

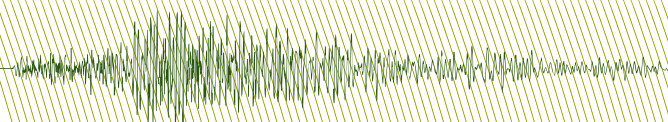


Australian Society of  
Exploration Geophysicists

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# PREVIEW



## NEWS AND COMMENTARY

Changes to the petroleum resource  
rent tax

The Three Princes of Serendip

Curvature, channels and compaction

Passive seismic file formats

## FEATURES

2018 student theses

Physical properties of  
manganese oxides

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## ADVERTISERS INDEX

Alpha Geoscience . . . . .	51
Archimedes Financial Planning . . . . .	51
CoRMaGeo . . . . .	51
EMIT . . . . .	OBC
Gap GeoPhysics . . . . .	51
GBG Australia . . . . .	51
Geophysical Software Solutions . . . . .	51
Groundwater Imaging . . . . .	51
Minty Geophysics . . . . .	51
Mira Geoscience . . . . .	52
Planetary Geophysics . . . . .	52
Tensor Research . . . . .	7, 52
Thomson Aviation . . . . .	2

## ASEG CORPORATE PLUS MEMBER

Velseis Pty Ltd  
Tel: +61 7 3376 5544  
Email: info@velseis.com



## ASEG CORPORATE MEMBERS

Archimedes Financial Planning  
Contact: Noll Moriarty  
Tel: 1300 387 351  
Email: Noll.Moriarty@ArchimedesFinancial.com.au



Instrumentation GDD Inc.  
Contact: Pierre Gaucher  
Tel: +1 418 877 4249  
Email: pgaucher@gcc.ca



Santos Ltd  
Tel: +61 8 8116 5000  
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Southern Geoscience Consultants Pty Ltd  
Tel: +61 8 6254 5000  
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Web: http://sgc.com.au/



## FRONT COVER



Winning photo in the ASEG Photo Competition submitted by Richard Barnwell (Terrex Group). See *Webwaves* for the full story.

Preview is available online at  
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## CONTENTS

Editor's desk	2
<b>ASEG news</b>	
President's piece	3
Table of officeholders	4
Executive brief	5
New Members	5
2019 ASEG AGM Notice	6
Committees:	7
• Update from the ASEG Young Professionals Network	7
• 2019 ASEG Honours and Awards: Call for nominations	8
Branch news	9
ASEG national calendar	11
<b>News</b>	
Conferences and events:	12
• AEGC 2019: Exhibition bookings now open	12
• Near Surface Geoscience and Engineering conference in Kuala Lumpur in 2019	12
• AGCC 2018:	13
◦ A review	13
◦ Student reports on participation	14
• AuScope workshop: Seeking community input to re-thinking approach to national geoscience challenges	16
• First Asia Pacific workshop on fibre-optic sensing a success	17
Geophysics in the Surveys:	18
• GA:	18
◦ Update on geophysical survey progress	18
◦ New regional AEM survey in northern Australia	20
• GSNSW: Largest AEM survey ever planned for NSW	21
• GSWA: Acquisition of 2018 aerogravity surveys complete	22
• GSSA: Event news	23
<b>Commentary</b>	
Canberra observed:	24
• Changes to the petroleum resource rent tax	24
• Research grants blocked, university funding removed, ARC allocation delayed, and freedom of speech reviewed on university campuses	24
• Award of offshore petroleum permits	25
Education matters:	28
• The next two generations of earth scientists	28
• Geophysics theses in Australian universities in 2018	28
• Highlighting the importance of earth sciences in our schools	35
Environmental geophysics: Reflections on the 2018 SEG conference	37
Minerals geophysics: Mineral exploration and The Three Princes of Serendip	38
Seismic window: Curvature, channels and compaction	39
Data trends: Exploring passive seismic file formats for data exchange	40
Webwaves: Endings and a new beginning	41
<b>Feature</b>	
Pyroclastic supergene manganese oxides: inductive properties, EM conductivity and magnetic susceptibility	42
Business directory	51
International calendar of events	IBC

**Editor**  
Lisa Worrall  
Email: [previeweditor@aseg.org.au](mailto:previeweditor@aseg.org.au)

**Associate Editors**  
Education: Michael Asten  
Email: [michael.asten@monash.edu](mailto:michael.asten@monash.edu)

Government: David Denham  
Email: [denham1@iinet.net.au](mailto:denham1@iinet.net.au)

Environmental Geophysics: Mike Hatch  
Email: [michael.hatch@adelaide.edu.au](mailto:michael.hatch@adelaide.edu.au)

Minerals Geophysics: Terry Harvey  
Email: [terry.v.harvey@glencore.com.au](mailto:terry.v.harvey@glencore.com.au)

Petroleum Geophysics: Michael Micenko  
Email: [micenko@bigpond.com](mailto:micenko@bigpond.com)

Geophysical Data Management and Analysis:  
Tim Keeping  
Email: [Tim.Keeping@sa.gov.au](mailto:Tim.Keeping@sa.gov.au)

Book Reviews: Ron Hackney  
Email: [ron.hackney@ga.gov.au](mailto:ron.hackney@ga.gov.au)

**ASEG Head Office & Secretariat**  
Alison Forton  
The Association Specialists Pty Ltd (TAS)  
Tel: (02) 9431 8622  
Email: [secretary@aseg.org.au](mailto:secretary@aseg.org.au)  
Website: [www.aseg.org.au](http://www.aseg.org.au)

**Publisher**  
CSIRO Publishing

**Production Editor**  
Helen Pavlatos  
Tel: (03) 9545 8472  
Email: [helen.pavlatos@csiro.au](mailto:helen.pavlatos@csiro.au)

**Advertising**  
Tel: (03) 9545 8400  
Email: [publishing.advertising@csiro.au](mailto:publishing.advertising@csiro.au)



## Editor's desk



This bumper Christmas issue of *Preview* features an article by Don Emerson and Phil Schmidt on the physical properties of pyrolusitic supergene manganese oxides. This important article fills a gap in the literature on the properties of these minerals and, as a consequence, Don has refrained from reflecting, in his inimitable style, on the place of these minerals in history. He has promised to return to that style for a consideration of pyrite in the next Christmas issue of *Preview* – only 12 months to wait!

In addition, we feature our annual summary of student projects completed

in geophysics in Australia (Michael Astén *Education matters*). Many of the completing students will be presenting at the various ASEG State Branch student presentation nights in late November and early December, and we will report on the presentation night award winners in the February issue.

We also welcome Tim Keeping to our regular commentary team. Tim is a geophysicist who was trained at the University of Adelaide and works for the Geological Survey of South Australia. He will be known to many ASEG Members as the current Chair of the ASEG Technical Standards Committee. He now luxuriates in the additional and rather grand title of *Preview* Associate Editor for geophysical data management and analysis. In this issue Tim (*Data trends*) takes a look at file formats for passive seismic data exchange and asks readers for feedback on their experience. David Denham (*Canberra observed*) reports on the latest Federal Government attacks on the university sector. Mike Hatch (*Environmental geophysics*) reflects on the SEG conference in Anaheim, California. Terry Harvey (*Minerals*


*geophysics*) muses on the role of serendipity in mineral exploration. Mick Micenko (*Seismic window*) considers the use of curvature to rapidly identify sand-rich areas within complex channel systems, and Dave Annetts (*Webwaves*) announces the winners of the ASEG photo competition – the first place winner appears on our cover.

This issue will be the last issue of *Preview* produced by CSIRO Publishing. The ASEG's partnership with CSIRO Publishing has been fruitful, and I would particularly like to thank Helen Pavlatos, who has been *Preview*'s Production Editor for most of the last eight years. Helen has worked with several *Preview* Editors and has always shown great professionalism, patience and generosity under what must have occasionally been very trying circumstances. I will miss her, but look forward to developing an equally fruitful partnership with the team at Taylor & Francis.

A safe and happy festive season to you all.


Lisa Worrall  
Preview Editor  
[previeweditor@aseg.org.au](mailto:previeweditor@aseg.org.au)

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David Abbott [david@thomsonaviation.com.au](mailto:david@thomsonaviation.com.au)

Season's Greetings

Paul Rogerson [paul@thomsonaviation.com.au](mailto:paul@thomsonaviation.com.au)





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## President's piece



Marina Costelloe (far right) at the AGCC with other members of the ASEG Federal Executive.

Firstly I'd like to thank Andrew Long for representing the ASEG at the SEG 2018 conference, and Koya Suto for representing our Society at SEGJ conference, both are long term, active, trusted and valued Members of the ASEG and SEG, and do a lot to promote Australia, geophysics and the ASEG.

I was fortunate enough to attend the AGCC in Adelaide, those of you who are 'LinkedIn' with me would have seen what a busy week it was, busy but very educational. Some of the highlights were Dr James Johnson's opening address, where he explained the value of the work we do in the geosciences to all Australians, and the official opening of the MinEx CRC, the world largest mineral exploration collaboration bringing together industry, government and research organisations. It was great to see how people with very different backgrounds have found a common vision in this CRC, and I can't wait to see how it progresses over the next 10 years. It was also very exciting to listen to, and meet, Professor Iain Stewart (of BBC fame). His insights into how to tell a science story were very powerful. In short, he spoke about connecting with people and the purpose behind the work we all do. I was invited to speak at a mentoring event run by WOOMESA, hosted a Women in STEM workshop (yes blokes were there too) that will contribute to an Academy of Science decadal plan, and represented the ASEG and Geoscience Australia at the ANSIR and AuScope meetings. I saw many old colleagues and met a whole new crop ready to be converted to geophysics. Thank you to the AGC organising committee and to Dr Bill Shaw and Kim Frankcombe for their tireless efforts to get this conference up and running.

Another shout out to the committee organising the AEGC 2019 Data to

Discover Conference, thank you for your hard work. Abstracts are now open, as are sponsorship packages and workshop opportunities. As I have mentioned before, Tim Dean (ASEG) and the Perth organisers have a cracker program. Have a look at the updated website <http://2019.aegc.com.au>, Perth, 2–5 September 2019. I hope to see you there.

We are approaching the ASEG's 50th anniversary. Just in case you are too young to know, or need reminding, the ASEG will be celebrating its 50th anniversary in 2020. In preparation, we will start to see some festivities being rolled out in 2019, including special interviews with ASEG Members, memories in *Preview*, and new opportunities for all Members to get involved in the festivities. Roger Henderson and Mike Smith have published a wonderful resource called 'A brief history of the formation of the ASEG', go to: <https://www.aseg.org.au/about-aseg/aseg-formation>. Included in the appendices are the minutes of the first meeting on 4 June 1970, plus a reference to it in the ASEG Bulletin, Volume 1, Number 1, September 1970. While you are on the website have a look around, David Annetts and the web team have been very busy updating large portions. If there is material you would like to see added don't hesitate to contact [webmaster@aseg.org.au](mailto:webmaster@aseg.org.au), thank you web team.

April will see us have our AGM; details have been published in this edition of *Preview*. The Federal Executive hopes to get your support for making minor changes to the Constitution around being able to vote electronically. Details will be sent out in January. Each year we are asked 'how does the President get elected?'. Well, it is a good question, and the answer is in the Constitution (available on the website). But if you are interested, and still reading, a Presidential Nominating Committee is formed each year and consists of the President and the two most recent past Presidents. The Nominating Committee nominates candidates (ASEG Members) with the skills and experience to steer the leadership of the Society over the next 3–5 years. The Nominating Committee then approaches the preferred candidate to request that they take on the three year term (President Elect, President, and then Immediate Past President). All other Federal Executive positions are open to all ASEG Members (that's YOU). Please contact me today if you are interested in self-nominating, or

nominating someone else.

Last, but by no means least, I am very honoured to have been successfully nominated to join the Board of Science and Technology Australia (STA). The Australian Geoscience Council (AGC) is the peak council of geoscientists in Australia. It represents eight major Australian geoscientific societies, with a total membership of over 8000 individuals including industry, government and academic professionals in the fields of geology, geophysics, geochemistry, mineral and petroleum exploration, environmental geoscience, hydrogeology and geological hazards ([www.agc.org.au](http://www.agc.org.au)). I thank Bill Shaw and the AGC council for their support of my nomination to represent these eight professional societies. The appointment to the STA Board for the Geological and Geographical Sciences cluster means I get to represent the members of the Australian Geoscience Council, the Australian Quaternary Association (AQUA), the Institute of Australian Geographers (IAG), and the International Ocean Drilling Program (IODP). Science and Technology Australia's mission is to bring together scientists, governments, industry and the broader community to advance the role, reputation and impact of science and technology across the nation. Science and Technology Australia is Australia's peak body in science and technology – and if you add in the 8000 strong Geology and Geography cluster, the organisation represents about 70 000 Australian scientists and technologists working across all scientific disciplines (<http://scienceandtechnologyaustralia.org.au/>).

By the time you read this it is going to be close to Christmas, and what a year 2018 has been. I hope for you it has been a good year. If this time of year is particularly difficult for you, please reach out for help. Friends and colleagues might be able to help and there are, of course, wonderful organisations like beyondblue and Lifeline. Check in with your family and colleagues and make sure they are ok.

Wishing you and your family a Merry Christmas, happy holidays, safe travels and see you in 2019.

Marina Costelloe  
ASEG President  
[president@aseg.org.au](mailto:president@aseg.org.au)



## ASEG Federal Executive 2017–18

Marina Costelloe: President  
Tel: (02) 6249 9347  
Email: [president@aseg.org.au](mailto:president@aseg.org.au)

Ted Tyne: President Elect (Publications Committee Co-Chair, ASEG Research Foundation)  
Tel: 0434 074 123  
Email: [president-elect@aseg.org.au](mailto:president-elect@aseg.org.au)

Megan Nightingale: Secretary (Young Professionals Network)  
Tel: 0438 861 556  
Email: [fedsec@aseg.org.au](mailto:fedsec@aseg.org.au)

Danny Burns: Treasurer (Finance Committee Chair)  
Tel: 0407 856 196  
Email: [treasurer@aseg.org.au](mailto:treasurer@aseg.org.au)

Andrea Rutley: Past President (Promotions Committee Chair)  
Tel: (07) 3834 1836  
Email: [pastpresident@aseg.org.au](mailto:pastpresident@aseg.org.au)

Katherine McKenna: (International Committee)  
Tel: 0400 594 220  
Email:

Kim Frankcombe (AGC Representative, Conference Advisory Committee and Technical Standards Committee)  
Tel: (08) 6201 7719  
Email: [kfrankcombe@iinet.net.au](mailto:kfrankcombe@iinet.net.au)

Marina Pervukhina (Professional Development Committee Chair, State Branch Representative, Specialist and Working Groups Liaison)  
Tel: (08) 6436 8746  
Email: [branch-rep@aseg.org.au](mailto:branch-rep@aseg.org.au)

David Annetts (Web Committee Chair)  
Tel: (08) 6436 8517  
Email: [david.annetts@csiro.au](mailto:david.annetts@csiro.au)

Kate Robertson (Communications Committee)  
Tel: (08) 8429 2564  
Email: [communications@aseg.org.au](mailto:communications@aseg.org.au)

Leslie Atkinson (Membership Committee)  
Tel: 0414 804 028  
Email: [membership@aseg.org.au](mailto:membership@aseg.org.au)

Andrew Squelch (Education Committee Chair)  
Tel: (08) 9266 2324  
Email: [education@aseg.org.au](mailto:education@aseg.org.au)

## Standing Committee Chairs

Finance Committee Chair: Danny Burns  
Tel: 0407 856 196  
Email: [treasurer@aseg.org.au](mailto:treasurer@aseg.org.au)

Membership Committee Chair:  
Leslie Atkinson  
Tel: 0414 804 028  
Email: [membership@aseg.org.au](mailto:membership@aseg.org.au)

State Branch Representative: Marina Pervukhina  
Tel: (08) 6436 8746  
Email: [branch-rep@aseg.org.au](mailto:branch-rep@aseg.org.au)

Conference Advisory Committee Chair:  
Michael Hatch  
Email: [cac@aseg.org.au](mailto:cac@aseg.org.au)

Honours and Awards Committee Chair:  
Andrew Mutton  
Tel: 0408 015 712  
Email: [awards@aseg.org.au](mailto:awards@aseg.org.au)

