnitude events, because these earthquakes present the most significant seismic hazard (Stein and Wysession, 1991). However, with the recent increase in fluid injection activities for hydraulic fracturing (or stimulation) and waste-water disposal, small events that are orders of magnitude weaker than those felt by humans have taken on an outsized importance (e.g. Rutledge and Phillips, 2003; Maxwell, 2010). Detecting and accurately locating these small events is critical for determining the efficiency and effectiveness of a fracture program – as well as the risks and potential hazards associated with subsurface fluid injection (e.g. Warpinski, 2013; British Columbia Oil and Gas Commission, 2016).

Producing accurate event locations, though, is largely a function of the signal strength and accurate knowledge of the subsurface velocity, both of which are often lacking during micro-seismic monitoring. Currently, there is no reliable established method for improving the velocity model from low signal-to-noise micro-seismic data. The primary objective of this article is to review a new method for improving subsurface velocity models using low signal-to-noise micro-seismic data that is able to produce accurate and reliable location estimates.

Herein, we review the cause of fluid-induced seismicity and how it is monitored by sensing arrays. We then briefly discuss current methods for locating the observed (micro-) seismic events and inverting the data for improved velocity models. These methods include standard earthquake seismology techniques that require picking arrivals on individual traces, and more recent techniques suitable for weak arrivals based on exploration seismology principles such as seismic migration and image-domain inversion. Finally, we summarise the new methodology and demonstrate its robustness to low signal-to-noise data with a case study from a hydraulic fracture data set in the Marcellus Shale, Ohio, USA.

Injection-related seismicity

Fluid-induced seismicity is driven by the injection of fluid into a subsurface geologic interval through boreholes, typically terminating between 1 and 3 km depth. The primary uses of fluid injection are long-term geologic storage of fluids, such as wastewater disposal and CO_2 sequestration (Elliston and Davis, 1944; Metz et al., 2005; Ferguson, 2015), as well as hydraulic fracturing (Economides and Nolte, 2000; Legarth et al., 2005). For sequestration, large volumes of fluid, often by-products of oil and gas extraction, are injected into suitable geologic reservoirs to mitigate potential environmental hazards. Hydraulic fracturing is also undertaken to improve permeability of a geologic interval for enhanced oil and gas extraction or geothermal production. The mechanism of fluid-induced seismicity is, fundamentally, the same in most instances: fluid injection increases the pore pressure leading to mechanical rock failure - an earthquake. The failure could be in the form of tensile breaking, shear displacement, or a combination thereof (Fischer and Guest, 2011). Hydraulic fracturing uses high-pressure injection with the intent of increasing the pore pressure beyond the minimum principal stress in the formation to cause tensile failure, thus inducing earthquakes as new fractures are formed (Hubbert and Willis, 1957). Fluid injection also induces shear displacements, which occur when pore pressure increases within a pre-existing fault causing a decrease in effective normal stress, either directly (McGarr et al., 2002; Zoback and Gorelick, 2012) or through pressure diffusion (Talwani and Acree, 1984; Shapiro et al., 2003). When the normal stress decreases beyond a critical point, an earthquake initiates as slip along the fault. For a more thorough discussion on reservoir geo-mechanics and fluid-induced seismicity see Zoback (2007) and Shapiro (2015).

When an earthquake occurs it releases energy in the form of seismic waves. The seismic waves are radiated outward as both compressional (P-) and shear (S-) waves, with the P-wave energy traveling at a faster speed than the S-wave energy. The energy is not released uniformly in space, but has a radiation pattern that depends on the failure mechanism and orientation, with P-wave amplitudes generally weaker than those of S-wave. The moment magnitude (M_w), or total energy released by an induced earthquake, is usually in the micro-seismic range (i.e.,

M_w < 4) and is not felt by humans. While most fluid induced earthquakes have M_w < 0, larger earthquakes on pre-existing faults have been induced by fluid injection [i.e. M_w = 5.7 and M_w = 5.3 in Oklahoma and Colorado, respectively (Keranen et al., 2013; Rubinstein et al., 2014)].

Seismic Monitoring

To monitor for potential fluid-induced seismicity, an array of seismometers or geophones is often deployed to measure the energy released as seismic waves as a function of ground motion. These devices can be placed in boreholes (e.g. Warpinski et al., 1998; Maxwell et al., 2010), at or near the surface (e.g. Duncan and Eisner, 2010; Pesicek et al., 2014), or a combination thereof (Eisner et al., 2010). Figure 1 shows a schematic diagram of an induced seismic monitoring program. In this diagram, the wellbore, shown in black, injects fluid in the subsurface, indicated by the dashed maroon lines. The fluid injection process may induce earthquakes nearby or at a distance through pressure diffusion, which is represented by the light red dashed arcs. The earthquakes, also called 'events', are shown as red 'explosions'. The red lines emanating from the near event represent seismic waves propagating from the source to the monitoring stations shown as triangles. In this case, there are both borehole and surface arrays, shown in blue and orange, respectively.

Borehole arrays have the dual advantage that they are usually located closer to the events and farther away from anthropogenic noise generated at the surface. Thus, they often record high signal-to-noise data and one can detect and process very weak events. Borehole monitoring, however, is limited by the number of suitable boreholes near the injection well, and therefore poor spatial coverage. Even where a suitable well is available the spatial distribution of the receivers is often poor, sometimes comprising only tens of sensors per well (e.g. Rutledge and Phillips, 2003; Maxwell et al., 2010). This limits the ability of the borehole arrays to record the full radiation pattern of an earthquake. When no suitable pre-existing borehole is available, the cost of drilling might be prohibitive for this type of monitoring.

Conversely, surface monitoring arrays have good spatial coverage with large channel counts, hundreds to thousands of sensors (e.g. Duncan and Eisner, 2010, Birkelo et al., 2012), and generally have the aperture to measure a much larger portion of the radiation pattern. Surface arrays often are comprised of relatively cheap sensors that are quick and easy to deploy, making them a cost effective monitoring solution. However, the drawback of surface arrays is the higher levels of noise and increased distance from the events, which lead to low signal-to-noise data (S/N < 1). Therefore, surface arrays usually do not detect events as weak as those measurable on borehole arrays.

Figure 2 show data for strong (M_w = 0.24) and moderate (M_w = –0.47) micro-seismic events located more than 1.5 km below the surface. The data were recorded on a single three-component (3C) surface station, where the vertical component is shown in magenta and the two horizontal components are red and blue, respectively. For the strong event, the P- and S-wave first arrivals are clearly identifiable on the individual traces, while for the moderate event it is not possible to accurately identify the arrivals. Figure 3*a–c* and 3*d–f* show the complete 3C array data for the strong and moderate event, respectively. The data shown in Figure 2 are taken from trace 114 in this array. While it is possible to identify the events in the array data, picking accurate arrivals on each trace even in the strong example would be challenging.

Detected seismic arrivals can be used to produce estimates of the event properties such as location, magnitude and orientation. Of these, the event location is the most critical. Location estimates impact the determination of magnitude and orientation, and help evaluate the hydraulic fracture program by estimating both the lateral and vertical fracture growth and the complexity of the fracture network to optimise well completion (e.g. Maxwell, 2014). Additionally, the spatial and temporal distribution of events assists with estimating reservoir properties (e.g. Shapiro and Dinske, 2009), assessing potential hazards, and determining causality (i.e., natural vs induced seismicity) (Schoenball et al., 2015; Dempsey et al., 2016). This has implications for both effective completion operations and potential hazards from triggering a larger earthquake along the faults. Maxwell (2014) presents a more complete discussion on micro-seismic monitoring.