Publications Committee Chairs:  
Danny Burns and Ted Tyne  
Tel: 0407 856 196 and 0434 074 123  
Email: [publications@aseg.org.au](mailto:publications@aseg.org.au)

Technical Standards Committee Chair:  
Tim Keeping  
Tel: (08) 8226 2376  
Email: [technical-standards@aseg.org.au](mailto:technical-standards@aseg.org.au)

ASEG History Committee Chair:  
Roger Henderson  
Tel: 0406 204 809  
Email: [history@aseg.org.au](mailto:history@aseg.org.au)

International Affairs Committee Chair:  
Nick Direen  
Tel: –  
Email: [international@aseg.org.au](mailto:international@aseg.org.au)

Professional Development Committee Chair:  
Marina Pervukhina  
Tel: (08) 6436 8746  
Email: [continuingeducation@aseg.org.au](mailto:continuingeducation@aseg.org.au)

Education Committee Chair: Andrew Squelch  
Tel: (08) 9266 2324  
Email: [education@aseg.org.au](mailto:education@aseg.org.au)

Web Committee Chair: David Annetts  
Tel: (08) 6436 8517  
Email: [david.annetts@csiro.au](mailto:david.annetts@csiro.au)

Research Foundation Chair: Philip Harman  
Tel: 0409 709 125  
Email: [research-foundation@aseg.org.au](mailto:research-foundation@aseg.org.au)

Communications Committee Chair:  
Kate Robertson  
Tel: (08) 8429 2564  
Email: [communications@aseg.org.au](mailto:communications@aseg.org.au)

## Specialist Groups

Near Surface Geophysics Specialist Group  
President: David Annetts  
Tel: (08) 6436 8517  
Email: [nsadmin@aseg.org.au](mailto:nsadmin@aseg.org.au)

Young Professionals Network  
President: Megan Nightingale  
Tel: 0438 861 556  
Email: [ypadmin@aseg.org.au](mailto:ypadmin@aseg.org.au)

## ASEG Branches

### Australian Capital Territory

President: James Goodwin  
Tel: (02) 6249 9705  
Email: [actpresident@aseg.org.au](mailto:actpresident@aseg.org.au)  
Secretary: Adam Kroll  
Tel: (02) 6283 4800  
Email: [actsecretary@aseg.org.au](mailto:actsecretary@aseg.org.au)

### New South Wales

President: Mark Lackie  
Tel: (02) 9850 8377  
Email: [nswpresident@aseg.org.au](mailto:nswpresident@aseg.org.au)  
Secretary: Steph Kovach  
Tel: (02) 8960 8443  
Email: [nswsecretary@aseg.org.au](mailto:nswsecretary@aseg.org.au)

### Queensland

President: Ron Palmer  
Tel: 0413 579 099  
Email: [qldpresident@aseg.org.au](mailto:qldpresident@aseg.org.au)  
Secretary: James Alderman  
Tel: –  
Email: [qldsecretary@aseg.org.au](mailto:qldsecretary@aseg.org.au)

### South Australia & Northern Territory

President: Kate Robertson  
Tel: (08) 8429 2564  
Email: [sa-ntpresident@aseg.org.au](mailto:sa-ntpresident@aseg.org.au)  
Secretary: Mike Hatch  
Tel: –  
Email: [sa-ntsecretary@aseg.org.au](mailto:sa-ntsecretary@aseg.org.au)

NT Representative: Tania Dhu  
Tel: 0422 091 025  
Email: [nt-rep@aseg.org.au](mailto:nt-rep@aseg.org.au)

### Tasmania

President: Mark Duffett  
Tel: (03) 6165 4720  
Email: [taspresident@aseg.org.au](mailto:taspresident@aseg.org.au)  
Secretary: Steve Kuhn  
Tel: (03) 6226 2477  
Email: [tassecretary@aseg.org.au](mailto:tassecretary@aseg.org.au)

### Victoria

President: Seda Rouxel  
Tel: 0452 541 575  
Email: [vicpresident@aseg.org.au](mailto:vicpresident@aseg.org.au)  
Secretary: Thong Huynh  
Tel: –  
Email: [vicsecretary@aseg.org.au](mailto:vicsecretary@aseg.org.au)

### Western Australia

President: Heather Tompkins  
Tel: 0477 988 810  
Email: [wapresident@aseg.org.au](mailto:wapresident@aseg.org.au)  
Secretary: Matt Owers  
Tel: –  
Email: [wasecretary@aseg.org.au](mailto:wasecretary@aseg.org.au)

### The ASEG Secretariat

Alison Forton  
The Association Specialists Pty Ltd (TAS)  
PO Box 576, Crows Nest, NSW 1585  
Tel: (02) 9431 8622  
Fax: (02) 9431 8677  
Email: [secretary@aseg.org.au](mailto:secretary@aseg.org.au)



## 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 monthly meetings that were held in October and November.

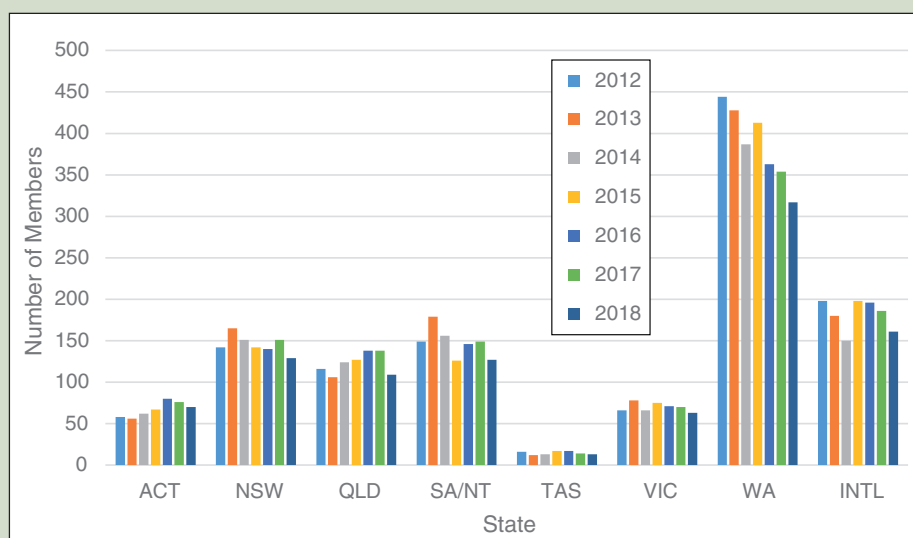
### Finances

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

Year to date income: \$419 500.00

Year to date expenditure: \$500 042.00

Net assets: \$807 301.00



**Figure 1.** ASEG membership levels by state between 2012 and 2018.

### Membership

At the time of this report, the Society had 989 Members. This figure is up from the figure of 970 Members reported in the October issue of *Preview*. It is down 13% from last year. Numbers are down similarly across most of the States, with the least drop in membership being 7% in Tasmania, and the greatest drop in

membership being 21% drop in Queensland (Figure 1).

Retired and Honorary membership has remained constant from last year, while there has been a 4% decrease in Active/Associate Members. There has also been significant decrease in the number of Student and Corporate Members.

Thanks to all our Members for their support and we look forward to your continued support and membership renewals in 2019!

Megan Nightingale  
Secretary  
[fedsec@aseg.org.au](mailto:fedsec@aseg.org.au)

## Welcome to new Members

The ASEG extends a warm welcome to 15 new Members approved by the Federal Executive at its October and November meetings (see table).

First name	Last name	Organisation	State	Country	Membership type
Sasha	Aivazpourporgous	Newexco Pty Ltd Services	QLD	Australia	Active
Brandon	Alessio	University of Adelaide	SA	Australia	Student
Sheree	Armistead	University of Adelaide	SA	Australia	Student
Simon	Brealey	Bass Oil Limited	SA	Australia	Active
Michael	Curtis	University of Adelaide	SA	Australia	Student
Ryan	Frazier	Marine and Earth Sciences	QLD	Australia	Active
Katarina	Kosten	University of Adelaide	SA	Australia	Student
Michael	McWilliams	CSIRO	WA	Australia	Active
Thomas	Montgomery	Marine and Earth Sciences	ACT	Australia	Active
Francis	Moul	Condor North Consulting	BC	Canada	Active
Matthew	Shrimpton	University of Melbourne	VIC	Australia	Student
Darwinaji	Subarkah	University of Adelaide	SA	Australia	Student
Joshua	Valencic	GHD	NSW	Australia	Active
Xueyu	Zhao	University of Sydney	NSW	Australia	Student
Priya	Priya	University of Adelaide	SA	Australia	Student

## Notice of Annual General Meeting (AGM)

The 2019 AGM of the Australian Society of Exploration Geophysicists (ASEG) will be held at Geoscience Australia in Canberra on 4 April 2019. The meeting will be hosted by the ACT Branch. Details will 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 preceded by a scientific presentation, details will be advertised as they come to hand.

### Invitation for candidates for the Federal Executive

Members of the Federal Executive serve in an honorary capacity. They are all

volunteers and ASEG 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. Self-nominations are encouraged.

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:

- a President,
- a President Elect,
- a Secretary, and
- a Treasurer.

These officers are elected annually by a general ballot of Members. Dr Ted Tyne was elected as President-Elect in 2018 and as such will stand for the position of President.

The following offices are also recognised:

- Vice President,
- the Immediate Past President (unless otherwise a member of the Federal Executive),
- the Chair of the Publications Committee,
- the Chair of the Membership Committee,

- the Chair of the State Branch Committees, and
- 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](mailto:fedsec@aseg.org.au)

**Nominations must be received via post, fax or email no later than COB**

**Tuesday 7 March 2019.** Positions for which there are multiple nominations will then be determined by ballot of Members and the 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.

## Congratulations



Emeritus Professor Kurt Lambeck AO (Australian National University) recently won the 2018 Prime Minister's Prize for Science. This prize is very well deserved acknowledgment of a life time of great achievements by Professor Lambeck, who has had a profound impact on our Society. According to Professor Lambeck our planet changes shape every day, indeed, the planet 'breathes' as if it is alive.



Professor Dietmar Müller (Sydney University) has won the 2018 NSW Premier's prize for Excellence in Mathematics, Earth Sciences, Chemistry and Physics. Professor Müller has been an outstanding scientific leader, responsible for advancing geological and geophysical modelling that is transforming our understanding of the Earth's evolution. The work of his current research group, the Basin GENESIS Hub, was featured in the August 2018 issue of *Preview* (PV 195).

Marina Costelloe  
ASEG President



## Update from the ASEG Young Professionals Network

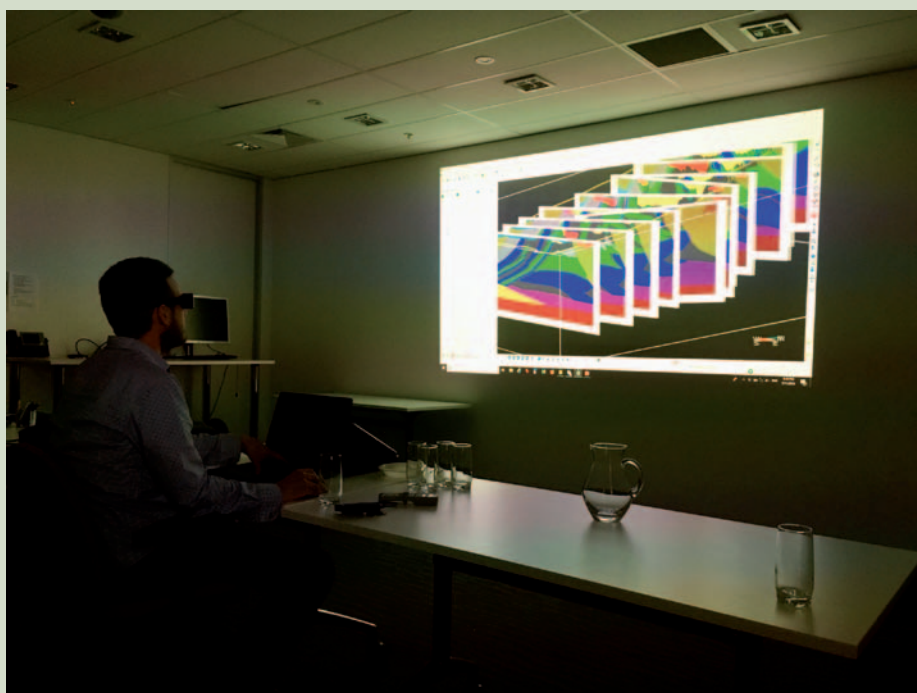
Applications are now open for the joint ASEG and PESA Queensland Mentoring Program. The program is targeting early career professionals in the geophysics and petroleum industries. We are seeking both mentees and mentors with applications closing 31 December 2018. The program will launch on 1 February 2019 and will run until 1 September 2019.

Early career professionals had a large presence at the recent AGCC event in Adelaide. As well as a booth in the exhibition hall sponsored by the AGC, there were two social events organised for the week. The first was a networking event on the Monday night that was generously supported by the GSA, AusIMM and AIG. It offered early career geoscientists and students a chance to network with more senior people from across industry, government and academia, and was attended by over 70 people. The second social event was the Trivia Night sponsored by Anglo America and held on the Tuesday night of the conference. The event was attended by 30 people and was hotly contested with the leading table changing several times during the night. Finally, the CSIRO rapid fire presentations offered students and early career geoscientists an opportunity to present their research in just three minutes! The event was hugely successful with an amazing range of talk topics offered and six well deserving winners.

The Victorian YPs have continued their seminar series with a fascinating talk integrating geology, geophysics and 3D visualisation by Ross Cayley, Phil Skladzien and Mark McLean of the GSV. Their talk was an inspiring look at a new and self-consistent model for the complex and undercover geology of the Stavely region in Western Victoria. Their work has been described in a previous edition of *Preview* but, since then, the 3D model they built and their interpretation with reference to copper mineralisation potential has led to an encouraging uptake of exploration permits in the region.

On 28 November we're looking forward to our final talk for the year from Ian Filby of CarbonNet, which will address issues in stakeholder management. We'll wrap up the year in late December with a networking and social event to review our first year of mentoring and to commence planning for local training opportunities in 2019.

*Megan Nightingale and Jarrod Dunne*  
ASEG Young Professionals Network  
[ypadmin@aseg.org](mailto:ypadmin@aseg.org)

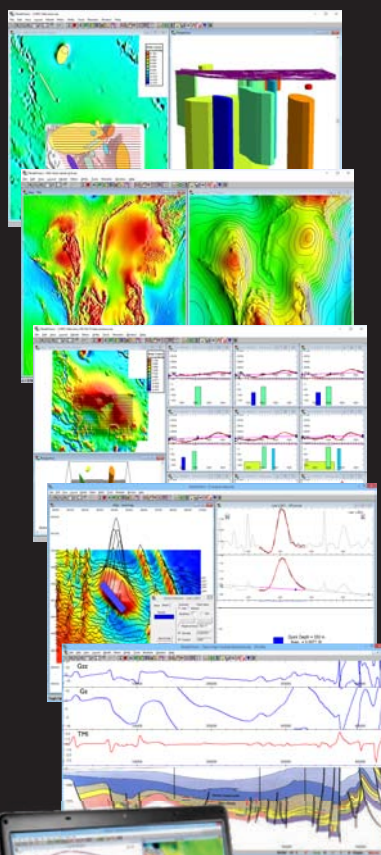


**Figure 1.** Mark McLean presenting the Stavely 3D GoCAD model using a 3D projector.

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## 2019 ASEG Honours and Awards: call for nominations now open



An important role of the ASEG is to acknowledge the outstanding contributions of its individual Members both to the profession of geophysics and to the ASEG. The Society has a number of different Honours and Awards across a range of categories. Nominations are now open for the next round of Awards, scheduled to be presented in conjunction with AEGC 2019, 2–5 September 2019, Perth, Western Australia.

All ASEG Members as well as State and Federal executives are invited to nominate those they consider deserving of these awards. A list of the various available awards is set out below.

These awards carry considerable prestige within the Society and the geoscience community and therefore require some documentation to support the nomination. Please visit <https://www.aseg.org.au/about-aseg/honours-awards> or contact the Committee Chair if you require further guidelines on what is required.

### ASEG Gold Medal

For exceptional and highly significant distinguished contributions to the science and practice of geophysics, resulting in wide recognition within the geoscientific

community. The nominee must be a Member of the ASEG.