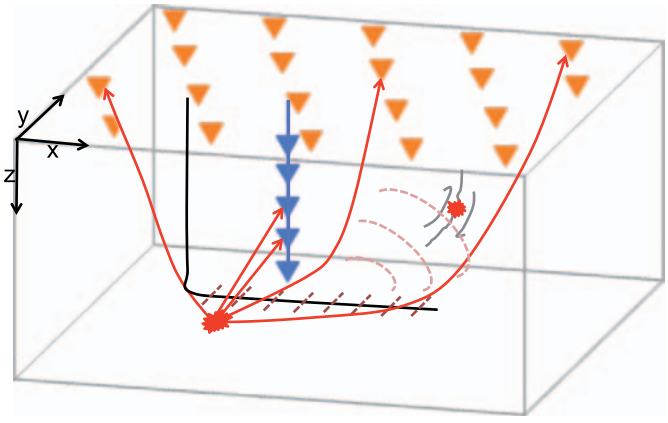


Figure 1. *Schematic diagram of fluid-induced seismicity with borehole and surface monitoring arrays. The black line is the injection well. The dashed maroon lines and dashed red arcs represent fluid injection and pressure diffusion, respectively. The red 'explosions' are earthquakes that emit seismic energy, shown as red arrows recorded at surface (orange) and borehole (blue) receivers.*

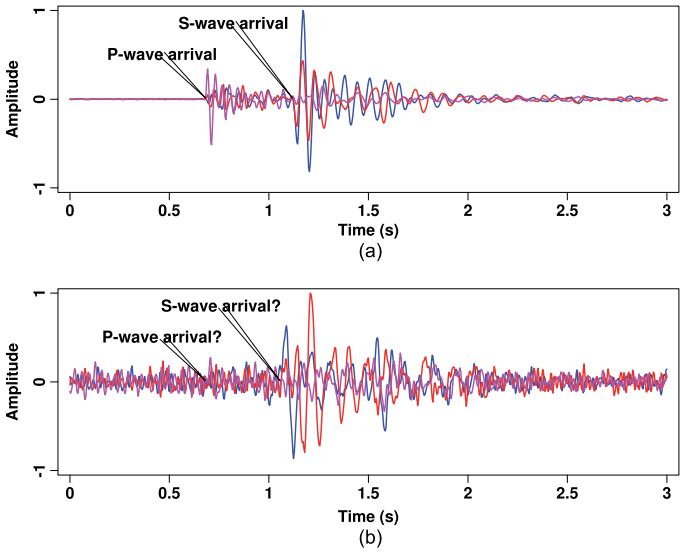


Figure 2. *Example of (a) strong, Mw=0.24, and (b) moderate, Mw=-0.47, micro-seismic arrivals recorded at a single surface station, normalized to respective maximum amplitude. The magenta trace is the vertical component, while the blue and red traces are the two horizontal components. Picked P- and S-wave arrivals are indicated.*

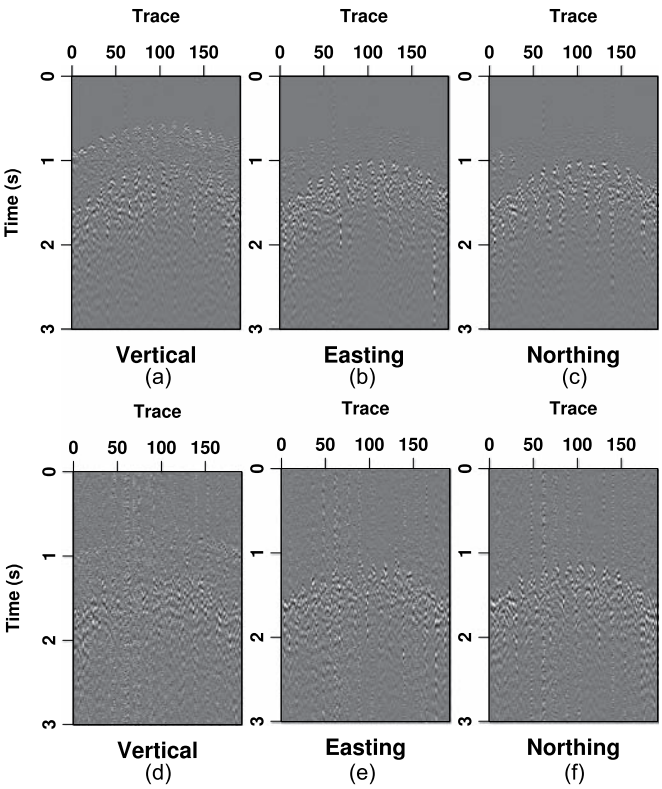


Figure 3. *Vertical, Northing, and Easting components for full surface array data from the strong (a–c) and moderate event (d–f) shown in Figure 2.*

Inaccurate location estimates can lead to incorrect conclusions about the causes and effects of induced seismicity. In late 2008, a few events were felt in the Dallas–Fort Worth (DFW), Texas area. This area is historically aseismic, which raised concerns that a nearby wastewater injection well could be inducing the earthquake events. This was concerning because of the potential hazard to the large population in the area and proximity to the DFW airport. Surface sensors were deployed to investigate whether the seismicity was natural or induced by the injection well. Reiter et al. (2012) and Janská and Eisner (2012) both examine this data set. Despite using the same data and similar location methods, the two studies locate the events at different depths, which appears to be largely driven by differing velocity models. Reiter et al. (2012) estimates that the events originate near the injection interval, while Janská and Eisner (2012) places them much deeper. This led to opposing conclusions as to whether the observed seismicity was natural or triggered. While further investigation determined the events were anthropologically induced (Frohlich et al., 2016), this clearly demonstrates that inaccurate location estimates caused by velocity model errors can lead to misinterpretation of subsurface processes and, in this case, the risk associated with the well and injection activities.

Earthquake location techniques

There are numerous ways to estimate earthquake event locations. Most techniques were developed to locate large earthquakes that produce high signal-to-noise data and generally require picking the P- and S-wave arrivals on individual traces, such as in Figure 2*a*. This process reduces the dataset from the full waveform to the pick times. Amongst the most straightforward ways to estimate the location is trilateration or the method of spheres (commonly known as triangulation). In this method, one estimates the distance from each receiver using the difference between the P- and S-wave arrival times and constant estimates of the P- and S-wave velocities (V_p and V_s). Using the distance estimates, we can draw spheres of equiprobable event locations. Doing this for at least three station locations yields an estimated source location where the spheres intersect. This method, while simple, assumes a homogeneous earth, which is obviously incorrect and may lead to imprecise (i.e., large region of intersection) and/or inaccurate (i.e., incorrect radius of spheres) location estimates.

To account for the heterogeneity of the earth, one can generate travel-time surfaces that conform to the variable velocity of the geology. These variable travel-time surfaces are usually created by tracing rays (Cerveny, 2000) from each cell in a P- and/or S-wave velocity model to create a travel-time surface between each model point and every receiver. Using the calculated synthetic travel times, it is common to implement grid search methods (e.g. Geiger, 1910; Buland, 1976; Sambridge and Kennett, 1986), which formulate the location estimation as an optimisation problem to find the grid cell with the minimum residual defined as the square of the difference between the calculated and observed travel times. The grid location with the minimal residual is the estimated earthquake location. While this is usually performed in a deterministic fashion, probabilistic extensions have been developed (Lomax et al., 2000; Husen et al., 2003). Grid search methods have been used to locate large events in many areas (e.g. Dreger et al., 1998; Richards-Dinger and Shearer, 2000).

Pick-based methods become infeasible when the signal-to-noise level of the data is too low to permit identification of individual arrivals, such as in Figure 2*b*. To handle low signal-to-noise data, methods using seismic migration principles have been developed for micro-seismic data (e.g. Kao and Shan, 2004; Artman et al., 2010). For earthquake monitoring data, migration creates an image of the source by refocusing the recorded waveform as a function of space. Figure 4 present the results of using a homogeneous Earth model to forward model 2D synthetic data as well as the resulting image created by applying migration to that data to refocus the event to the source location at $\mathbf{x_0}$=[x,z]=[2.8,1.5] km. There are two primary migration algorithms to generate this type of image: Kirchhoff and wave equation. Both techniques exploit the power of stacking recorded data across all traces to enhance the signal-to-noise ratio. Therefore, relative to pick-based methods, these approaches can be used to locate events from datasets exhibiting much lower signal-to-noise levels.

The Kirchhoff migration approach is similar to the grid search algorithm above, in the sense that travel times are computed

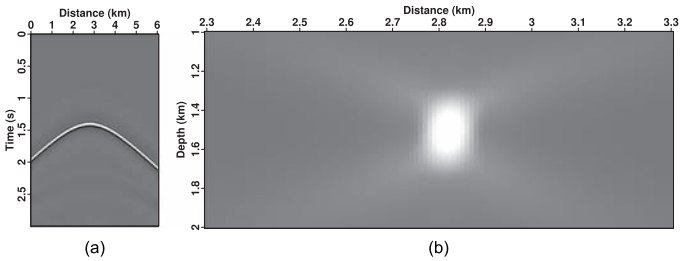


Figure 4. *Example 2D synthetic data (a) and resulting migrated image (b) with source location at $\mathbf{x_0}$= [2.8, 1.5] km. The migration algorithm refocuses the recorded energy in the migrated image. By using the correct velocity, the maximum in the image is at the true source location.*

from each grid cell to each receiver by ray tracing. However, rather than solving an optimisation problem, trace data are summed across the isochron (an equal time surface) generated from each grid cell for an assumed origin time, t_0, and stored for that location. Kirchhoff migration has been used successfully to locate micro-seismic events from low signal-to-noise micro-seismic data (e.g. Duncan and Eisner, 2010; Pesicek et al., 2014; Roux et al., 2014). This is also referred to as the back-projection method (Ishii et al., 2005) since it projects the data backward in time along the calculated rays. Given a *correct* velocity model and t_0 estimate, summing across the isochron from the cell containing the event location should optimally stack the arrivals to produce a maximized output. For all other grid locations at the same t_0 the isochrons will not perfectly coincide with the data and a lower amplitude output is produced. The grid cell with the maximum amplitude is the most likely source location for the given t_0. The assumed origin time is then shifted and the process repeated for all time samples in the recorded data. This method is computationally more expensive than pick-based methods and requires additional sensors, the appropriate number of which depends on the signal-to-noise level of the data. However, by stacking over an array of sensors and using the full wavefield, it can locate events using data with much lower signal-to-noise levels than the methods discussed above.

The second class of migration algorithms is wave-equation migration, also called back-propagation, which numerically propagates recorded data backwards in time through a velocity model to reconstruct the source wavefields. This can be done with either time- or frequency-domain propagators. Given a suitably accurate velocity model, the recorded energy will maximally constructively interfere at the source location, $\mathbf{x_0}$, and t_0. Figure 5 shows example reconstructed P- and S-wavefield snapshots at different propagation times. The left (right) panels are the P-wave (S-wave) snapshots. The upper panels are when $t>t_0$, the middle panels are at $t=t_0$, and the lower panels for $t<t_0$. Once the wavefields have propagated through the source location, they defocus and are no longer representative of the true wavefield since we would need to remove the energy at the source location due to causality arguments. We see here that both the P- and S-wavefields collapse and focus at the source location ($\mathbf{x_0}$ = [2.8,1.5] km) and at t_0 as they both originate at the same spatial and temporal point. One could scan through snapshots to identify the location and time of maximum focus as recognized by McMechan (1982). To eliminate the time-consuming 3D scanning process, one can apply a zero-lag imaging condition that stacks over the time coordinate to produce an image solely as function of space (e.g. Figure 4*b*). Correlation-based imaging conditions are similar to those used in reflection seismic migration (Claerbout, 1971). These imaging conditions correlate various modes of the source wavefield, such as auto- and cross-correlation of P- and S-wavefield energy (Artman et al., 2010). The P-P and S-S autocorrelation imaging conditions are:

$$I_{pp}(\boldsymbol{x}) = \int_T^0 u_p(\boldsymbol{x},t)u_p(\boldsymbol{x},t)dt, \quad (1)$$

$$I_{ss}(\boldsymbol{x}) = \int_T^0 u_s(\boldsymbol{x},t)u_s(\boldsymbol{x},t)dt, \quad (2)$$

and the P-S cross-correlation imaging condition is expressed as:

$$I_{ps}(\boldsymbol{x}) = \int_T^0 u_p(\boldsymbol{x},t)u_s(\boldsymbol{x},t)dt, \quad (3)$$

where I_{ij} are the images, and u_p and u_s are the reconstructed P- and S-wavefields, respectively.

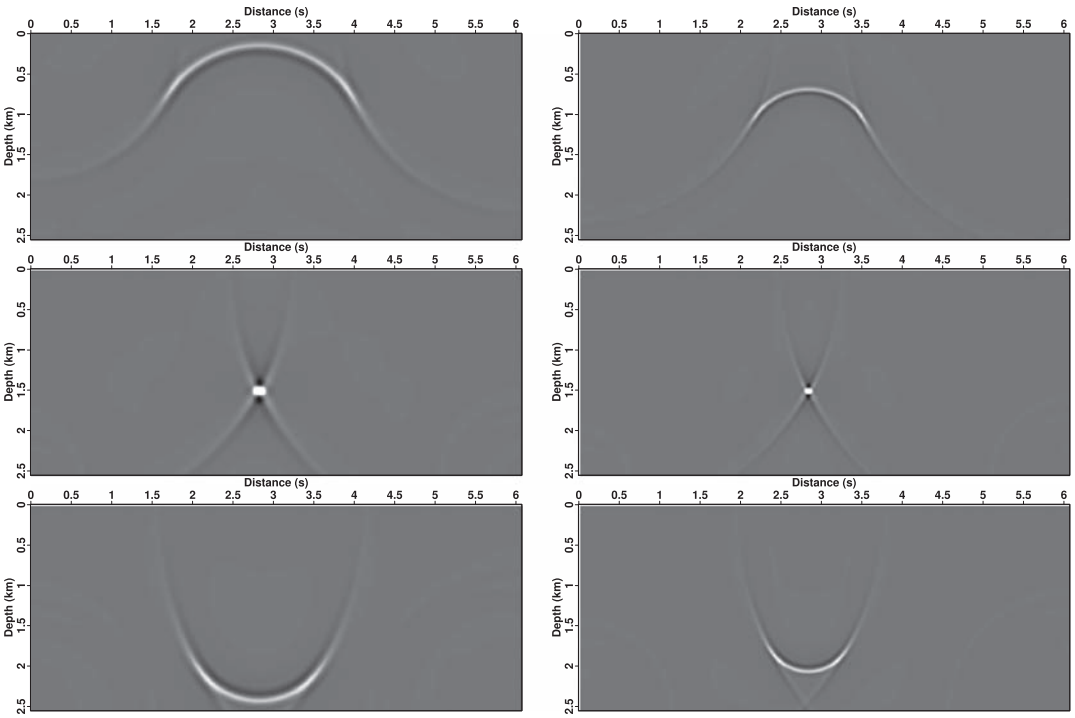


Figure 5. *Snapshots reconstructed P- and S-wavefields (left and right columns, respectively) using wave-equation migration. Top panels are after source initiation ($t > t_0$), middle panels are at source initiation time ($t = t_0$), and bottom panels are prior to source initiation ($t < t_0$).*

Similar to Kirchhoff methods, wave-equation migration can locate events in low signal-to-noise data by effectively stacking the recorded waveforms. In contrast to Kirchhoff migration, it more accurately replicates wave propagation physics through a more physically accurate (i.e., non-asymptotic) form of the wave equation that may account for particle motion, anisotropy, multi-pathing, etc. The principle drawback of this technique is that it is more computationally expensive than any of the methods described above.

All the location methods described thus far are sensitive to the inputs. The inputs are pick or trace data for the pick-based and migration methods, respectively, and a velocity model. Provided accurate input, both types of methods produce accurate locations. However, when the signal-to-noise level of individual traces becomes too low to pick with confidence, location estimates from pick-based methods become inaccurate (e.g. Pavlis, 1986; Billings et al., 1994). For migration-based methods, the signal-to-noise can be substantially lower, though there are still limits based on noise characteristics and acquisition geometry (Cieslik et al., 2016). All event location methods rely on an accurate velocity model to produce accurate locations (e.g. Gajewski and Tessmer, 2005; Eisner et al., 2009). Relative approaches, such as the double-difference method (Waldhauser and Ellsworth, 2000), try to account for velocity error to provide relative locations. However, even these methods are similarly sensitive to velocity model error (Michelini and Lomax, 2004). Therefore, constructing an accurate velocity model is essential to produce reliable location estimates.