### Honorary Membership

For distinguished contributions by a Member to the profession of exploration geophysics and to the ASEG over many years. Requires at least 20 years as a Member of the ASEG.

### Grahame Sands Award

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

### Lindsay Ingall Memorial Award

For the promotion of geophysics to the wider community. This award is intended for an Australian resident or former resident for the promotion of geophysics (including but not necessarily limited to applications, technologies or education), within the non-geophysical community, including geologists, geochemists, engineers, managers, politicians, the media or the general public. The nominee does not need to be a geophysicist nor a Member of the ASEG.

### Early Achievement Award

For significant contributions to the profession by a Member under 36 years of age, by way of publications in *Exploration Geophysics* or similar reputable journals, or by overall contributions to geophysics, ASEG Branch activities, committees, or events. The nominee must be a Member of the ASEG and have graduated for at least 3 years.

### ASEG Service Awards

For distinguished service by a Member to the ASEG, through involvement in and contribution to State Branch committees, Federal Committees, Publications, or Conferences over many years. The nominee will have been a Member of the ASEG for a sustained period of time. All nominations will be considered for the award of an ASEG Service Certificate. Where the nomination details outstanding contributions to the shaping and the sustaining of the Society and the conduct of its affairs over many years, consideration will be given to the award of the ASEG Service Medal to the nominee. Honorary Members are not eligible for nomination.

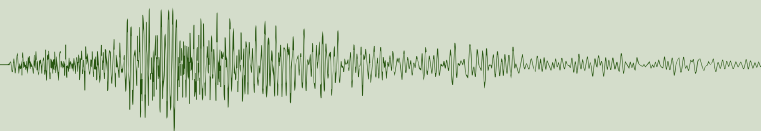
### Nomination procedure

Any Member of the Society may submit nominations. These nominations are to be supported by a seconder, and in the case of the Lindsay Ingall Memorial Award by at least four geoscientists who are members of an Australian geoscience body (e.g. GSA, AusIMM, AIG, IAH, ASEG or similar).

Nominations must be specific to a particular award and all aspects of the defined criteria should be addressed. To view the criteria for each award and the information required for a nomination, nominators are advised to access and view the nomination guidelines and *pro forma* nomination forms at: <https://www.aseg.org.au/about-aseg/honours-awards>.

*Pro forma* nomination forms are also available by contacting the Committee Chair. Nominations including digital copies of all relevant supporting documentation are to be sent electronically to the Chair, ASEG Honours and Awards Committee via email: [awards@aseg.org.au](mailto:awards@aseg.org.au).





## ASEG Branch news

### Victoria

The spring season has been quiet for the Victorian Branch, but we co-hosted the November Young Professionals meeting, which was very interesting. We will all see the Grampians with a new eye on our next visit! Representatives from the Geological Survey of Victoria gave a detailed and enthusiastic presentation on the Stavely Arc project, turning the venue into a 3D-vision room!

The next event will be the joint ASEG-SPE Christmas lunch. Details will be announced shortly.

An invitation to attend Victorian Branch meetings is extended to interstate and international visitors who happen to be in Melbourne at the time. Meetings are generally held on the third Thursday of each month from 5:30 pm in the Kelvin Club, 18–30 Melbourne Place, Melbourne. Meeting notices, addresses and relevant contact details can be found on the Victorian Branch page of the ASEG website.

*Seda Rouxel*  
[vicpresident@aseg.org.au](mailto:vicpresident@aseg.org.au)

### Western Australia

The 9 October \*Young Professionals\* Tech Night was jointly hosted with PESA, and saw two presenters summarise their recent work to an audience of young professionals from each Society. **Vincent Crombez** (CSIRO) presented 'From cores to stratigraphic modelling: an innovative workflow to characterise unconventional targets, with applications to the Montney and Doig Formations in Western Canada' and **Tasman Gilfeather-Clark** (UWA) summarised his work on 'Machine learning for land classification, a self-organising map case study of Broken Hill'. The WA Branch continued young professional and student engagement with two events in November, comprising the ASEG-PESA mentoring program closing session on 27 November, and our annual student night on 28 November with presentations from undergraduate and post-graduate students from UWA and Curtin University.

Upcoming WA events include:

- 12 December – AGM and Christmas Party at Mayfair Lane, West Perth
- 13 February Tech night – **Richard**

**Chopping** will summarise his recent publication 'The Australian Continent: a geophysics synthesis'

Event planning for 2019 has commenced, and the WA Branch intends to hold two lunchtime tech events during the year, while also continuing to host evening technical events with both PESA and AIG where applicable. The WA committee is actively filling the technical calendar for 2019, so if you or your organisation would like to present at a function please get in touch with us as soon as possible ([wapresident@aseg.org.au](mailto:wapresident@aseg.org.au); [wasecretary@aseg.org.au](mailto:wasecretary@aseg.org.au)).

We look forward to seeing you at the AGM and at our first tech event of 2019 in February. On behalf of the WA Branch committee, we wish you all a safe and happy holiday season.

*Heather Tompkins*  
[wapresident@aseg.org.au](mailto:wapresident@aseg.org.au)

### Australian Capital Territory

In October the ASEG's President, **Marina Costelloe**, presented a fantastic talk on the history of the ASEG, her personal journey as a geophysicist, and the importance of diversity in science. Marina is the third woman in 30 years to hold the role of President, and also the first Public Sector leader to hold this role. Marina spoke about how, as a society, the ASEG is committed to diversity, inclusion and anti-discrimination through respect and appreciation of what makes our membership so varied in terms of age, gender, ethnicity, disability, education and national origin. Since its foundation in 1970, the ASEG has become an inclusive and diverse society, bringing new ideas, new thinking and innovation into our member forums and conventions.

In November, our Branch was delighted to present **Kathryn Hayward** with the 2018 ACT Student Award. Kathryn presented an interesting talk to the Branch that described how pore fluids influence rupture dynamics during earthquakes, and discussed the seismological evidence that suggests there is a significant difference in fault behaviour between classic stress-driven earthquakes and those driven by changes in pore fluid pressure. The ACT Branch would like to congratulate Kathryn on her outstanding achievements so far.

To finish off the year the ACT Branch held a Christmas Party and Technical Evening on 6 December with guest speaker **Richard Chopping**. Richard presented on the recently launched book: *The Australian Continent – A Geophysical Synthesis*.

Thank you to all the ACT Branch members for making this year so fantastic. Wishing you all a merry Christmas!

*James Goodwin*  
[actpresident@aseg.org.au](mailto:actpresident@aseg.org.au)

### New South Wales

In September the Macquarie University student committee did all the hard work. They were given the remit to organise and run the ASEG NSW Branch meeting, and to attract as many students along as possible.

The abstract for the meeting was: 'It can be difficult for recent graduates to know what to do once their undergraduate studies are over. Should you pursue further study, or transition into the workforce? What opportunities are there out there?'

There were three speakers, all giving great presentations, outlining to the students in the audience (and students at heart!!) how they made their choice and where it led them. They were:

- **Jose Fernando Gomez Martinez** – geotechnical engineer at Geotesta
- **Sam Matthews** – PhD student at Macquarie University
- **Josh Valencic** – engineering geophysicist at GHD

In October, we had our annual student night, where Honours and Masters students present their research. This year we had four speakers, all giving great talks with much discussion and hand gesturing afterwards. The speakers and topics were:

- **Xueyu (Tom) Zhao and Jie Wang** (UNSW) – 'Digital regolith mapping of soil salinity and clay content in 3-d using reconnaissance EM data and inversion modelling'
- **Steph Hawkins** (Macquarie University) – 'Investigating an igneous dyke swarm using applied field magnetism'
- **Alice Van Tilburg** (Macquarie University) – 'Exploring Lithospheric Scale Structure in the Eastern Yilgarn Craton with 3D Magnetotellurics'

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

Mark Lackie  
[nswpresident@aseg.org.au](mailto:nswpresident@aseg.org.au)

## Queensland

**Tariq Rahiman** of Golder Associates presented to the ASEG QLD Branch in September on 'The application of geophysics for marine geohazard assessment: A case study from the Fiji Islands.' Tariq's talk was almost exactly 65 years to the day after the event, when on 14 September 1953, a powerful tsunami hit Suva City, the capital of Fiji, following a moderate to large earthquake. Suva is located within a seismotectonically active region of Fiji and Suva remains vulnerable to similar events. Tariq gave us an overview of how high resolution marine geophysical imaging assisted in the discovery of the source submarine landslide of the 1953 Suva tsunami. This discovery led to numerical modelling of the tsunami waves and inundation hazard zonation mapping for Suva City.

**Matt Higgins** was our October guest speaker. Matt is Manager of geodesy and positioning in the Queensland Department of Natural Resources, Mines and Energy. He is also President of the Australian based IGNSS Society and a Member of Australia's National Positioning Infrastructure Advisory Board. In 2013, the NASA Administrator appointed Matt to the U.S. Position, Navigation and Timing Advisory Board, which is a Presidential committee that advises the U.S. Government on GPS-related policy, planning and funding issues.

Matt's talk, 'Modernising Australia's Datum: Drivers and Processes for the Move to GDA2020', was a brisk and engaging tour of the basics and developments of the Global Navigation Satellite system (GNSS) as a background for the drivers for moving to GDA2020. The talk also covered interesting aspects such as augmentation services, including the recent \$225m federal funding of our National Position Infrastructure, and mass market positioning and the future of 30 cm accuracy in consumer electronics. Matt also showed his Xiaomi Mi 8, the world's first mobile phone with dual frequency support (L1 and L5) and potential for high resolution positioning, as more L5 capable satellites are put up in orbit.

We were also lucky to have **Jennifer Market**, the global acoustics advisor at Lloyd's Register and MPC Kinetic

presenting on 22 November. Jennifer's talk was on 'Diamonds in the noise – treasures lurking in acoustic data'.

Applications are now open for a mentoring program being jointly run by the Queensland ASEG and PESA Branches. The program is targeting Queensland based early career professionals in the geophysics and petroleum industries. We are seeking both mentees and mentors with applications closing 31 December 2018. The program will launch on 1 February 2019 and will run until 1 September 2019.

James Alderman  
[qldsecretary@aseg.org.au](mailto:qldsecretary@aseg.org.au)

## South Australia & Northern Territory

It has been a busy few months for the SA/NT Branch, with all of the usual ASEG events, not to mention the Australian Geoscience Council Convention being hosted in Adelaide. The SA/NT ASEG Branch proudly supported 6 students to attend the AGCC and various associated workshops (see this issue of *Preview* to read about their time at the conference).

On 24 September the ASEG SA/NT Branch co-hosted a 'Spring Fling' event at the Havelock Hotel with the Petroleum Exploration Society of Australia, the Society of Petroleum Engineers and the Young Petroleum Professionals. This was a wonderful event with great networking opportunities, with around 50 young professionals and more experienced geoscientists and engineers attending. We also took the opportunity to introduce the joint mentoring program for 2019, and to get expressions of interest from potential mentees and mentors for the program. I would love any feedback if you enjoyed this event, or if you would enjoy more collaborative events in the future.

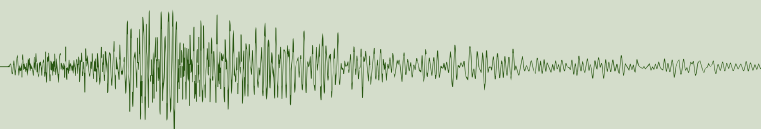
**Dr Alison Kirkby** from Geoscience Australia visited the Branch at the Coopers Alehouse on 11 October and gave a talk titled, 'Integration of seismic, magnetotelluric and magnetic data to reveal crustal structure in the Arunta region, Central Australia'. The talk was very interesting with a great turnout and some stimulating conversations.

Our next event was the 31st Annual ASEG Melbourne Cup Luncheon, very generously sponsored by Terrex Seismic. **Megan Nightingale** and **Ben Shave** from Terrex made the trip down from



Left to right: Student presenters at the NSW ASEG Branch meeting: Alice Van Tilburg, Steph Hawkins, Xueyu (Tom) Zhao and Jie Wang. Mark Lackie, the NSW Branch President, is on the far right.





Queensland for the event. This year we were impressed with the food, venue and service of The Gallery. The event provided a great chance to catch up with colleagues and share some laughs. **Dennis Conway** from the University of Adelaide kindly gave a talk, ‘Gambling, winning, and horse racing: an unlikely trifecta?’ that was insightful and very funny. Our usual MC bowed out with his own horse racing in the Melbourne Cup events, and former SA/NT ASEG President **Josh Sage** stepped in and did a wonderful job. **Rod Lovibond, Adam Davey, Maeri-Jo Davey** and **Sam Jennings** all provided invaluable assistance with making the day run so smoothly.

The next day, up in Darwin, the 2018 Haddon Forrester King Medal Seminar was given by Professor **David R Cooke**. The event was co-hosted by the Northern Territory Division of the Geological Society of Australia and the Australian Institute of Mining and Metallurgy, Professor Cooke’s talk was titled, ‘Porphyry copper, gold and molybdenum deposits – new geochemical exploration methods to aid discovery’.

Lastly, on 19 November, the ASEG co-hosted a lunch time technical event with the Geological Survey of South Australia (GSSA). Dr **Kristina Tietze** from GFZ Potsdam, Germany presented a

talk on ‘Imaging fluid imprints along active and fossil margins with 3D magnetotelluric inversions; examples from the San Andreas fault and the Gawler Craton’. The catered event was held at the GSSA’s new building. It was a great talk with good attendance and some new faces, as lunch time events tend to attract those who can’t always make the evening events.

As always, very happy to hear any feedback at [sa-ntpresident@aseg.org.au](mailto:sa-ntpresident@aseg.org.au). Hope to see you soon at an ASEG event, check the ASEG website for updates.

Until next time,

*Kate Robertson*  
[sa-ntpresident@aseg.org.au](mailto:sa-ntpresident@aseg.org.au)

### Tasmania

The Tasmanian Geoscience Forum has become the pre-eminent annual event for catching up with the latest developments and ideas underpinning Tasmania’s exploration and mining industries. The 2018 edition was held at the Tall Timbers Resort in Smithton on Thursday 6 December, with optional field trips before and after.

In the New Year the Tasmania Branch will welcome back **Richard Chopping**

to talk about the book he recently co-authored with **Brian Kennett** and **Richard Blewett**; *The Australian Continent: A Geophysical Synthesis*. This will be an event held jointly with the Tasmania Division of the Geological Society of Australia, starting with nibbles and drinks at 5.30 pm on Thursday 28 February 2019 in the Earth Sciences Building at the University of Tasmania. It will be preceded by the ASEG Tasmania Branch AGM. Further details will be included in a more formal notice of meeting distributed to local Members closer to the time.’

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](mailto:taspresident@aseg.org.au)

### ASEG national calendar: technical meetings, courses and events

Date	Branch	Event	Presenter	Time	Venue	
6	Dec	ACT	Christmas party and technical evening	Richard Chopping	1700	Scrivener Room, Geoscience Australia, Symonston, followed by dinner at Rubicon Restaurant in Griffith
11	Dec	SA–NT	Honours night and Christmas party	TBA	TBA	TBA
12	Dec	WA	AGM and Christmas Quiz	Various	TBA	Mayfair Lane, West Perth
12	Dec	NSW	Quiz night	TBA	1730	99 on York Club, 99 York Street, Sydney
	Dec	VIC	ASEG-SPE Christmas lunch	TBA	TBA	TBA
1	Feb	QLD	Launch joint ASEG PESA YPN Mentoring Program	Various	TBA	TBA
13	Feb	WA	Tech night	Richard Chopping	TBA	TBA
20	Feb	NSW	Tech Talk	Richard Chopping	1730	99 on York Club, 99 York Street, Sydney
21	Feb	VIC	Tech talk	Richard Chopping	1730	The Kelvin Club, 18–30 Melbourne Place, Melbourne
28	Feb	TAS	AGM and Tech night	Richard Chopping	1730	Earth Sciences Building, University of Tasmania, Sandy Bay, Hobart
5	Mar	QLD	Tech night	Richard Chopping	1730	XXXX Brewery, Corner Black Street and Paten Street, Milton, Brisbane
21	Mar	TAS	Tech night	Paul Winberry	TBA	Earth Sciences Building, University of Tasmania, Sandy Bay, Hobart

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

## Australasian Exploration Geoscience Conference 2019: exhibition bookings now open

Exhibition bookings are now open for the second Australasian Exploration Geoscience Conference (AEGC 2019) – the largest geoscience conference in the southern hemisphere!