Velocity inversion techniques

Velocity updating for earthquake data is most commonly done through travel-time tomography (TTT) (e.g. Aki and Lee, 1976; Thurber, 1983; Rawlinson and Sambridge, 2003). TTT attempts to produce a velocity model that minimizes differences between ray-traced travel times for all source-receiver pairs and picked arrivals. In micro-seismic monitoring, this has been used when source locations and origin times are known, such as perforation and calibration shots recorded in a borehole (Warpinski et al., 2003; Bardainne and Gaucher, 2010). However, for scenarios where source locations and onset times are unknown, as is the case with (micro-seismic) earthquakes, it is preferable to jointly update the source location and velocity model (Thurber, 1992) since the original location estimate may be incorrect due to velocity model error. This method has been successfully applied to events detected during borehole micro-seismic monitoring (Grechka and Yaskevich, 2014; Chen et al., 2017). Like pick-based location algorithms, this method is limited by the requirement of picking arrivals on individual traces and, therefore, may not be suitable for surface micro-seismic monitoring.

Another class of velocity updating methods uses the entire waveform through adjoint-state tomography. Adjoint-state tomography forms velocity updates by correlating 'state variables' with 'adjoint-state variables'. In seismic monitoring scenarios, the state variables are wavefields generated by back-propagating the recorded data, and the adjoint-state variables are the forward-propagated 'adjoint sources' derived from residuals defined as the mismatch between the expected and current estimate of the input (e.g. trace data or image). There are two primary classes of geophysical adjoint-state tomography that are distinguished by the domain where the residuals are calculated. The first are data-domain methods, such as full waveform inversion (FWI) (Lailly, 1983; Tarantola, 1984; Fichtner et al., 2006), where one attempts to match forward-modelled synthetic data to the recorded trace data. The second are image-domain techniques, like differential semblance optimisation (DSO) (Symes and Carazzone, 1991; Symes, 1993; Shen, 2008), which attempt to optimally focus images.

FWI is similar to TTT in the sense that synthetic data are generated and compared to observations. However, FWI uses wave-equation propagation to forward model the data, and the residuals are usually computed as the difference between the modelled and recorded traces, rather than ray tracing and picked arrival times. This precludes a need for picking and can produce high-resolution velocity models. While FWI has been used to produce velocity models for large-magnitude earthquake data (e.g. Tape et al., 2009; Kamei et al., 2012), it has not been applied on field micro-seismic data. This is due to the associated computational complexity, the requirements of a very accurate starting velocity model, origin time t_0, and source location estimate $\mathbf{x_0}$, and low signal-to-noise levels of recorded micro-seismic data. If the data exhibit an insufficient signal-to-noise ratio the FWI algorithm will fit the noise rather than signal, leading to poor convergence and inaccurate interpretation. Thus, FWI is largely impractical for surface micro-seismic monitoring.

In contrast to the velocity updating techniques above, DSO does not attempt to directly match the input data; rather, it optimises the foci of migrated images. DSO has primarily been used to improve images of subsurface structure either through controlled source reflection experiments (e.g. Mulder and ten Kroode, 2002; Albertin et al., 2006; Shen and Symes, 2008) or converted waves from earthquake data (Shabelansky et al., 2015). The quality of the migrated image is assessed by extending the correlation beyond zero lag. For this imaging case, the extended P-S image of equation 3 is

$$I_{ps}(\boldsymbol{x},\boldsymbol{\lambda},\tau) = \int_T^0 u_p(\boldsymbol{x}-\boldsymbol{\lambda},t-\tau)u_s(\boldsymbol{x}+\boldsymbol{\lambda},t+\tau)dt, \quad (4)$$

where λ and τ are spatial and temporal shifts, respectively. Since the P- and S-wavefields both originate at the same point in space and time, the image should be maximal at the source location and at zero lag in space and time (i.e., λ = 0 m and τ = 0 s). An image having a maximum at $\lambda \neq 0$ m and/or $\tau \neq 0$ s indicates velocity error (Witten and Shragge, 2015). Residuals are defined by applying a penalty function to the extended image, which removes energy around zero lag. While DSO cannot achieve the resolution of FWI, it has a less stringent requirement on the initial model, making it applicable to locations where little *a priori* information is known. Since the residuals for DSO are defined in the image domain it is potentially suitable for producing reliable velocity updates for surface micro-seismic data.

In addition to the extended image (equation 4), the velocity model can be assessed by examining the suite of zero-lag images (equations 1-3). Since the P- and S-waves for a given event originate at the same point in the earth, all images should have maxima at the same model location. If the images are inconsistent this is an additional indication of P- and/or S-wave velocity error. Witten and Shragge (2017*a*) present an adjoint-state inversion methodology that exploits the expected consistency amongst the suite of zero-lag and extended images that is robust to low signal-to-noise data and common micro-seismic acquisition geometries.

Field data example

Figure 6 shows the acquisition geometry of a surface monitoring data set collected over a multi-well hydraulic fracture job in the Marcellus Shale, Ohio, USA. The red dots show the surface location of 192 3C geophones covering an area of approximately 6.5 x 6.0 km^2. The white box indicates the approximate extent of the horizontal injection wells. The hydraulic stimulation consisted of multiple wells, and more than 100 stages were completed that targeted the Marcellus Shale Formation (MSF), a thin organic rich interval located at approximately 1.75 km below the surface (1.5 km below mean sea level). The MSF is bounded directly below by a thick limestone layer, which has been shown to form a barrier for fracture growth.

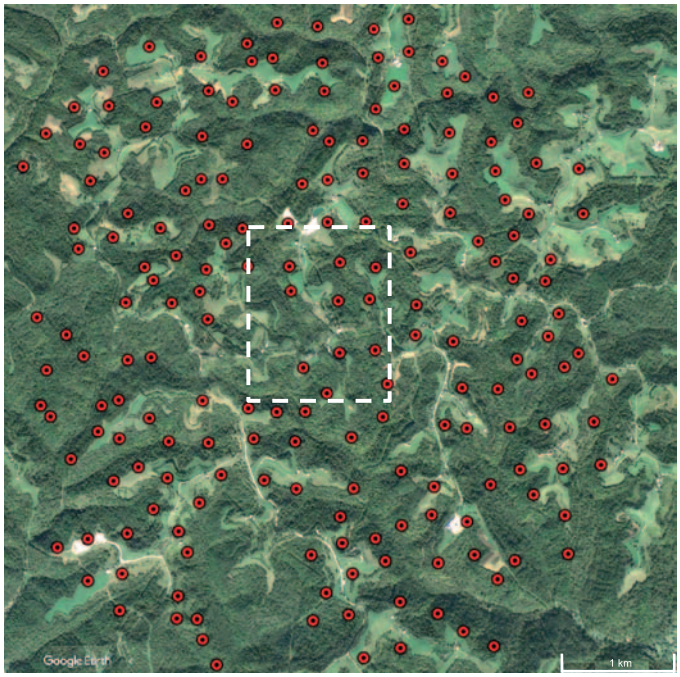


Figure 6. *Satellite image showing topography with geophone locations in red. The white box (1.5 x 1.25 km^2) indicates the approximate stimulated volume (from Witten and Shragge, 2017b).*

The initial velocity information is taken from a single dipole sonic log acquired at the well head. The P- and S-wave velocities are measured from below the reservoir almost up to the surface. The well-log data were smoothed and extrapolated into a 3D volume, accounting for known minor regional structural dip of approximately 2%. The background of Figure 7 shows the initial velocity model. Each face of the flattened cube shows a slice extracted through the 3D volume in the X1–X2 plane (top face), X2–Z plane (front face), and X1–Z plane (side face). The crosshairs on the panels indicate the extraction locations for each face. In this case, the faces shown are the following planes: Z = 1.53 km, X1 = 3.22 km, and X2 = 2.93 km. For reference, we project approximate boundaries of the stimulated volume on the 2D faces as dashed white boxes. The region of low V_P/V_S values is the reservoir interval.

A catalog of over 10,000 detected events was provided by the operator, from which we selected 28 events for inversion and another 100 events for validating the inversion results. The 100 validation events vary in magnitude from Mw = –1.14 to Mw = –0.18. For a full discussion on the methodology and results see Witten and Shragge (2017*b*). The symbols on Figure

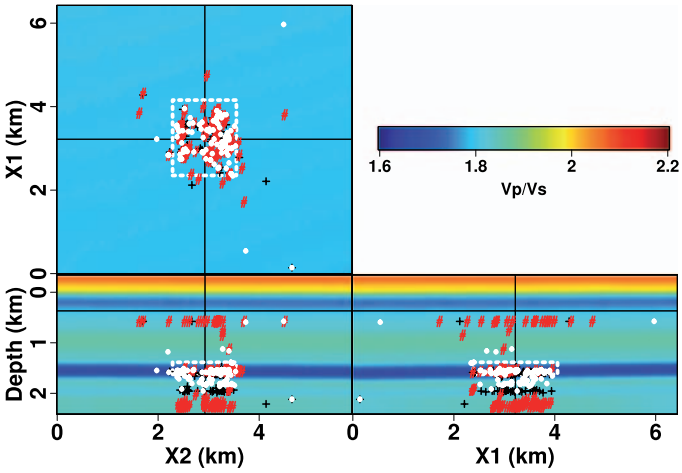


Figure 7. *Initial Vp/Vs model and 100 estimated event locations. The black '+', red '#', and white 'o' indicate the PP, SS, and PS event location estimates. The dashed white boxes indicate the approximate stimulated volume.*

7 are the estimated event location of the 100 validation events using the initial imaging velocity model. The black '+' are the PP image locations (equation 1), the red '#' are the SS image locations (equation 2), and the white 'o' are the PS image locations (equation 3). We note that there are large discrepancies between the location estimates between the various imaging conditions. In particular, the SS locations are often either much too deep or shallow, while the PP ones are deeper than expected. Due to the underlying limestone formation mentioned above, it is unlikely that the events originate in this unit.

Figure 8 shows the PP, SS, zero-lag PS, and an extraction from the extended PS volume, respectively. The input data are the event traces shown in Figure 3*d–f*, which are migrated through the initial velocity model. We see a clear discrepancy between focal locations of the zero-lag images, particularly the SS image and a slight shift from, and lack of symmetry about, zero-lag in the extended image volume. This indicates velocity error and provides image-domain residual for the inversion procedure.

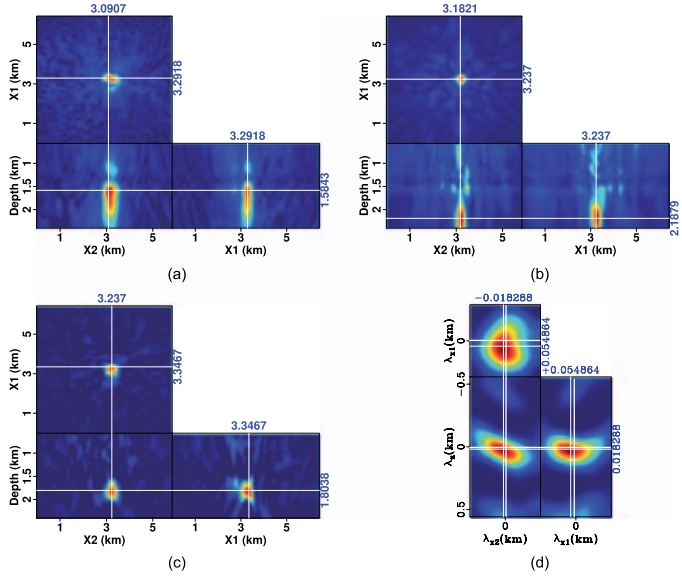


Figure 8. *Image volumes using the initial velocity model data of the moderate event shown in Figure 3d–f. Panels a–c are the zero-lag PP, SS, and PS images. Panel d shows a slice through the extended PS image volume extracted at the maximum location of the zero-lag image (from Witten and Shragge, 2017b).*

Using images such as those in Figure 8, we invert for P- and S-wave velocity models that optimally focus the suite of images without picking any event arrivals. Figure 9 shows the inverted V_P/V_S. Again, the symbols (black '+', red '#', and white 'o') indicate the estimated PP, SS, and PS event locations for the 100 validation events. Comparing the event locations in Figure 9 to those in Figure 7, we note that the inverted velocity model produces much more self-consistent event locations with many fewer situated beneath the reservoir interval. Figure 10 shows the same event as Figure 8 for the zero-lag PP, SS, and PS images, and an extraction from the extended PS volume, respectively, using the inverted velocity model. Again, we note much better focal location self-consistency among the zero-lag images and a more symmetric focus around zero lag in the extended image.

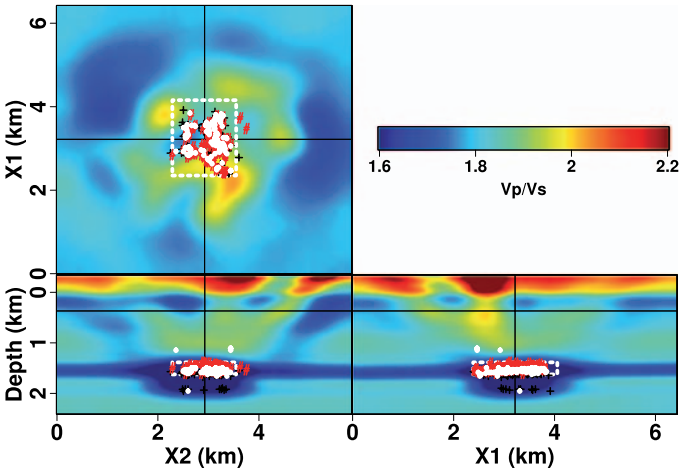


Figure 9. *Final inverted Vp/Vs model and 100 estimated event locations. The black '+', red '#', and white 'o' indicate the PP, SS, and PS event location estimates. The dashed white boxes indicate the approximate stimulated volume.*

Discussion and conclusions

While the results shown in Figure 9 do not depict an accurate representation of the geology, they do provide a suitable imaging velocity. Unlike in the conventional exploration seismic context, the goal in micro-seismic monitoring is not to make interpretations about the geological structure of the earth; rather, it is to determine the location and potential causality of detected earthquakes to assess oil and gas production efficiency and mitigate potential hazards. Therefore, the obtained inversion results provide the optimal solution for imaging. The main drawback of the image-domain inversion methodology presented is the computational expense. However, as shown a limited number of events are needed for the inversion and with modern computation hardware, particularly graphics processing units (GPUs), the results can be obtained in a reasonable time frame. The principal benefit of this technique is that it provides a viable means to invert for the elastic velocity model to optimally image the detected events without the need for picking arrivals. This is particularly important for surface micro-seismic monitoring where the detected events are often too weak to be seen on individual traces. Therefore, the image domain technique provides the only known means to accurately update the model in these scenarios.