AEGC 2019 is jointly hosted by the Australian Institute of Geosciences, Australian Society of Exploration Geophysicists and the Petroleum Exploration Society of Australia, and is expected to attract well over 1000 delegates involved in the exploration for energy resources, metals and industrial minerals, as well as near surface and groundwater exploration. The conference is being held at the beautiful Crown Perth, which has an array of restaurants, bars and entertainment options.

Exhibiting at AEGC 2019 is fabulous way to get in front of prospective clients, and a great opportunity to form new connections and foster existing



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*Maud Kay*  
AEGC 2019 Publicity & Marketing Chair  
[maudkay@gmail.com](mailto:maudkay@gmail.com)

## Near Surface Geoscience and Engineering conference in Kuala Lumpur in 2019

The Geological Society of Malaysia (GSM) and the European Association of Geoscientists & Engineers (EAGE) are organising the second Asia Pacific Meeting on Near Surface Geoscience & Engineering (NSGE) in Kuala Lumpur from 22–26 April 2019. This conference follows the tremendous success of the first event in Yogyakarta, Indonesia in 2018 and is supported by the Australian Society of Exploration Geophysicists, the Myanmar Geosciences Society, the Society of Exploration Geophysicists Japan, the Chinese Geophysical Society, the Korean Society of Earth and Exploration Geophysicists, the Geological Survey of Papua New Guinea, the Australian Geomechanics Society and the Indonesian Association of Geophysicists. The ASEG's very own Koya Suta is the Co-Chair of the Technical Committee.

NSGE 2019 promises to be another excellent opportunity for geoscientists from all parts of the world to consider research, technology and services in the near surface field. The conference will be

preceded by a one-day short course run by Dr Loke and Dr Toke, on 'A Practical Guide to Multi-Dimensional ERT Surveys, Interpretation and Data Integration'.

Another conference highlight will be the keynote address by Professor Kenneth H. Stokoe from the University of Texas at Austin. Professor Stokoe will be speaking on 'The Increasing Role of Field and Laboratory Seismic Measurements in Geotechnical Engineering.' Over nearly 40 years, Professor Stokoe has accumulated vast experience in the areas of *in situ* seismic measurements, laboratory measurements of dynamic material properties, and dynamic soil structure interaction. Earlier in his career he was instrumental in developing the crosshole seismic method for *in situ* shear wave velocity measurement, now adopted as the standard by the American Society for Testing and Materials (ASTM D4428M). The method is used by geotechnical engineering firms worldwide.

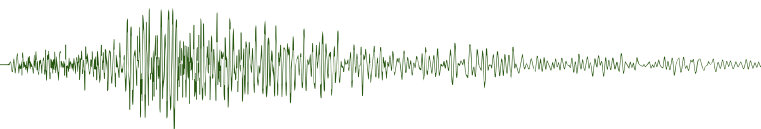
Professor M Atilla Ansal from the Ozyegin University in Istanbul, Turkey

and Professor Joy Jacqueline Pereira from Universiti Kebangsaan Malaysia will also be keynote speakers. Professor Atilla Ansal will be speaking about 'Uncertainties in Site Specific Response Analysis' and Professor Pereira will be speaking about 'Disaster Risk Reduction and Climate Action for Sustainable Development: Opportunities for Geoscience & Engineering in Limiting Warming to 1.5°C'.

The two-day NSGE conference has already proved itself to be the place for near-surface geoscientists to meet, exchange knowledge, and network with professional peers and Kuala Lumpur provides a fitting venue for delegates as a hub of entertainment, shopping, commerce, culture and most activities of import to the nation. Particular thanks go to the Platinum Sponsor, Guideline Geo, for supporting this event.

Registration will open on 2 January 2019 – go to <https://events.eage.org/en/2019/eage-gsm-nsge-2019>.





## Australian Geoscience Council Convention 2018: a review

The Australian Geoscience Council (AGC) is the umbrella body for geoscience organisations within Australia. It was formed in 1981 as a mechanism for offering critical advice to government on geoscience related matters. It provides a more authoritative voice than any one individual organisation and, in the case of the ASEG, gives Members a means to lobby for issues that lie outside of the Objects of the Society - such as the professional interests of geoscientists.

Up until about 2013 the AGC was largely re-active to issues and kept a relatively low profile, indeed most Australian geoscientists would have been unaware of its existence. However, in 2012 the AGC hosted the International Geological Congress (IGC) in Brisbane, on behalf of the International Union of Geological Sciences (IUGS). This conference attracted around 6000 delegates from around the world and made a significant surplus. The surplus was split between the AGC and the Australian Academy of Sciences (AAS), with the AAS share going towards a travel fund for young geoscientists to attend conferences or academic extensions: <http://www.agc.org.au/resources/geoscience-grants/>. This travel fund is jointly administered by the AGC and AAS. In order not to waste the AGC share of the surplus, the Council developed a strategic plan: <http://www.agc.org.au/resources/agc-strategic-plan-2015-2020/>.

The surplus had also allowed the AGC to be proactive rather than re-active, and to seek out and fund causes that were falling between, or outside of, the particular interests of the eight member organisations. One of the pillars of the strategic plan was sustainable funding of the AGC so that it could continue this work and, in so doing, make a positive difference to Australian geoscience. In 2015 a joint, member organisation, conference was proposed as a way of not only providing revenue for the AGC, but also as a means of encouraging collaboration between the member organisations. That proposal finally came to fruition with the Australian Geoscience Council Convention (AGCC), held during Earth Science week in October of 2018.

For the ASEG this posed something of a conundrum, because the ASEG relies very heavily on its conferences for its financial wellbeing. Any surplus from the AGCC was to be split 50:50 between the AGC and the eight member organisations, and each member organisation's share was to

be based on relative total membership numbers, which meant that the ASEG would only receive around 3.5% of the total surplus. This compares to the AEGC model that sees the surplus split on the basis of the affiliation of the conference delegates. That saw the ASEG retaining a little over 50% of the surplus from the AEGC 2018 in Sydney. Clearly there was a strong financial case for not bundling the AEGC with the AGCC. However, ASEG is also a strong supporter of the AGC and has historically punched well above its 7% membership numbers in weight. For several decades the ASEG has provided at least one of the three member executive of the AGC, and at one point two of the three were ASEG Members.

The AEGC conference has a strong focus on exploration technology, which as the ASEG is a society of exploration geophysicists is fundamentally important. However, not all ASEG Members are explorers, and the AGCC platform was seen as a way of providing a stage and forum for educators, academics, government, solid earth and planetary geophysicists, as well as those who have moved beyond a technical role to a more strategic position.

As AGCC 2018 was to be the first of its kind, the organising committee set some high goals in order to make the convention stand out as something different to any of the conferences run by the member organisations. It was designed to be a large event, with 10 concurrent streams and, in keeping with its constituency, it aimed to address the big issues facing geoscientists in Australia. In order to do this a day was set aside with the normal technical programme suspended and replaced by a four consecutive plenary sessions. Each session covered one topic and was led by a convener, each of whom assembled a panel of experts in their particular topic. Audience participation was achieved through Yes/No (Green/Red) auction style voting cards, and the web based Slido tool that allowed members of the audience to pose questions and have them up or down voted by the whole audience. The questions were displayed live on the projection screens, and then put to the panellists by the session convener. This ensured that the whole audience was engaged, rather than having a handful of the usual suspects dominating discussion. External media coverage of the event helped to build geoscience as a brand amongst the wider Australian population.

Nearly 1100 delegates attended the convention and, although the exhibition was less than half the size of those we see at the AEGC, it was very well laid out so never felt empty. The central 'GeoHub' formed a focal point for discussion and networking, and was always well patronised.

The organising committee placed a strong focus on engaging with students and early career geoscientists (ECG) with discounted registration, and even free registration for those prepared to volunteer their time on a one for one basis. In addition, CSIRO sponsored a rapid fire session where students and ECGs had 3 minutes to present their research. This was well supported by both presenters and delegates, and the general standard of presentations was high.

With \$10 000 dollars of sponsorship from Nexus and the AGC, the AGCC was also able to facilitate a creche within the conference centre, charging users around half the normal commercial hourly rate. The facility was run by an external provider at arm's length from the AGCC in order to isolate liability.

The finances have not yet been closed out, but early indications are that conference will not top up the AGC coffers to the extent initially hoped for. This is disappointing, but as a first effort some risks needed to be taken. However, the atmosphere at the event was ebullient and feedback from attendees has so far been positive. A survey of delegates has been created and will hopefully go on line prior to this review being published. This survey will be used to inform decisions about the future of the AGCC. If you would like to be involved in a future event the AGC would love to hear from you.

*Kim Frankcombe*  
ASEG AGC Representative  
[kfrankcombe@iinet.net.au](mailto:kfrankcombe@iinet.net.au)



*Adam Lewis, Ron Hackney and Marina Costelloe representing Geoscience Australia at the AGCC 2018.*

## Australian Geoscience Council Convention 2018: Student reports on participation

The SA/NT Branch of the ASEG sponsored six students to attend the Australian Geoscience Council Convention (AGCC). All of these students are returning the favour by reporting on the conference to ASEG Members via *Preview*.

**Great experience** *Bo Yang, PhD candidate, University of Adelaide*

The AGCC is the biggest conference that I have attended in Australia. I liked the atmosphere in there, full of heat and vitality, but in a casual way, which made people feel very comfortable. This conference was creatively planned to incorporate all attendees, stimulating people into delving deeper and wider. It also provided a lot of opportunities for early career geoscientists, encouraging them to learn from the great minds, and also network with their peers. The coffee breaks were also thoughtfully organised, giving people enough time to refresh their minds. Personally, my favourite part was the poster session. It was a time when people become relaxed, held a beer and snacks in their hand, talked to the presenters and enjoyed the posters. The poster session gave us a lot of time for communication and I had some great conversations with those presenters and learned a lot from them.

I was quite lucky to get a chance to present my PhD work. This work focuses on the sedimentary formations in the upper Beetaloo Sub-basin, North

Territory. I presented the new whole-rock shale geochemistry data and our new understanding of the tectonic geography of the Mesoproterozoic North Australia Craton. This presentation got a lot of feedback from experts from the geological surveys and Geoscience Australia. Their comments were constructive and thought provoking, and will improve the quality of my work.

Attending the AGCC was a great experience and I gained so much. Many thanks for the sponsorship that was kindly offered by the ASEG.

**Fantastic opportunity** *Sheree Armistead, PhD candidate, University of Adelaide*

The AGCC in Adelaide was a fantastic opportunity to meet up with geoscientists from all over Australia and around the world to discuss big issues and ideas in geoscience.

My AGCC kicked off with the Women in Earth and Environmental Science Australasia (WOMEESA) workshop where I was invited as a panellist to discuss some of the challenges and solutions for gender equity in geoscience. WOMEESA is a relatively new network that aims to connect women working in Earth and Environmental Sciences from academia, government and industry. It was great to have the workshop before the conference, as we got to meet a great group of women that we could then reconnect with during the conference.

Check out [www.womeesa.net](http://www.womeesa.net) for more information and to join!

Later in the week I gave a talk on my PhD research as part of the Proterozoic Tectonics session where I discussed the evolution of northern Madagascar during the Neoproterozoic. This was a great opportunity to share my research with other scientists in my field and get some feedback on my work.

Overall the conference was a great way to catch up with colleagues and to meet new ones. Conferences are incredibly important for early career researchers to broaden their scientific knowledge, network with other scientists, and share their research with the geoscience community. The financial support that ASEG provided allowed me to participate in this fantastic event, and their support to students is very much appreciated.

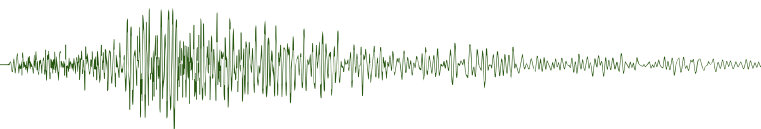
**Thank you ASEG** *Drew Lubiniecki, PhD candidate, University of Adelaide*

I would like to express my gratitude to the ASEG for their support and scholarship to attend AGCC 2018 in Adelaide. The experience was fantastic! I presented my research during the Monday technical session and received good feedback, giving me a new perspectives on fault geometry. The event was also great for networking, allowing me to make many new connections with other geoscientists from all over Australia. Hoping to get as much out of the event as



The WOMEESA pre-conference workshop from the WOMEESA twitter account (@WOMEESA).





possible, I attended a pre-conference short course on 3D Modelling and Machine Learning because I wanted to see if I could apply the technology to my own research. Now I have a better idea regarding the functionality and potential of these technologies, and I am confident that I can use them.

My research focuses on the structural evolution of faults in sedimentary sequences and their effects on subsurface fluid flow, using deformation bands and fractures to understand the evolution of palaeo-stress and the mechanisms of structural permeability. To better understand the structural evolution of the Mt. Lofty Ranges and Flinders Ranges, I developed a workflow to temporally reconstruct regional palaeo-stress, using fundamental stratigraphic and structural concepts. My models provide new constraints on the tectonic history of the region. I am also working on a similar project in the Athabasca Basin with the Cameco Inc. and the Saskatchewan Geological Survey. The Saskatchewan Government wrote a small article about me and my early geological career with the Saskatchewan Geological Survey that featured on the front page of the Saskatchewan Government webpage <http://www.saskatchewan.ca/government/our-stories/he-rocks-around-the-world>.

**Thanks ASEG** *Matthew Musolino, PhD candidate, University of Adelaide*

Thanks to the ASEG I was able to attend the AGCC conference this year. The conference was packed full of presentations and workshops that brought together knowledge from industry, academia and government. I was initially interested in the conference because I wanted to attend talks on themes regarding resources and applied geoscience. However, I found great value in the large group sessions as well. Those sessions focused on industry and sustainability. The panel and Q&A gave me a great insight into the job market as well as information on sought-after skills in the industry, such as data analytics. The discussions surrounding sustainability helped me to conceptualise how our industry must communicate and evolve with a changing social climate.

My PhD project concerns *in situ* stress estimates and their implications for geomechanical predictions. I'm focusing on quantifying the uncertainty of principal stress estimations. To do this I'm reviewing and analysing the current estimation methodology using large

petroleum datasets. In my first year I completed research that identified subtle nuances when calculating vertical stress that highlighted vectors of uncertainty into estimates. I expanded upon this by making recommendations to increase stress estimation accuracy. My new challenge is minimum horizontal stress estimation. The conference talks on mathematics, modelling AI, and machine learning were invaluable to my understanding of what can be done currently and what is possible. I'm planning on incorporating some of the techniques discussed there into my work, particularly interpolation methods and machine learning.

I'd like to thank ASEG for their continued support of students and giving me the opportunity to attend such an enlightening national event.

**ASEG support appreciated** *Brandon Alessio, PhD candidate, University of Adelaide*

As a PhD candidate at the University of Adelaide I am researching the tectonic evolution of the Southern Irumide Belt, located in Zambia, Malawi, Mozambique and Tanzania. This belt resides along the southern margin of the Congo Craton that comprises present-day central Africa, and its evolution provides a record spanning over a billion years that can be used to constrain the tectonic development of the region. Understanding the development of key orogens such as the Southern Irumide Belt is a fundamental step in refining global palaeogeographic reconstructions, which can in-turn be used to understand the interplay between the evolving continents and greater earth system, including the development of natural resources, the climate, and life.

I was awarded an ASEG sponsorship to attend the AGCC in Adelaide. I presented part of my PhD research that investigated the development of, and relationship between, different tectono-metamorphic overprints in southern Zambia. This conference was a valuable opportunity to keep informed with a wide range of Australian geoscience research, and I was lucky to attend several engaging talks that served to instil the importance of geoscience in our society. Unique amongst the many other conferences I have attended, the AGCC provided me with the opportunity to not only network with academic geoscientists, but also industry and government based geoscientists.

Attending this conference was highly beneficial to my professional development, both in terms of expanding my professional network and staying informed of the latest geoscience research. Sponsorships such as this are vitally important for enabling early career researchers to attend these events, and the support of ASEG in this regard is greatly appreciated.