As injection programs are becoming increasingly common, it will be more important to monitor for subsurface changes to ensure the social license to operate, guarantee safe operations

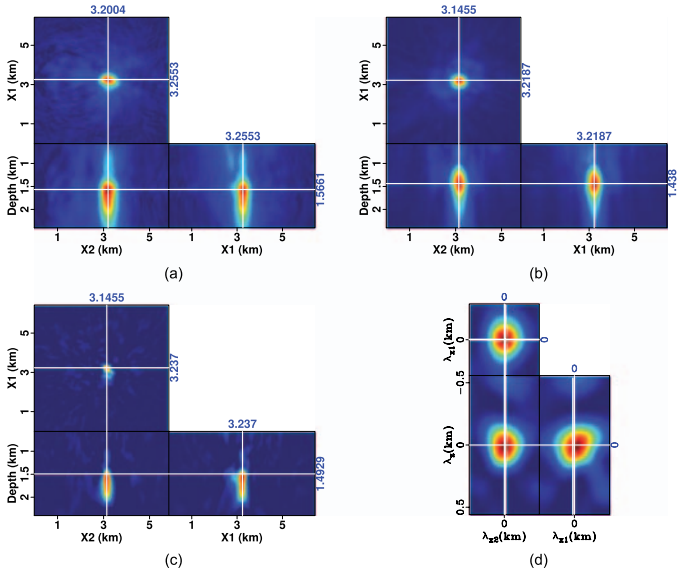


Figure 10. *Zero-lag image volumes (a) PP, (b) SS, and (c) PS using the inverted velocity model and data of the moderate event shown in Figure 3d–f and (d) shows a slice through the extended PS image volume extracted at the maximum location of the zero-lag image (from Witten and Shragge, 2017b).*

or, perhaps, to meet regulatory requirements. Given that the monitoring will often be surface-based to help minimise costs, the method may be optimal to produce the most accurate location estimates and therefore reliable interpretations of the subsurface changes resulting from the injection.

Acknowledgements

We thank Statoil USA for providing the Marcellus dataset and allowing publication of the results. Ben Witten acknowledges funding by an Australian Government Research Training Program Scholarship. We especially thank the Australian Society of Exploration Geophysics Research Foundation (ASEGRF) for providing a grant that supported the research, development, and application of the work described herein.

References

Aki, K., and Lee, W. H. K., 1976, Determination of three dimensional velocity anomalies under a seismic array using P-arrival times from local earthquakes: part I-a homogeneous initial model: *Journal of Geophysical Research*, **81**, 4381–4399. doi:10.1029/JB081i023p04381

Albertin, U., Sava, P., Etgen, J., and Maharramov, M., 2006, Adjoint wave-equation velocity analysis: 76th Annual International Meeting, SEG Technical Program Expanded Abstracts, SEG, 3345–3349.

Artman, B., Podladtchikov, I., and Witten, B., 2010, Source location using time-reverse imaging: *Geophysical Prospecting*, **58**(5), 861–873. doi:10.1111/j.1365-2478.2010.00911.x

Bardainne, T., and Gaucher, E., 2010, Constrained tomography of realistic velocity models in microseismic monitoring using calibration shots: *Geophysical Prospecting*, **58**(5), 739–753. doi:10.1111/j.1365-2478.2010.00912.x

Billings, S. D., Sambridge, M. S., and Kennett, B. L. N., 1994, Errors in hypocenter location: picking, model, and magnitude dependence: *Bulletin of the Seismological Society of America*, **84**(6), 1978–1990.

Birkelo, B., Cieslik, K., Witten, B., Montgomery, S., Artman, B., Miller, D., and Norton, M., 2012, High quality surface microseismic data illuminates fracture treatments: a case study in the Montney: *The Leading Edge*, **31**(11), 1318–1325. doi:10.1190/tle31111318.1

British Columbia Oil and Gas Commission, 2016, *Ground Motion monitoring and submission guideline*: https://www.bcogc.ca/ground-motion-monitoring-and-submission-guideline (accessed 13 March 2017).

Buland, R., 1976, The mechanics of locating earthquakes: *Bulletin of the Seismological Society of America*, **66**(1), 173–187.

Cerveny, V., 2000, *Seismic ray method*: Cambridge University Press.

Chen, Y., Zhang, H., Miao, Y., Zhang, Y., and Liu, Q., 2017, Back azimuth constrained double-difference seismic location and tomography for downhole microseismic monitoring: *Physics of the Earth and Planetary Interiors*, **264**, 35–46. doi:10.1016/j.pepi.2016.10.003

Cieslik, K., Artman, B., Roche, S., and Gumble, J., 2016, Signal to noise analysis of densely sampled microseismic data: Presented at the AAPG/SEG International Conference & Exhibition.

Claerbout, J., 1971, Toward a unified theory of reflector mapping: *Geophysics*, **36**, 467–481. doi:10.1190/1.1440185

Committee on Induced Seismicity Potential in Energy Technologies, 2013, *Induced seismicity potential in energy technologies*: National Academies Press.

Dempsey, D., Suckale, J., and Huang, Y., 2016, Collective properties of injection-induced earthquake sequences: 2. Spatiotemporal evolution and magnitude frequency distributions: *Journal of Geophysical Research. Solid Earth*, **121**(5), 3638–3665. doi:10.1002/2015JB012551

Dreger, D., Uhrhammer, R., Pasyanos, M., Franck, J., and Romanowicz, B., 1998, Regional and far-regional earthquake locations and source parameters using sparse broadband networks: a test on the Ridgecrest sequence: *Bulletin of the Seismological Society of America*, **88**(6), 1353–1362.

Duncan, P. M., and Eisner, L., 2010, Reservoir characterization using surface microseismic monitoring: *Geophysics*, **75**(5), A139–A146. doi:10.1190/1.3467760

Economides, M. J., and K. G. Nolte, 2000, *Reservoir stimulation*: Wiley: New York.

Eisner, L., Duncan, P. M., Heigl, W. M., and Keller, W. R., 2009, Uncertainties in passive seismic monitoring: *The Leading Edge*, **28**(6), 648–655. doi:10.1190/1.3148403

Eisner, L., Hulsey, B. J., Duncan, P., Jurick, D., Werner, H., and Keller, W., 2010, Comparison of surface and borehole locations of induced seismicity: *Geophysical Prospecting*, **58**(5), 809–820. doi:10.1111/j.1365-2478.2010.00867.x

Elliston, H., and Davis, W., 1944, A method of handling salt-water disposal, including treatment of water: drilling and production practice, American Petroleum Institute, API-44-122.

Ferguson, G., 2015, Deep injection of waste water in the Western Canada Sedimentary Basin: *Ground Water*, **53**(2), 187–194. doi:10.1111/gwat.12198

Fichtner, A., Bunge, H.-P., and Igel, H., 2006, The adjoint method in seismology: I. Theory: *Physics of the Earth and Planetary Interiors*, **157**(1–2), 86–104. doi:10.1016/j.pepi.2006.03.016

Fischer, T., and Guest, A., 2011, Shear and tensile earthquakes caused by fluid injection: *Geophysical Research Letters*, **38**(5). doi:10.1029/2010GL045447

Frohlich, C., DeShon, H., Stump, B., Hayward, C., Hornbach, M., and Walter, J. I., 2016, A historical review of induced earthquakes in Texas: *Seismological Research Letters*, **87**, 1022–1038. doi:10.1785/0220160016

Gajewski, D., and Tessmer, E., 2005, Reverse modelling for seismic event characterization: *Geophysical Journal International*, **163**(1), 276–284. doi:10.1111/j.1365-246X.2005.02732.x

Geiger, L., 1910, Herdbestimmung bei erdbeben aus den ankunftszeiten: Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen: *Mathematisch-Physikalische Klasse*, **1910**, 331–349.

Grechka, V., and Yaskevich, S., 2014, Azimuthal anisotropy in microseismic monitoring: a Bakken case study: *Geophysics*, **79**(1), KS1–KS12. doi:10.1190/geo2013-0211.1

Hubbert, M. K., and Willis, D. G., 1957, Mechanics of hydraulic fracturing: *Journal of Petroleum Technology*, **IX**(6), 153–166.

Husen, S., Kissling, E., Deichmann, N., Wiemer, S., Giardini, D., and Baer, M., 2003, Probabilistic earthquake location in complex three-dimensional velocity models: application to Switzerland: *Journal of Geophysical Research. Solid Earth*, **108**(no. B2).