**New connections** *Venkata Pavan Katuru, PhD candidate, University of Adelaide*

The AGCC was the first major scientific conference I have attended since the commencement of my PhD. The conference has provided me with background about the Australian continent and the latest research trends on various geological units with perspectives from several sub-topics in geological research. I have attended several talks by various faculty and students from across the country and beyond about supercontinent cycles, Proterozoic tectonics, basin formation and architecture, Archean earth, geochronology and geochemistry of various tectonic regimes on the globe. The presentations were highly informative and provided insights from a global perspective and introduced me to the various projects that are currently being undertaken by research groups that have attended the conference.

The evening sessions provided me with ample opportunity to interact and network with several faculty and fellow PhD students and get to know about their field of expertise and their current projects. I have made new connections and forged friendships with fellow geologists working in similar projects.

I presented a poster on the Kaladgi-Badami basin in South India, which we have interpreted as the Paleoproterozoic reworking of the margins of the Archean Dharwar craton based on detrital zircon data from various sedimentary units on the basin. The basin consists of deformed Kaladgi sedimentary groups unconformably overlain by undeformed Badami sandstone. All the sub-groups in the Kaladgi formation have major contribution from the Closepet granite body, a major granite body in the Dharwar craton, dated at 2.55 Ga, which is also their maximum depositional age. The sandstone has its youngest detrital zircon population of 1.8 Ga signifying that the deformation of the Kaladgi group took place within the interval of 2.55–1.8 Ga interpreted as the reworking of the

Archean margins during the Paleoproterozoic era.

**Exciting opportunity** *Priya Priya, Honours student, University of Adelaide*

I was really excited to receive the opportunity to attend the AGCC conference, particularly, the field trip to Naracoorte Caves National Park, which involved visiting multiple cave sites in the region, some of which were beyond public access.

My honours project was to reconstruct past environments from a sedimentary sequence in Alexandra Cave, Naracoorte. I explored palaeo-environmental

indicators like pollen, charcoal and geochemistry of the sediment, together with optically stimulated luminescence dating of the sedimentary sequence. While I spent a lot of time studying the sediment in the cave, I did not know much about the overlying geology of the region.

The biggest takeaway for me were discussions with the field trip organiser, Ian Lewis. Ian has been studying the geology and palaeo-hydrology of the caves for the past decade, and was responsible for mapping the caves in the region, including my study site. This trip broadened my understanding of the cave

system, and gave me an appreciation for the geology that played a critical role in the formation of the caves.

Overall, this trip was really fun. I have driven down to Naracoorte several times this year, but this trip was by far the most entertaining one. I met many interesting geologists, from all around the world, and our conversations ranged from controversial scientific theories to aboriginal astronomy. Turns out, conference field trips are the best way to network!

I would like to thank the ASEG for this opportunity.

## AuScope workshop: Seeking community input to re-thinking approach to national geoscience challenges

Following a week of 'big ideas' at the AGCC in Adelaide in October, the national research infrastructure provider AuScope gathered 100 researchers from across the country to discuss, over two days, what tools, data and analytics Australia will need to solve national geoscience challenges of the coming decade.

AuScope continues to seek community input in the lead up to submission of an investment plan to its funder, the Australian Government, in mid-2019. Please visit [auscope.org.au](http://auscope.org.au) for more information on AuScope's approach, timeline, and how you can become involved in the discussion.

With the Australian Academy of Science's recent *2018 Decadal Plan for Geoscience* in mind, researchers from geoscience, environmental, climate,

atmospheric and data science communities started the workshop by 'thinking big' about national challenges like natural resources security and sustainability, geohazards, and working with and preserving big research data.

Individuals then had the opportunity to zoom into specific community needs across different areas of geoscience and, finally, to prioritise areas of focus across these communities. AuScope CEO, Dr Tim Rawling, was overwhelmed with the community response to this workshop:

*'The workshop was a great success for us as we were able to discuss research opportunities with a number of groups that have not been involved with AuScope in the past, as well as think about large scale infrastructure needs that will build on our existing projects.'*

He acknowledged that the discussion had only just begun and urged the next wave of researchers to join the conversation:

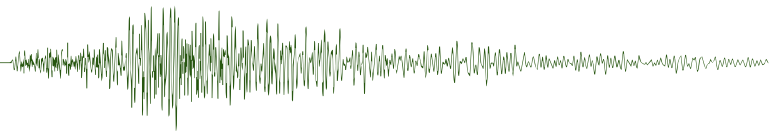
*'...we really encourage anyone who has an idea about the types of equipment, monitoring, tools and data that will be required for the geoscience researchers of the 2020s to please help design the next AuScope.'*

AuScope is currently synthesising ideas collected during the workshop and will establish working groups on focus areas between December 2018 and January 2019. If you are interested in receiving updates about its investment plan between now and mid-2019, please register your details here: <http://eepurl.com/dGjeBn>.



Researchers from Australia's earth and environmental science communities pause in Adelaide's Botanical Gardens between think tank sessions of AuScope's Strategy Workshop in October. Image: © AuScope 2018.





## First Asia Pacific workshop on fibre-optic sensing a success

Fibre optic sensing involves using fibre optic cables, which can be specially manufactured or standard telecom-style cables, to measure a wide variety of conditions, ranging from the presence of chemicals to electric fields. The resource industry is particularly interested in measuring strain (Distributed Acoustic Sensing) and temperature (Distributed Temperature Sensing) as these quantities can be measured across the full length of the fibre simultaneously. To discuss recent advances in the field the First Asia Pacific Workshop on Fibre Optic Sensing was co-hosted in Perth by Curtin University and CSIRO 13–15 November 2018.

The workshop began with a masterclass on fibre-optic sensing by Dr Arthur Hartog, who first demonstrated distributed optical fibre sensing in 1982. It continued with 25 presentations covering a wide variety of topics including the acquisition of surface and downhole seismic data; the monitoring of bridges, rock bolts and conveyor belts; and even temperature monitoring of bushfires and wheat crops.

On the final day the workshop moved from the lecture theatre to the National Geosequestration Laboratory facility located on the Curtin University campus. The facility incorporates a 900 m well



*Associate Professor Brett Harris explains the construction of the test well to workshop participants.*

equipped with permanently installed fibre-optic cables that allowed a variety of sensing systems to be demonstrated, including several vertical seismic profiles acquired over the full length of the well using a single sweep from a 26 000 lb peak force Univibe seismic vibrator.

The workshop was highly successful with over 60 people attending each of the

days. Many participants had been unaware of the variety of applications of fibre-optic sensing and we trust that the workshop will foster further interest in the field in the future.

*Tim Dean*  
Department of Exploration Geophysics  
Curtin University  
[tim.dean@curtin.edu.au](mailto:tim.dean@curtin.edu.au)



# AEGC2019

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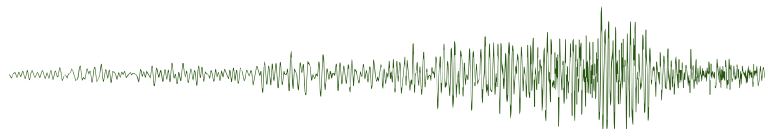
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## Update on geophysical survey progress from Geoscience Australia and the Geological Surveys of Western Australia, South Australia, Northern Territory, Queensland, New South Wales, Victoria and Tasmania (information current on 1 November 2018)

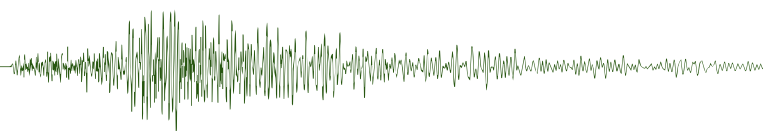
Further information on these surveys is available from Dr Yvette Poudjom Djomani at GA via email at [Yvette.PoudjomDjomani@ga.gov.au](mailto:Yvette.PoudjomDjomani@ga.gov.au) or telephone on (02) 6249 9224.

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km <sup>2</sup> )	End flying	Final data to GA	Locality diagram (Preview)	GADDS release
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	The National Collaborative Framework Agreement between GA and MRT is being updated
Tallaringa N (1A)	GSSA	GA	Thomson Aviation	26 Oct 2017	97 922	200 m 60 m E-W	17 320	26 Mar 2018	TBA	190: Oct 2017 p. 26	TBA
Tallaringa S (1B)	GSSA	GA	Thomson Aviation	26 Sep 2017	145 367	200 m 60 m E-W	26 010	12 May 2018	TBA	190: Oct 2017 p. 26	TBA
Coober Pedy (8A)	GSSA	GA	Thomson Aviation	18 Sep 2017	90 425	200 m 60 m N-S	16 140	21 Dec 2017	TBA	190: Oct 2017 p. 26	TBA
Billa Kalina (8B)	GSSA	GA	MAGSPEC Airborne Surveys	10 Oct 2017	90 353	200 m 60 m N-S	16 140	18 Dec 2017	27 Jul 2018	190: Oct 2017 p. 26	TBA
Childara (9A)	GSSA	GA	MAGSPEC Airborne Surveys	5 Nov 2017	134 801	200 m 60 m N-S	23 910	2 May 2018	30 Nov 2018	190: Oct 2017 p. 26	TBA
Lake Eyre (10)	GSSA	GA	MAGSPEC Airborne Surveys	2 Oct 2017	91 938	200 m 60 m E-W	16 180	22 Mar 2018	TBA	190: Oct 2017 p. 26	TBA
Streaky Bay (5)	GSSA	GA	GPX Airborne Surveys	21 Jun 2018	90 630	200 m 60 m E-W	15 966	28 Sep 2018	TBA	194: Jun 2018 p. 19	TBA
Gairdner (6A)	GSSA	GA	GPX Airborne Surveys	31 Jul 2018	105 075	200 m 60 m N-S	18 307	TBA	TBA	194: Jun 2018 p. 19	60% complete at 18 Nov 2018
Spencer (7)	GSSA	GA	MAGSPEC Airborne Surveys	11 Jun 2018	50 280	200 m 60 m E-W	8716	6 Aug 2018	TBA	194: Jun 2018 p. 19	TBA
Kingoonya (9B)	GSSA	GA	MAGSPEC Airborne Surveys	5 Aug 2018	150 565	200 m 60 m N-S	26 651	TBA	TBA	194: Jun 2018 p. 19	42.7% complete at 30 Sep 2018
Tanami	NTGS	GA	Thomson Aviation	14 Jul 2018	275 216	100/200 m 60 m N-S/E-W	48 267	TBA	TBA	195: Aug 2018 p. 16	E-W 100% complete at 21 Oct 2018; N-S 93% complete at 22 Nov 2018

TBA, to be advised.





## News

Table 2. Gravity surveys

Survey name	Client	Project management	Contractor	Start survey	No. of stations	Station spacing (km)	Area (km <sup>2</sup> )	End survey	Final data to GA	Locality diagram (Preview)	GADDS release
Kidson Sub-basin	GSWA	GA	CGG Aviation (Australia)	14 Jul 2017	72 933	2500 m line spacing	155 000	3 May 2018	TBA	The survey area covers the Anketell, Joanna Spring, Dummer, Paterson Range, Sahara, Percival, Helena, Rudall, Tabletop, Ural, Wilson, Runtan, Morris and Ryan 1:250 k standard map sheet areas	TBA
Lawn Hill	GSQ	GA	Atlas Geophysics	21 May 2018	7240	1000 m line spacing	8024	8 Jul 2018	9 Aug 2018	194: Jun 2018 p. 19	13 Sep 2018
Little Sandy Desert W and E Blocks	GSWA	GA	Sander Geophysics	W Block: 27 Apr 2018 E Block: 18 Jul 2018	52 090	2500 m line spacing	129 400	W Block: 3 Jun 2018 E Block: 2 Sep 2018	TBA	195: Aug 2018 p. 17	TBA
Kimberley Basin	GSWA	GA	Sander Geophysics	4 Jun 2018	61 960	2500 m line spacing	153 400	15 Jul 2018	TBA	195: Aug 2018 p. 17	TBA
Warburton-Great Victoria Desert	GSWA	GA	Sander Geophysics	Warb: 14 Jul 2018 GVD: 27 Jul 2018	62 500	2500 m line spacing	153 300	Warb: 31 Jul 2018 GVD: 3 Oct 2018	TBA	195: Aug 2018 p. 17	TBA

TBA, to be advised.

Table 3. AEM surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km <sup>2</sup> )	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	31 Jul 2018	2 Oct 2018	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

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	289 stations deployed in 2017–18	50 km	Long period MT	The survey covers the area between Tennant Creek and Mount Isa. The 2018 field season commenced in May 2018.
AusLAMP NSW	NSW	AusLAMP NSW	126 stations deployed in 2018 to date	50 km	Long period MT	Covering the state of NSW with long period MT stations at approximately 50 km spacing.
Olympic Domain	SA	Olympic Domain	320 total	Varied 1.5 to 10 km	AMT and BBMT	The survey area extends west of Lake Torrens and covers mineral prospects such as Carrapateena, Fremantle Doctor, Red Lake, Punt Hill, Emmie Bluff and Mount Gunson. The survey was completed to Jul 2018.

Table 5. Seismic reflection surveys

Location	State	Survey name	Line km	Geophone interval	VP/SP interval	Record length	Technique	Comments
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 completed data acquisition south of Eden in NSW on 29 Apr 2018.
Kidson	WA	Kidson Sub-basin	Approx. 900	TBA	TBA	TBA	2D – Deep crustal seismic reflection	Within the Kidson Sub-basin of the Canning Basin extending across the Paterson Orogen and onto the eastern margin of the Pilbara Craton. The survey completed acquisition on 8 Aug 2018.

## New regional airborne electromagnetic survey in northern Australia

As part of the Exploring for the Future programme, Geoscience Australia (GA) will be conducting a regional airborne electromagnetic (AEM) survey from the Hamersley Ranges WA to the Lake Mackay region in NT (approximately 1 150 000 km<sup>2</sup>), expected to start in February 2019. The survey will consist of 20 km spaced lines over parts of the Broome, Halls Creek, Newcastle Waters, Hamersley Range, Oakover River, Lake Mackay, Alice Springs, Wiluna, Petermann Ranges and Onadatta 1:1 000 000 standard map sheets, as shown in Figure 1. The data collected will contribute to mapping regional features of the regolith, geology and hydrogeology and understanding the mineral and groundwater resource potential of the survey areas.

GA is inviting interested companies to subscribe to the survey. This opportunity will enable participants to obtain competitive pricing, as GA will cover mobilisation and stand-by costs, and ‘fit for purpose’ data that have been subject to GA’s stringent quality assurance and quality control procedures. Due to the size of the survey, the data are expected to be available approximately 6–12 months after completion of data acquisition. Participation is subject to the following conditions:

- The proposed boundary for the infill area must be a simple polygonal shape.
- Each infill area must be no less than 200 line km in total
- There will be no supply of any data to subscribers prior to the public release of the regional (non-infill) line data.

- There will be a one year moratorium period during which infill data will only be available to the relevant subscriber company and GA, after which it will be publically released. The one year moratorium will begin from the date of supply of the infill data.
- GA will release a Quotation Request to its panel of AEM providers. After GA selects the preferred system and supplier and a firm line kilometre rate is known, participants will be given the opportunity to either opt-in or opt-out. Participants who opt-in will be required to sign an agreement guaranteeing funding for their infill survey, before

GA enters into a contract with the preferred supplier.

Expressions of Interest must be submitted by COB AEDT Tuesday 11 December 2018. For more information about the survey or about submitting an EOI please contact [MineralGeophysics@ga.gov.au](mailto:MineralGeophysics@ga.gov.au) or Yusen Ley-Cooper: [yusen.leycooper@ga.gov.au](mailto:yusen.leycooper@ga.gov.au) or +61 2 6249 9374.

GA is also seeking assistance with borehole geophysical induction conductivity logging from tenement holders in the survey area. Again, for more information please contact [MineralGeophysics@ga.gov.au](mailto:MineralGeophysics@ga.gov.au).