Ishii, M., Shearer, P. M., Houston, H., and Vidale, J. E., 2005, Extent, duration and speed of the 2004 Sumatra-Andaman earthquake imaged by the Hi-Net array: *Nature*, **435**(7044), 933–936. doi:10.1038/nature03675

Janská, E., and Eisner, L., 2012, Ongoing seismicity in the Dallas–Fort Worth area: *The Leading Edge*, **31**(12), 1462–1468. doi:10.1190/tle31121462.1

Kamei, R., Pratt, R. G., and Tsuji, T., 2012, Waveform tomography imaging of a megasplay fault system in the seismogenic Nankai subduction zone: *Earth and Planetary Science Letters*, **317–318**, 343–353. doi:10.1016/j.epsl.2011.10.042

Kao, H., and Shan, S.-J., 2004, The source-scanning algorithm: mapping the distribution of seismic sources in time and space: *Geophysical Journal International*, **157**(2), 589–594. doi:10.1111/j.1365-246X.2004.02276.x

Keranen, K. M., Savage, H. M., Abers, G. A., and Cochran, E. S., 2013, Potentially induced earthquakes in Oklahoma, USA: links between wastewater injection and the 2011 Mw 5.7 earthquake sequence: *Geology*, **41**(6), 699–702. doi:10.1130/G34045.1

Lailly, P., 1983, The seismic inverse problem as a sequence of before stack migration: Conference on Inverse Scattering, Theory and Application, Society of Industrial and Applied Mathematics, Expanded Abstracts, 206-220.

Legarth, B., Huenges, E., and Zimmermann, G., 2005, Hydraulic fracturing in a sedimentary geothermal reservoir: results and implications: *International Journal of Rock Mechanics and Mining Sciences*, **42**(7–8), 1028–1041. doi:10.1016/j.ijrmms.2005.05.014

Lomax, A., Virieux, J., Volant, P., and Berge-Thierry, C., 2000, *Probabilistic earthquake location in 3D and layered models: advances in seismic event location*, Springer: The Netherlands, 101–134.

Maxwell, S., 2010, Microseismic: growth born from success: *The Leading Edge*, **29**(3), 338–343. doi:10.1190/1.3353732

Maxwell, S., 2014, Microseismic imaging of hydraulic fracturing: improved engineering of unconventional reservoirs: Canadian Society of Exploration Geophysicists.

Maxwell, S., Rutledge, J., Jones, R., and Fehler, M., 2010, Petroleum reservoir characterization using downhole microseismic monitoring: *Geophysics*, **75**(5), A129–A137. doi:10.1190/1.3477966

McGarr, A., Simpson, D., and Seeber, L., 2002, Case histories of induced and triggered seismicity, in *International Handbook of Earthquake and Engineering Seismology, Part A*: Academic Press, *International Geophysics*, 81, 647–661.

McMechan, G. A., 1982, Determination of source parameters by wavefield extrapolation: *Geophysical Journal International*, **71**(3), 613–628. doi:10.1111/j.1365-246X.1982.tb02788.x

Metz, B., Davidson, O., De Coninck, H., Loos, M., and Meyer, L., 2005, IPCC special report on carbon dioxide capture and storage: technical report, Intergovernmental Panel on Climate Change, Geneva (Switzerland). Working Group III.

Michelini, A., and Lomax, A., 2004, The effect of velocity structure errors on double-difference earthquake location: *Geophysical Research Letters*, **31**, L09602.

Mulder, W., and ten Kroode, A., 2002, Automatic velocity analysis by differential semblance optimization: *Geophysics*, **67**(4), 1184–1191. doi:10.1190/1.1500380

Pavlis, G. L., 1986, Appraising earthquake hypocenter location errors: a complete, practical approach for single-event locations: *Bulletin of the Seismological Society of America*, **76**(6), 1699–1717.

Pesicek, J. D., Child, D., Artman, B., and Cieślik, K., 2014, Picking versus stacking in a modern microearthquake location: comparison of results from a surface passive seismic monitoring array in Oklahoma: *Geophysics*, **79**(6), KS61–KS68. doi:10.1190/geo2013-0404.1

Rawlinson, N., and Sambridge, M., 2003, Seismic traveltime tomography of the crust and lithosphere: *Advances in Geophysics*, **46**, 81–198. doi:10.1016/S0065-2687(03)46002-0

Reiter, D., Leidig, M., Yoo, S.-H., and Mayeda, K., 2012, Source characteristics of seismicity associated with underground wastewater disposal: a case study from the 2008 Dallas-Fort Worth earthquake sequence: *The Leading Edge*, **31**(12), 1454–1460. doi:10.1190/tle31121454.1

Richards-Dinger, K. B., and Shearer, P. M., 2000, Earthquake locations in southern California obtained using source-specific station terms: *Journal of Geophysical Research. Solid Earth*, **105**(no. B5), 10939–10960. doi:10.1029/2000JB900014

Roux, P.-F., Kostadinovic, J., Bardainne, T., Rebel, E., Chmiel, M., Van Parys, M., Macault, R., and Pignot, L., 2014, Increasing the accuracy of microseismic monitoring using surface patch arrays and a novel processing approach: *First Break*, **32**(7), 95–101.

Rubinstein, J. L., Ellsworth, W. L., McGarr, A., and Benz, H. M., 2014, The 2001-present induced earthquake sequence in the Raton Basin of northern New Mexico and southern Colorado: *Bulletin of the Seismological Society of America*, **104**, 2162–2181. doi:10.1785/0120140009

Rutledge, J. T., and Phillips, W. S., 2003, Hydraulic stimulation of natural fractures as revealed by induced microearthquakes, Carthage Cotton Valley gas field, east Texas: *Geophysics*, **68**(2), 441–452. doi:10.1190/1.1567214

Sambridge, M. S., and Kennett, B. L. N., 1986, A novel method of hypocentre location: *Geophysical Journal International*, **87**(2), 679. doi:10.1111/j.1365-246X.1986.tb06644.x

Schoenball, M., Davatzes, N. C., and Glen, J. M. G., 2015, Differentiating induced and natural seismicity using space-time-magnitude statistics applied to the Coso Geothermal field: *Geophysical Research Letters*, 42(15), 6221–6228.

Shabelansky, A. H., Malcolm, A. E., Fehler, M. C., Shang, X., and Rodi, W. L., 2015, Source-independent full wavefield converted-phase elastic migration velocity analysis: *Geophysical Journal International*, **200**(2), 952–966. doi:10.1093/gji/ggu450

Shapiro, S., 2015, *Fluid-induced seismicity*: Cambridge University Press.

Shapiro, S., and Dinske, C., 2009, Fluid-induced seismicity: pressure diffusion and hydraulic fracturing: *Geophysical Prospecting*, **57**(2), 301–310. doi:10.1111/j.1365-2478.2008.00770.x

Shapiro, S. A., Patzig, R., Rothert, E., and Rindschwentner, J., 2003, Triggering of seismicity by pore-pressure perturbations: permeability-related signatures of the phenomenon: *Pure and Applied Geophysics*, **160**(5), 1051–1066. doi:10.1007/PL00012560

Shen, P. 2008, Wave equation migration velocity analysis by differential semblance optimization: PhD thesis, Rice University, Houston, TX.

Shen, P., and Symes, W., 2008, Automatic velocity analysis via shot profile migration: *Geophysics*, **73**(5), VE49–VE59. doi:10.1190/1.2972021

Stein, S., and Wysession, M., 1991, An introduction to seismology, earthquakes, and Earth structure: Wiley.