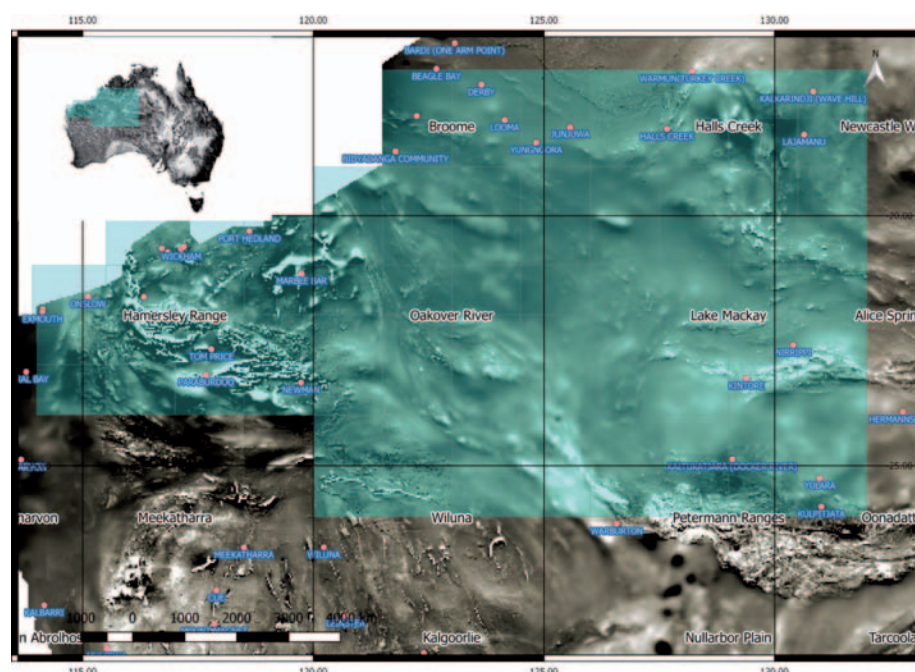


Figure 1. Locality map showing the proposed regional survey area (green shading) to be covered at 20 km line spacing.



## Geological Survey of New South Wales: largest AEM survey ever planned for NSW

The Geological Survey of NSW (GSNSW) and Geoscience Australia (GA) are preparing to fly the largest airborne electromagnetic (AEM) survey in NSW (by area) ever!

It is expected that the survey will be flown between April and June next year with final data delivered by December 2019. The survey will be in central-western NSW over the Cobar region, see Figure 1.

GSNSW is undertaking this survey as part of a data collection project focussed on five areas in the state's central and far west to better understand geology in under cover areas and support exploration for major metallic mineral deposits deep beneath the earth's surface (up to 500 m).

GSNSW will undertake geological mapping, geophysical and geochemical data acquisition and drilling programs in these areas from 2019 to 2028. Drilling is planned from 2022 to 2026.

For more information visit: <https://www.resourcesandgeoscience.nsw.gov.au/miners-and-explorers/applications-and-approvals/mining-and-exploration-in-nsw/new-mineral-allocation-areas>.

The survey will be flown east-west at 2.5 km line spacing over MinEx project areas and 5 km line spacing in between. The path of the flight lines will be designed to go over water monitoring boreholes, mineral drill holes, and follow sections of existing seismic data to help correlate the results and aid interpretation.

Expressions of interest for infill flying are currently being sought to assist with survey planning. The cost of an infill area is to be funded by the interested party and will be calculated on an infill line kilometre cost. The minimum infill area size will be 5 km by 5 km. Lines must be oriented east-west. The infill line kilometre cost will be based on the successful tender. Interested parties will be informed of the cost and given the opportunity to proceed. These parties will benefit from a lower line kilometre price due to the large size of the survey. In addition, GSNSW will handle community consultation and GA will handle contracting, data QA/QC, delivery and specialist processing. There will also be a one year confidentiality period from the public release of the Government data for the infill lines.

Expressions of Interest for infill flying close on 24 December 2018. A request for quote will be posted on AusTender by GA in February 2019. An AEM contractor will be selected and engaged by Geoscience Australia in collaboration with GSNSW.

For more information about the survey or the EOI process please contact [geophysics.products@geoscience.nsw.gov.au](mailto:geophysics.products@geoscience.nsw.gov.au).

Astrid Carlton  
Geological Survey of New South Wales  
[astrid.carlton@planning.nsw.gov.au](mailto:astrid.carlton@planning.nsw.gov.au)

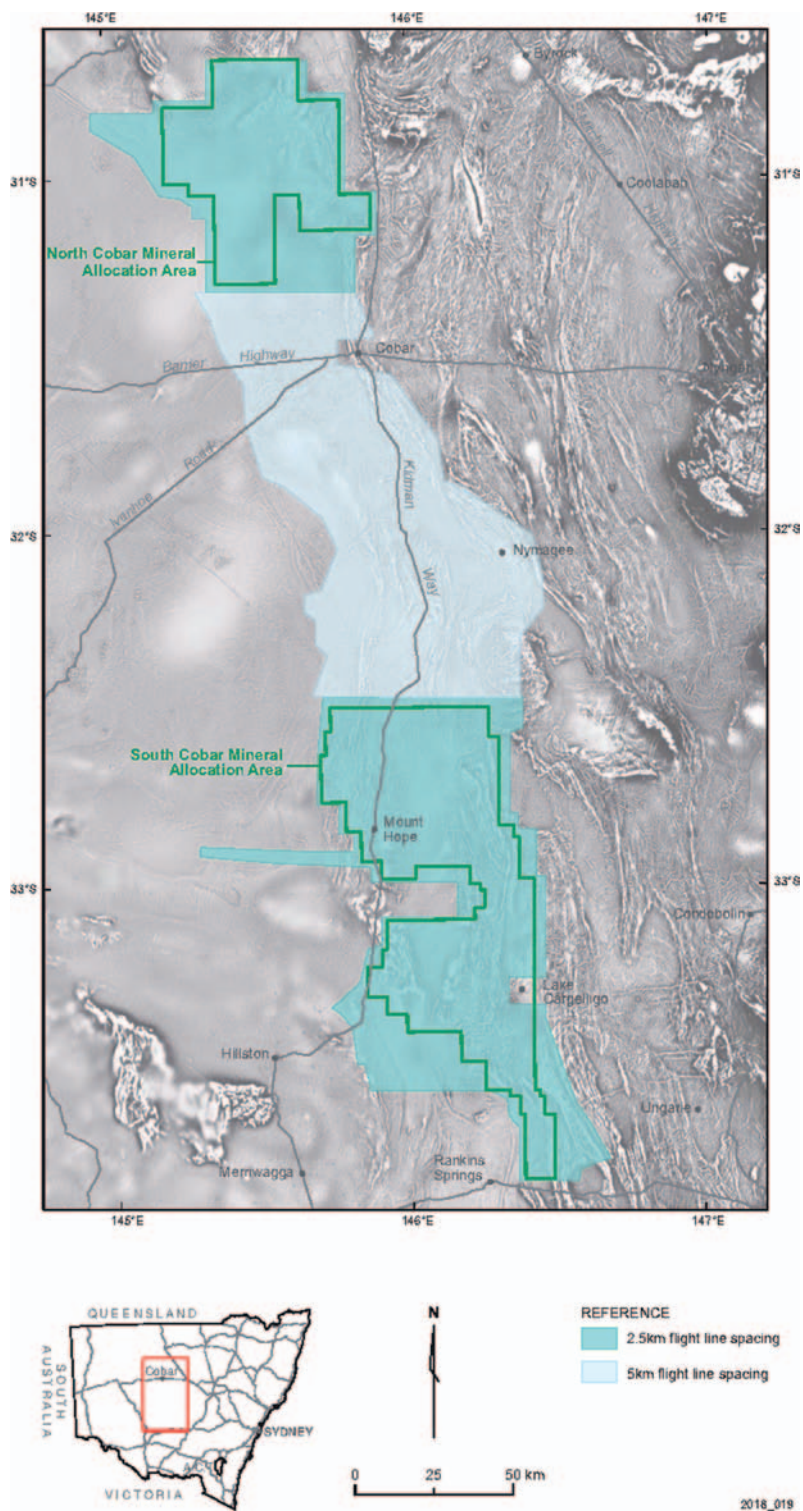
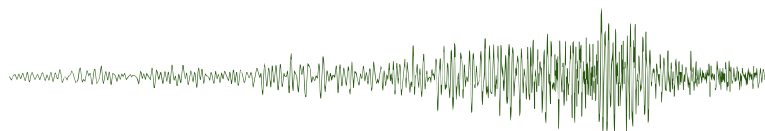


Figure 1. Area of proposed AEM survey.





## Geological Survey of Western Australia: acquisition of 2018 aerogravity surveys complete

Acquisition is complete on the three 2018 airborne gravity surveys in Stage 9 of the Geological Survey of Western Australia's (GSWA) 'Generation-2' regional gravity program being undertaken in collaboration with Geoscience Australia (Figure 1, Table 1).

The surveys, contracted to Sander Geophysics, which deployed its AIRGrav system in two aircraft, were flown over a period of five months to cover an aggregate area of some 450 000 km<sup>2</sup> with 177 000 line km of traverses at a line spacing of 2.5 km. The surveys were flown without tie-lines and data were levelled to the existing ground data from the Australian National Gravity Database.

An image of the Bouguer anomaly grid from the Little Sandy Desert West block is shown in Figure 2.

Figure 3 shows the unadjusted, unlevelled airborne field data profiles (5000 m full-wavelength filter) from both aircraft along a line of ground data points at 2.5 km station spacing.

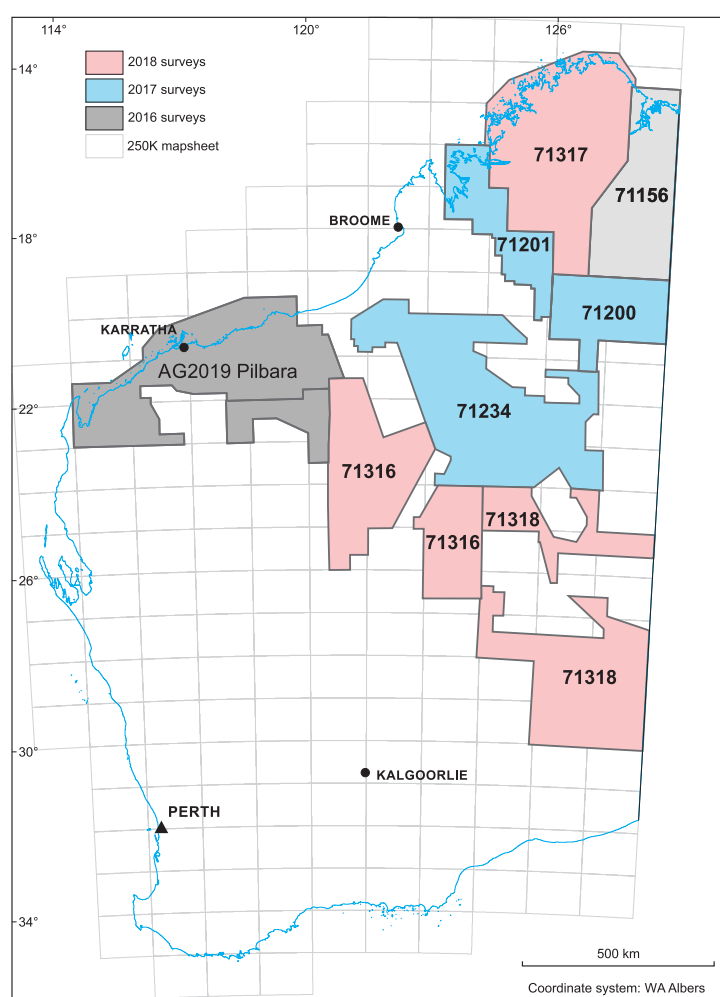
Data are being released in stages for public access via the national Geophysical Archive Data Delivery System ([www.ga.gov.au/gadds](http://www.ga.gov.au/gadds)), and the GSWA airborne geophysics database, which is accessible through the GeoVIEW.WA online mapping application ([www.dmp.wa.gov.au/](http://www.dmp.wa.gov.au/)

[geoview](http://www.dmp.wa.gov.au/geoview)) on the Department of Mines, Industry Regulation and Safety (DMIRS) website ([www.dmirs.wa.gov.au](http://www.dmirs.wa.gov.au)). All releases should be complete before the end of January 2019.

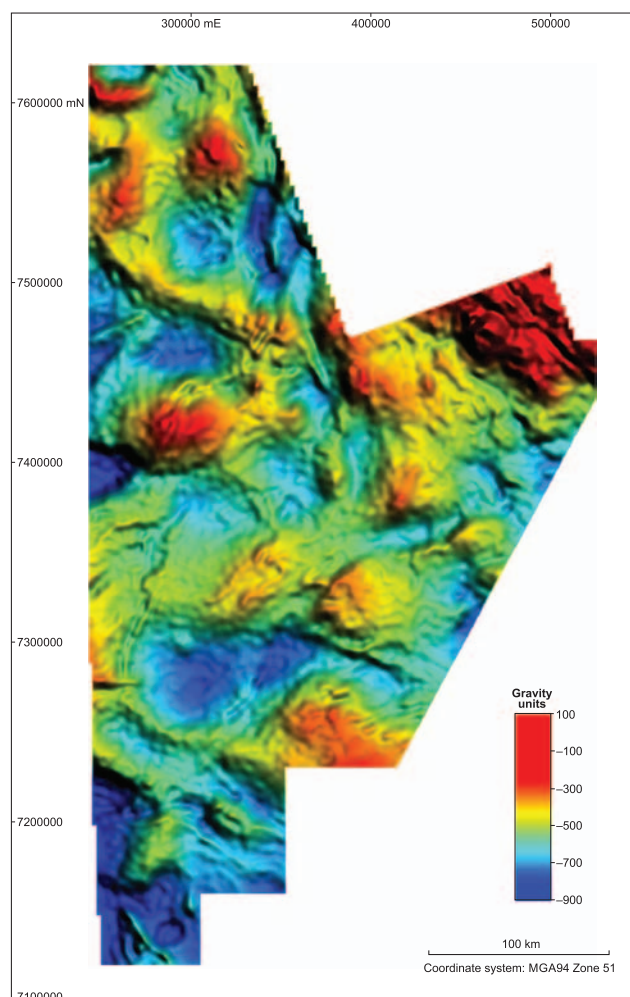
Subscribe to the GSWA mailing list for notification of data release dates ([www.dmp.wa.gov.au/gswaenewsletter](http://www.dmp.wa.gov.au/gswaenewsletter)).

A new survey in the Pilbara area, the 10th and final stage of the 'Generation-2' regional gravity program, is still under consideration.

For more information, contact David Howard ([geophysics@dmirs.wa.gov.au](mailto:geophysics@dmirs.wa.gov.au)).



**Figure 1.** Location of GSWA aerogravity surveys (labels indicate survey registration numbers).



**Figure 2.** Bouguer anomaly image Little Sandy Desert west block.

Table 1. GSWA airborne gravity surveys 2018

Registration number	Survey name	Line km
71316	Little Sandy Desert 2018	52 000
71317	Kimberley Basin 2018	61 000
71318	Warburton – Great Victoria Desert 2018	62 000

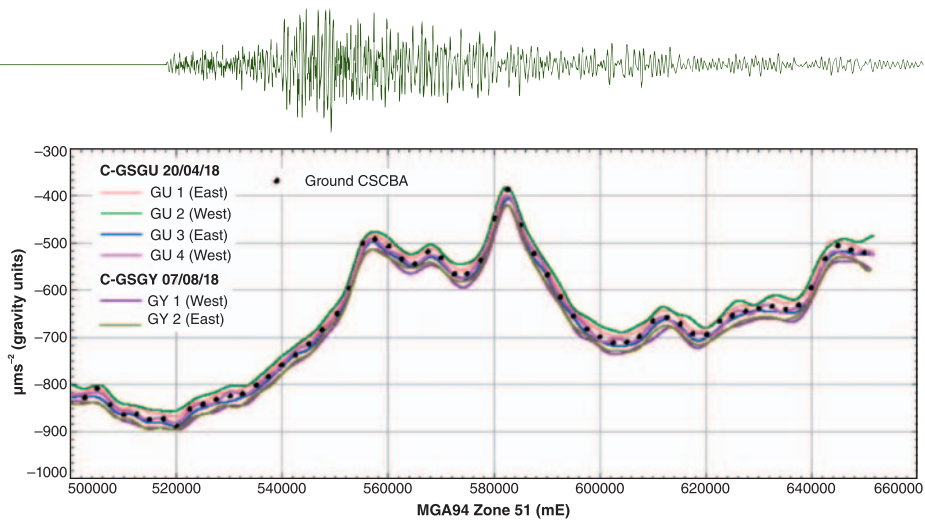


Figure 3. AIRGrav – ground data comparison, showing complete spherical cap Bouguer anomaly profiles, Line MGA51-7053N.