Symes, W., 1993, A differential semblance criterion for inversion of multioffset seismic reflection data: *Journal of Geophysical Research. Solid Earth*, **98**(no. B2), 2061–2073. doi:10.1029/92JB01304

Symes, W., and Carazzone, J., 1991, Velocity inversion by differential semblance optimization: *Geophysics*, **56**(5), 654–663. doi:10.1190/1.1443082

Talwani, P., and Acree, S., 1984, Pore pressure diffusion and the mechanism of reservoir-induced seismicity: *Pure and Applied Geophysics*, **122**(6), 947–965. doi:10.1007/BF00876395

Tape, C., Liu, Q., Maggi, A., and Tromp, J., 2009, Adjoint tomography of the southern California crust: *Science*, **325**(5943), 988–992. doi:10.1126/science.1175298

Tarantola, A., 1984, Inversion of seismic reflection data in the acoustic approximation: *Geophysics*, **49**(8), 1259–1266. doi:10.1190/1.1441754

Thurber, C. H., 1983, Earthquake locations and three-dimensional crustal structure in the Coyote Lake area, central California: *Journal of Geophysical Research. Solid Earth*, **88**(no. B10), 8226–8236. doi:10.1029/JB088iB10p08226

Thurber, C. H., 1992, Hypocenter-velocity structure coupling in local earthquake tomography: *Physics of the Earth and Planetary Interiors*, **75**(1–3), 55–62. doi:10.1016/0031-9201(92)90117-E

Waldhauser, F., and Ellsworth, W. L., 2000, A double-difference earthquake location algorithm: Method and application to the northern Hayward Fault, California: *Bulletin of the Seismological Society of America*, **90**(6), 1353–1368. doi:10.1785/0120000006

Warpinski, N. R., 2013, Understanding hydraulic fracture growth, effectiveness, and safety through microseismic monitoring: ISRM International Conference for Effective and Sustainable Hydraulic Fracturing, International Society for Rock Mechanics, ISRM-ICHF-2013-047.

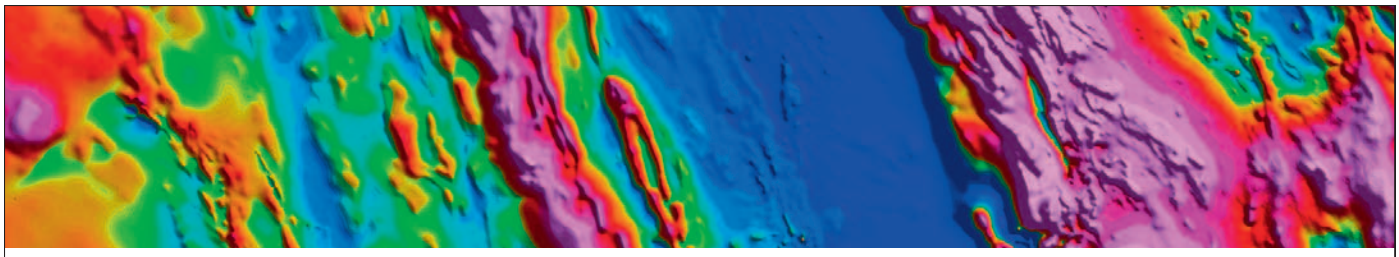
Warpinski, N., Branagan, P., Peterson, R., Wolhart, S., and Uhl, J., 1998, Mapping hydraulic fracture growth and geometry using microseismic events detected by a wireline retrievable accelerometer array: SPE Gas Technology Symposium, Society of Petroleum Engineers, SPE-40014-MS.

Warpinski, N. R., Sullivan, R. B., Uhl, J. E., Waltman, C. K., and Machovoe, S. R., 2003, Improved microseismic fracture mapping using perforation timing measurements for velocity calibration: *Society of Petroleum Engineers Journal*, **10**, 14–23.

Witten, B., and Shragge, J., 2015, Extended imaging conditions for passive seismic data: *Geophysics*, **80**(6), WC61–WC72. doi:10.1190/geo2015-0046.1

Witten, B., and Shragge, J., 2017*a*, Image-domain velocity inversion and event location for microseismic monitoring: *Geophysics*, **82**(5), KS71–KS83. doi:10.1190/geo2016-0561.1
Witten, B., and Shragge, J., 2017*b*, Microseismic image-domain velocity inversion: Marcellus Shale case study: *Geophysics*, **82**(6), KS99–KS112. doi:10.1190/geo2017-0263.1
Zoback, M., 2007, *Reservoir geomechanics*: Cambridge University Press.
Zoback, M. D., and Gorelick, S. M., 2012, Earthquake triggering and large-scale geologic storage of carbon dioxide: *Proceedings of the National Academy of Sciences of the United States of America*, **109**(26), 10164–10168. doi:10.1073/pnas.1202473109

Ben Witten recently completed his PhD in geophysics at the University of Western Australia. He also holds a BS in applied mathematics from Columbia University and an MS in geophysics from Stanford University. Prior to commencing his PhD, he worked at Spectraseis performing R&D and processing of micro-seismic monitoring data.



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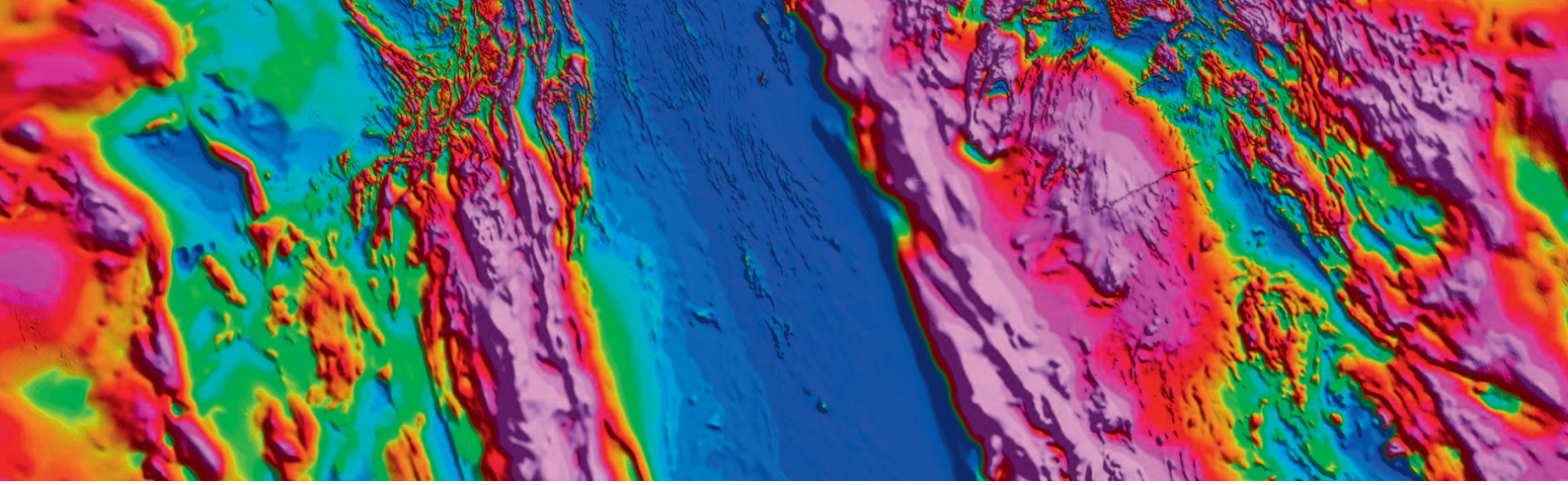

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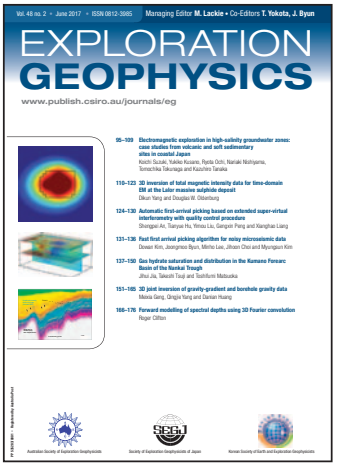

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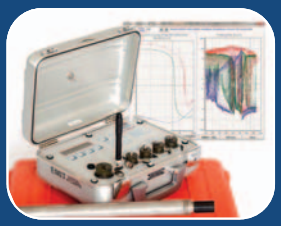

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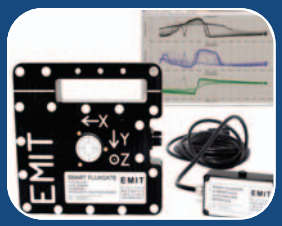

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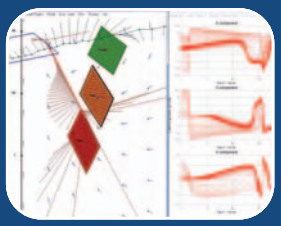

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