Geological Survey of South Australia: event news

South Australian Gawler Craton Airborne Survey workshop

On 4 December 2018 the Geological Survey of South Australia held a workshop to demonstrate the utility of the new Gawler Craton Airborne Survey (GCAS) datasets and value added products. It brought together the principal project participants, industry and other agencies who have an interest in the project and products to discuss methodologies, interpret the results, and deliver a roadmap for the remainder of the GCAS acquisition and data releases.

The complete package of project management, QC framework and enhanced deliverables have value to other jurisdictions as it sets new standards in magnetic/radiometric/elevation data capture and delivery. If you missed the workshop you can find the presentations on the GSSA minerals website.

At the time of writing, the Gawler Craton Airborne Survey is 92% complete. For more information please contact Laz Katona ([laz.katona@sa.gov.au](mailto:laz.katona@sa.gov.au)).

National magnetotelluric workshop and AusLAMP SA release day

On 5 December 2018, the Geological Survey of South Australia in conjunction with Geoscience Australia, hosted the ‘National magnetotelluric workshop and AusLAMP SA release day’. The day included sessions covering talks on

electromagnetic, seismological and geochemical aspects of Lithospheric Architecture, AusLAMP across Australia, crustal MT surveys for mineral systems targeting, and the interpretation, integration and future outlook of MT in Australia.

We are excited to announce that the South Australian component of AusLAMP (long period magnetotelluric data in a 55 km spaced grid across Australia) are now available for download from SARIG. Along with the AusLAMP data, the 176 sites of 5 km spaced broadband MT data of the Eucla-Gawler profile (following the railway from Haig, WA to Tarcoola, SA) are also available to download. In an effort to provide data to the geoscience community as soon as possible, we have also made available the Olympic Domain broadband MT and AMT data (328 sites in a grid with site spacing 1.5–5 km, covering Carapateena and other prospects in a ~100 km<sup>2</sup> area). Please note that final QA/QC of these data has not yet been undertaken, and the data are presented as collected by Zonge. For more information regarding any of these three new datasets or any SA MT data, please contact Stephan Thiel ([Stephan.Thiel@sa.gov.au](mailto:Stephan.Thiel@sa.gov.au)) or Kate Robertson ([Kate.Robertson2@sa.gov.au](mailto:Kate.Robertson2@sa.gov.au)).

Discovery Day 2018

Discovery day followed MT day on 6 December. The day was themed ‘Discover: New Data, New Technology,

New Insights’. The latest innovative work of the GSSA staff and key collaborators was showcased and new insights and opportunities for mineral exploration and discovery in South Australia were delivered. Talks will be available on the GSSA website at [www.energymining.sa.gov.au/gssa\\_dd](http://www.energymining.sa.gov.au/gssa_dd).

The SA Exploration and Mining Conference 2018

The SA Exploration and Mining Conference (SAEMC) is an annual event held in Adelaide and organised by the ASEG, AIG, GSA and AusIMM. It is also proudly supported by the SA Government. This year 17 speakers from the exploration and mining industry presented overviews of their various projects from around South Australia. Alex Blood, the Executive Director of the Mineral Resources Division presented a review of South Australia’s energy and mining from a government perspective, and the annual panel discussion tackled the issue of Land Access, and looked at future directions for the industry.

An archive of all presentations (dating back to 2004) can be downloaded via the conference website (<http://www.saexplorers.com.au>).

Kate Robertson and Phil Heath  
Geological Survey of South Australia,  
Department for Energy and Mining  
[Kate.Robertson2@sa.gov.au](mailto:Kate.Robertson2@sa.gov.au)  
[Philip.Heath@sa.gov.au](mailto:Philip.Heath@sa.gov.au)



## Canberra observed



David Denham AM  
Associate Editor for Government  
[denham1@inet.net.au](mailto:denham1@inet.net.au)

### Government hopes to raise an extra \$6 billion in revenue with changes to petroleum resource rent tax...

On 2 November 2018, the Treasurer, Josh Frydenberg, released the Government's final response to Michael Callaghan's review of the Petroleum Resource Rent Tax (PRRT). The review was initiated in November 2016, to provide advice about whether the PRRT is operating as it was originally intended, and to address the reasons for the rapid decline of Australia's PRRT revenues.

Since the PRRT was introduced in 1988 the nature of petroleum production has changed, shifting from crude oil and condensate to a more significant role for LNG. In fact, over the past 30 years, oil and condensate production has nearly halved, and gas production has increased over sevenfold. The government obviously wanted a bigger part of the action!

Its full response can be found at: <https://static.treasury.gov.au/uploads/sites/1/2018/11/p2018-t339508-govt-response-PRRT.pdf> and some of the changes, which will be introduced on 1 July 2019, do not appear to encourage petroleum exploration.

To quote from the Minister's media release these include:

**'Lower uplift rates:** *These changes will limit the scope for excessive compounding of deductions. For example, the uplift rate on exploration expenditure will be reduced from*

*Long Term Bond Rate (LTBR)+15 percentage points to LTBR+5. Existing investments will be respected.*

**Onshore projects removed from the PRRT regime:** *Since onshore projects were brought into the PRRT in 2012, no revenue has been collected and that was expected to remain unchanged into the future. In practice, it has been used to transfer exploration deductions to profitable offshore projects reducing PRRT payable. This change will simplify the system and strengthen its integrity.*

**Review of Gas Transfer Pricing Regulations:** *Treasury will commence a review into the regulations that determine the price of gas in integrated LNG projects for PRRT purposes. Treasury will consult closely with the industry and community.'*

This means that 'exploration expenditure' incurred by projects before 1 July 2019 will still be deducted at the current uplift rate of the long term bond rate (LTBR)+15 percentage points. But after 1 July 2019 the rate will fall to LTBR+5 percentage points. Consequently, existing projects that had been expecting to keep claiming high uplift rates for exploration expenditure will be forced to accept lower uplift rates from 1 July 2019.

It is not unreasonable to apply a RRT on the profits from LNG, but at a time when petroleum exploration in Australia is near an all-time low and we are going to have to rely more on imports of hydrocarbons for transport and PVC manufacture, one would have thought that the government should be providing more encouragement for exploration rather than just trying to milk the LNG cash cow.

The APPEA's Chief Executive Malcolm Roberts said that 'changes to the petroleum resource rent tax (PRRT) announced by the Commonwealth must be assessed carefully by Australia's oil and gas industry'. What an understatement!

### Saves \$4 million by blocking 11 research grants...

In one of the more bizarre decisions by the current government, its Education

Ministers Simon Birmingham (under Turnbull) and Dan Tehan (under Morrison) have vetoed 11 Discovery Grants approved by the Australian Research Council (ARC). Neither minister gave any reason for interfering with the ARC process or for selecting these eleven studies. It should be noted that the ARC is an independent body set up by an Act of Parliament that governs its activities. Tehan announced that university funding must now meet a 'national interest test', seemingly unaware that grant proposals already pass a 'national benefit test' before they are awarded. He has not yet spelled out what this test should be.

It looks as though both Ministers just looked at the titles of the grant applications and made their decision to exercise their right of veto without reading any further. For example, one of the grant applications most widely quoted in the media is entitled: 'Post-orientalist arts of the Strait of Gibraltar'. At first sight it does seem irrelevant, but as Van Badham wrote in the Guardian on 1 November 2018:

*'Gibraltar was once a geographical passageway between continental Europe and Africa and a place that shared dual language and cultural influences from Moorish and Judeo-Christian societies. From 1492-on, after the Spanish defeated the last Muslim government north of the straits, Gibraltar's role was affirmed by the victors as a barrier between cultures. If you're interested in what precise features distinguish 'western civilisation' from its neighbours, 'post-orientalist arts of the Straits of Gibraltar' would be a most useful place to start.'*

### removes \$134 million from research funding...

On 12 November 2018 the government announced that \$134 million would be taken from the Research Support Program, which funds researchers' salaries, laboratories and libraries, to pay for student places at regional universities.

delays next round of  
Australian Research  
Council grants...

Until the new national interest test for public funding is applied, there will be a delay in announcing the current round of \$300 million grants. These would usually have been announced in late October or early November. It now seems that researchers will have to wait until February 2019 to know if they have received an ARC grant for 2019. This will cause a high level of uncertainty to academics, particularly early career researchers, who won't know whether they're to be employed until the new year. Universities Australia has said it does not understand why the government wants to introduce a 'national interest test' on Research Council grants for academics, given applicants must already meet a 'national benefit' test.

It seems to me that the government does not really understand the value of research and how it is carried out, or what it hopes to achieve by reducing funding and adding a political filter over research projects.

and is undertaking a  
review into university  
freedom of speech

The review will examine the rules and regulations protecting freedom of speech on university campuses. It will among other activities:

- Assess the effectiveness of the Higher Education Standards Framework to promote and protect freedom of expression and freedom of intellectual inquiry in higher education.

- Assess the effectiveness of the policies and practices to address the requirements of the Standards, to promote and protect freedom of expression and intellectual inquiry.

Former Chief Justice of the High Court Robert French is heading-up the review, which will also examine existing material regarding free speech, including codes of conduct, enterprise agreements, policy statements and strategic plans.

The government did not indicate why the review was necessary, or when it is expected to report. More information can be found from the website: <https://ministers.education.gov.au/tehan/review-university-freedom-speech>

No wonder the universities say they feel they are under attack!

## Government awards seven offshore petroleum permits, attracting \$530 million exploration investment

There's nothing like an increase in the oil price to kick-start Australian petroleum exploration investment, which has been in the doldrums for the past two years.

On 1 November 2018 Minister Canavan announced the awarding of seven new offshore petroleum exploration permits as part of the 2017 Offshore Petroleum Exploration Acreage Release <https://petroleum-acreage.gov.au/>.

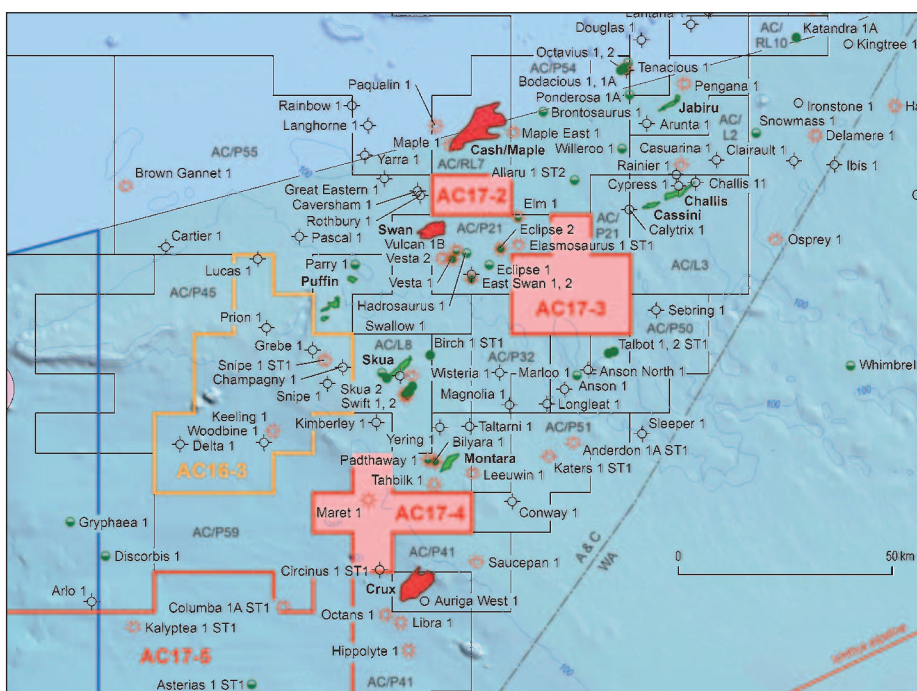
The new exploration permits are in Commonwealth waters offshore Western Australia, Victoria and the Territory of Ashmore and Cartier Islands. These permits will potentially see more than \$530 million in exploration investment over the next six years. This is a long way short of the heady days in 2014 when investment was approximately \$1 billion per quarter, but it is an encouraging indication. Notice that BP and Shell plan to increase their exploration investment and are exploring two large comparatively unexplored areas (W17-3 and W17-7).

Details of the proposed exploration programs are shown below:

- Carnarvon proposed a \$4.25 million guaranteed work program including licensing 542 km<sup>2</sup> of Cygnus multi-client 3D seismic data.
- The secondary work program totals \$30.5 million and includes an exploration well.
- No other bids were received for this area.

## Exploration permit VIC/P72

- The V17-1 release area in the Gippsland Basin (Figure 2), southeast of Lakes Entrance, was awarded to Cooper Energy (MGP) Pty Ltd.
- Cooper Energy proposed a \$31 million guaranteed work program including one exploration well.



**Figure 1.** Location of permit areas AC17-3, AC17-4 and AC17-5, Bonaparte Basin, Timor Sea.

Exploration permit AC/P63

- The AC17-3 release area, in the Timor Sea (Figure 1), was awarded to Carnarvon Petroleum Ltd



- The secondary work program totals \$31 million and includes one well.
- No other bids were received for this area.

### Exploration permit WA-533-P

- The W16-6 release area in the Canning Basin, north of Broome (Figure 3), was awarded to INPEX Browse E&P Pty Ltd.
- INPEX proposed a \$9.3 million guaranteed work program comprising acquiring 5005 km of 2D seismic data and 1035 km<sup>2</sup> of 3D seismic data.
- The secondary work totals \$26 million and includes one exploration well.
- No other bids were received for this area.

### Exploration permit AC/P64

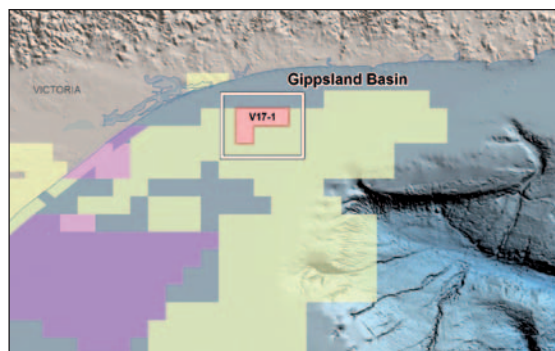
- The AC17-4 release area in the Timor Sea (Figure 1) was awarded to Shell Australia Pty Ltd.
- Shell proposed a \$76.5 million guaranteed work program including licensing and reprocessing 478 km<sup>2</sup> of the Cygnus MC3D seismic data and one exploration well.
- The secondary work program totals \$70.2 million and includes one exploration well.
- One other bid was received for this area.

### Exploration permit AC/P65

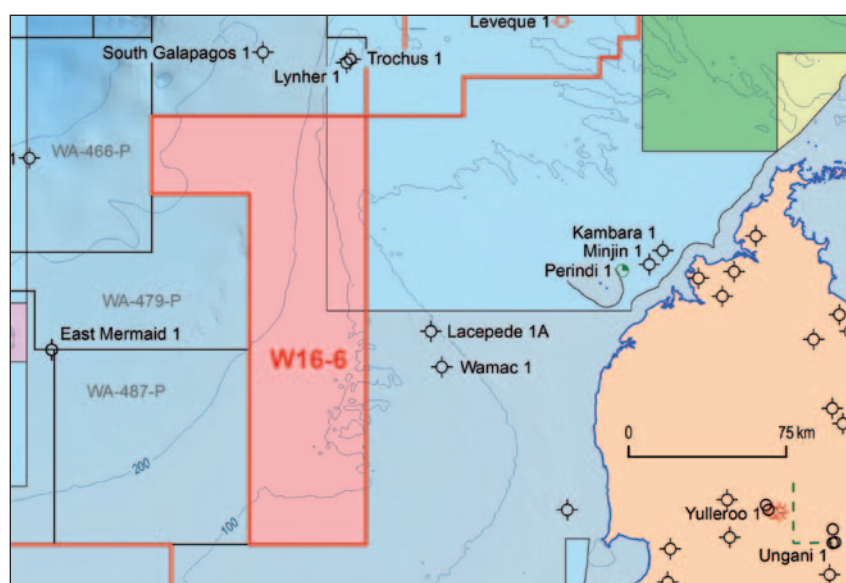
- The AC17-5 release area in the Browse Basin (Figure 1), off Western Australia, was awarded to Shell Australia Pty Ltd.
- Shell proposed a \$30.5 million guaranteed work program including licensing the Caswell and Heywood multi-client 3D data and the acquisition of 2910 km<sup>2</sup> of new 3D seismic data.
- The secondary work program totals \$70.2 million and includes one exploration well.
- One other bid was received for this area.

### Exploration permit WA-534-P

- The W17-3 release area in the Browse Basin (Figure 4), adjacent to the AC/



**Figure 2.** Location of permit area V17-1, Gippsland Basin, Bass Strait.



**Figure 3.** Location of permit area W16-6, Offshore Canning Basin.

- P65 permit, was awarded to Shell Australia Pty Ltd.
- Shell proposed a \$10.6 million guaranteed work program including licensing 753 km<sup>2</sup> of Caswell multi-client 3D seismic data and 1697 km<sup>2</sup> of Heywood multi-client 3D seismic data.
- The secondary work program totals \$72.4 million and includes acquisition of 330 km<sup>2</sup> 3D seismic data and one exploration well.
- One other bid was received for this area.

### Exploration permit WA-535-P

- The W17-7 release area on the Exmouth Plateau (Figure 5) was awarded to BP Development Australia Pty Ltd.
- BP proposed a \$6.4 million guaranteed work program including licensing Olympus 3D seismic data.
- The secondary work program totals \$68 million and includes one exploration well.
- No other bids were received for this area.

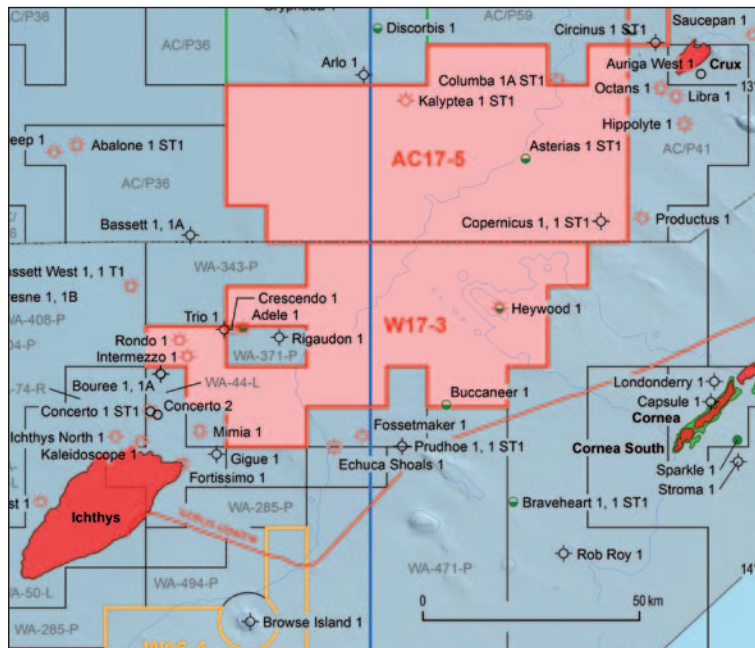
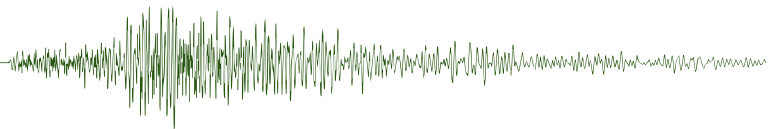


Figure 4. Location of permit area W17-3, Browse Basin.

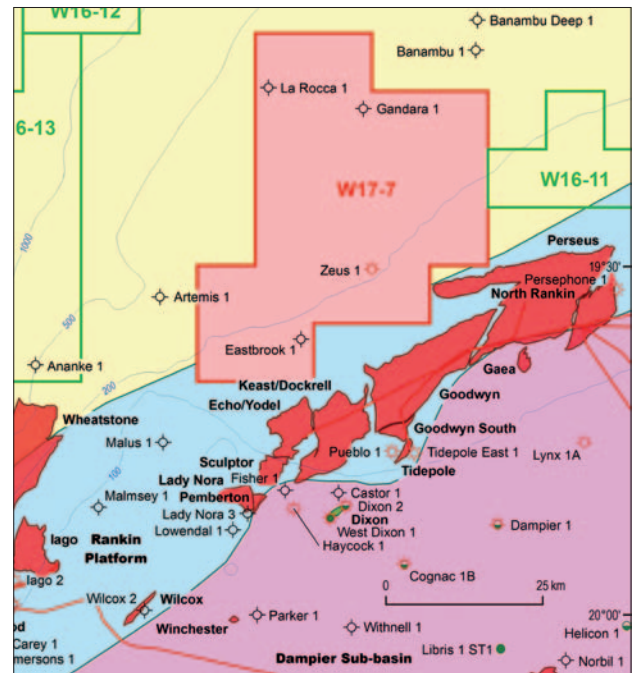


Figure 5. Location of permit area W17-7, Northern Carnarvon Basin.



## ASEG RESEARCH FOUNDATION

**Attention: All geophysics students at honours level and above**

- You are invited to apply for ASEG RF grants for 2019.
- Closing date: **28 February 2019.**
- Awards are made for:
  - BSc (Hons) Max. \$5000 (1 Year)
  - MSc Max. \$5000 per annum (2 Years)
  - PhD Max. \$10 000 per annum (3 Years)
- Application form and information at: <https://www.aseg.org.au/foundation/how-to-apply>
- Awards are made to project specific applications and reporting and reconciliation is the responsibility of the supervisor.
- Any field related to exploration geophysics considered, e.g. petroleum, mining, environmental, and engineering.
- The completed application forms should be emailed to Doug Roberts, Secretary of the ASEG Research Foundation: [dcrgео@tpg.com.au](mailto:dcrgео@tpg.com.au)
- The application documents have been reviewed and some rules have changed for 2019 and later grants.

### ASEG Research Foundation

**Goal:** To attract high-calibre students into exploration geophysics, and thus to ensure a future supply of talented, highly skilled geophysicists for industry.

**Strategy:** To promote research in applied geophysics, by providing research grants at the BSc (Honours), MSc, and PhD level (or equivalent).

**Management:** The ASEG RF Committee comprises ASEG Members from mining, petroleum and academic backgrounds, who serve on an honorary basis, and who share the administrative costs to spare Research Foundation funds from operating charges. The funds are used in support of the project, for example, for travel costs, rental of equipment, and similar purposes. Funds must be accounted for and, if not used, are returned to the ASEG Research Foundation.

Donations to the ASEG Research Foundation are always very welcome and are tax deductible. Contact the ASEG if you wish to make a donation



## Education matters



Michael Asten  
Associate Editor for Education matters  
[michael.asten@monash.edu](mailto:michael.asten@monash.edu)

### The next two generations of earth scientists

It is great, once again, to bring Members an overview of student research in geophysics for the past year. We have a total of seven PhD, three MSc and eight BSc Honours theses from four states; they represent some excellent work across

the spectrum of tectonics, potential field, electromagnetic and seismic projects.

Building for the longer-range future, Andrew Squelch of Curtin University brings us news of the Earth Science Western Australia (ESWA) educational program that educates primary and secondary school students and teachers about our earth, its place in the solar system, its rocks, mineral and hydrocarbon resources.

## Geophysics theses in Australian universities in 2018

### PhD theses

**Wenchao Cao**, The University of Sydney: *Global paleogeography since the late Paleozoic: integrating geological databases, plate tectonic models and reconstructions of past mantle flow.*



Palaeogeographic reconstructions are important for understanding the earth's plate tectonic evolution, past marine inundation history of continents, palaeoclimate and to reveal the influence of past mantle flow on the earth's topography. This thesis comprises three inter-connected studies exploring the connections between the earth's surface palaeoenvironments, palaeoclimate, eustatic sea-level change and deep mantle processes by integrating geological observations with numerical earth models over the last ~400 Ma. I developed a new workflow to refine time-varying global palaeogeographic maps by incorporating palaeoenvironmental data from the Palaeobiology Database. Using this approach, the consistency ratio between the palaeogeography and the palaeoenvironments as indicated by the marine fossil collections is increased

from an average of 75% to nearly full consistency. The palaeogeography in the regions of North America, South America, Europe and Africa is significantly revised, especially in the Late Carboniferous, Middle Permian, Triassic, Jurassic, Late Cretaceous and most of the Cenozoic.

I investigated the shifting climatic zones for the last ~400 Ma using a comprehensive database of climate lithologies, plate tectonic reconstructions and novel data analysis approaches. The results suggest that the palaeolatitudinal distributions of the lithologies have changed through deep geological time, notably a pronounced pole-ward shift in the distribution of coals at the beginning of the Permian. The changing distribution of coals from the Permian to the present also cannot be considered to have been constant as proposed by previous studies. My results indicate a predominantly bimodal distribution of evaporites over the past ~400 Ma. This suggests that the previously proposed bimodal or unimodal evaporite patterns could have alternated over geological times. The distribution of glacial deposits is consistent with previous interpretations of the main icehouse and greenhouse periods during the last ~400 Ma.

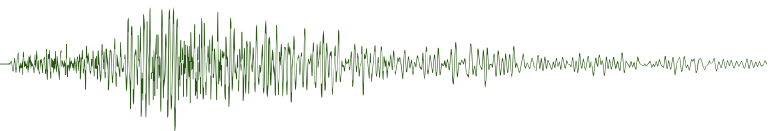
I used time-dependent mantle flow models to interpret the predicted dynamic topography in deep geological time to distinguish between eustatic and regional sea level change signals in the geological record. My results indicate that the trend in global-scale flooding over the late Paleozoic generally correlates with global sea level curves. The first-order flooding

history of North America correlates with some estimates of global long-term sea-level change. The flooding lows during the Early Carboniferous and high during the Late Carboniferous for South America are at odds with estimates of eustasy and can be explained by dynamic uplift and subsidence, respectively. According to the numerical models, the reference districts used to reconstruct eustatic curves which are most affected by dynamic topography are those in South China and North America. Therefore, the interpretation of stratigraphic data gathered from these regions should be treated with caution when used to estimate global sea level variations. The studies in this thesis highlight that combining digital palaeogeographic reconstructions, geological observations, plate tectonic motion models and reconstructions of past mantle flow provides insights into understanding the interaction between surface and deep earth processes over geological time.

**Maelis Arnould**, University of Sydney: *Some surface expressions of mantle convective instabilities.*



The earth's lithosphere, which is the upper boundary layer of mantle convection, represents the interface



between the external and internal envelopes of our planet. The multiple interactions between the mantle and lithosphere generate lateral (plate tectonics) and vertical (dynamic topography) deformations of the earth's surface. Understanding the influence of the dynamics of mantle convective instabilities on the surface is fundamental to improve our interpretations of a large range of surface observations, such as the formation of sedimentary basins, continental motions, the location of hotspots, the presence of gravity anomalies or sea-level variations.

This thesis aims at developing numerical models of whole-mantle convection self-generating plate-like tectonics in order to study the impacts of the development and the dynamics of mantle convective instabilities (such as slabs or mantle plumes) on the continuous reshaping of the surface.

First, I focus on the influence of the coupling between mantle convective motions and plate tectonics on the development of dynamic topography (i.e. surface vertical deformations induced by mantle convection) at different spatial and temporal scales. The results suggest that the earth's surface can deform over large spatial scales ( $>10^4$  km) induced by whole-mantle convection to small-scales ( $<500$  km) arising from small-scale sub-lithospheric convection. The temporal variations of dynamic topography range between five and several hundreds of millions of years depending on the convective instabilities from which they originate. In particular, subduction initiation and slab break-off events control the existence of intermediate scales of dynamic topography (between 500 and  $10^4$  km). This reflects that the interplay between mantle convection and lithosphere dynamics generates complex spatial and temporal patterns of dynamic topography consistent with constraints for the earth.

A second aim of this thesis is to understand the dynamics of mantle plumes and their interactions with the surface. I first characterise in detail the behaviour of mantle plumes arising in models of whole-mantle convection self-generating plate-like tectonics, in light of surface observations. Then, I study how the interactions between surface plate tectonics and mantle convection affect plume motions. Finally, I use observations of the thermal signature of plume/ridge interactions to propose

a reconstruction of the relative motions between the Azores mantle plume and the Mid-Atlantic Ridge.

**Sarah J. MacLeod**, University of Sydney: *Characteristics of extinct spreading centres and the relationship between spreading ridges, hotspots and deep mantle structure.*



Together, oceanic spreading ridges and mantle plumes present the major vehicles through which heat is lost from the deep earth and govern the distribution of almost all basic volcanism observed at the earth's surface. Despite a number of hotspots being located in close proximity to spreading ridges, generally, hotspots are seen to be independent of spreading ridges and a manifestation of 'dynamic' mantle processes, while ridges are considered to be primarily 'tectonic' and their locations not thought to be directly linked to deep mantle convection. This study firstly seeks to improve understanding of the evolution of spreading ridges, by cataloguing the many proposed extinct spreading ridges situated within preserved ocean crust and evaluating their physical and spreading characteristics. Variability of extinct spreading ridges related to tectonic subtype, such as extinct back-arc basin ridges, microplate spreading ridges and extinct large-scale mid-ocean ridges is described, with a comparison with active spreading ridge examples. Uncertain and controversial examples of extinct spreading ridges are compared with the 'characteristic' extinct ridges and this review assists in determining which are more likely to represent former spreading boundaries, as well as identifying a number of possible new ridges that have not been described elsewhere.

The spatial correlation of hotspots with both spreading ridges and subduction zones through time is then systematically assessed, taking into account reorganisations of spreading ridges at times of major ridge jumps, which are identified by preserved extinct spreading

centres. This evaluation determines that over the last 100 Ma spreading ridges have been in closer proximity to hotspots than expected by a random distribution, as they are at present-day. After most ridge jumps, spreading ridges are located in closer proximity to a hotspot after the reorganisation, particularly where microcontinents are generated. A different relationship was found for back-arc basin ridges, namely that they were more likely to migrate toward a hotspot after reorganisation only after a duration of spreading of 10 Ma or more and this suggests that large-scale mid-ocean ridges are more likely to be influenced by dynamic upwellings on shorter timescales.

Prior to 150 Ma, spreading ridges appear to have been distributed less extensively than at present-day and a random point on the earth's surface will be up to  $50^\circ$  from a ridge, in contrast with the present maximum distance of ca.  $30^\circ$  from a ridge. This difference could reflect greater uncertainty in reconstructed ridge locations, different active hotspots at earlier times or may be a consequence of supercontinent assembly. In contrast with spreading ridges, subduction zones are generally further from hotspots than expected by a random distribution over the last 100 Ma and this is particularly the case for those hotspots that are likely to have a deep mantle origin. These results support inferences from geodynamic models that deep mantle structure and large-scale convection, driven by subducting slabs, exerts a strong influence on the geometry of deep mantle upwellings, including the plume generation zone.

To better understand the relationship of plumes and deep mantle structure with surface tectonic features, four spherical convection models are evaluated, with three models using a different tectonic reconstruction that provide boundary conditions from plate velocities and subduction zone locations. The first order behaviour and motion of modelled hotspots is then compared with observations of present-day hotspots and their trails. This analysis provides information on the variability of model plume characteristics within and between models and predictions on plume motion in different mantle hemispheres. Large-scale modelled evolution of the large low-shear velocity provinces in the deep mantle is quantified by describing the direction and rate of retreat or advance of the boundaries of the African, Pacific and 'Perm' anomalies. The combined analyses



provide insight on the behaviour of plumes and predicted deformation of deep mantle structures, in response to tectonic processes and identifies where the modelled plumes differ significantly from observational data and further refinement of geodynamic models may be required.

**Michael Tetley**, University of Sydney: *Constraining Earth's plate tectonic evolution through data mining and knowledge discovery.*



Global reconstructions are reasonably well understood to ~200 Ma. However, two first-order uncertainties remain unresolved in their development: first, the critical dependency on a self-consistent global reference frame; and second, the fundamental difficulty in objectively predicting the location and type of tectonic palaeo-boundaries. In this thesis I present three new studies directly addressing these fundamental geoscientific questions. Through the joint evaluation of global seafloor hotspot track observations (for times younger than 80 Ma), first-order geodynamic estimates of global net lithospheric rotation (NLR), and parameter estimation for palaeo-trench migration (TM) behaviours, the first chapter presents a suite of new geodynamically consistent, data-optimised global absolute reference frames spanning from 220 Ma through to present-day. In the second chapter, using an updated palaeomagnetic pole compilation to contain age uncertainties, I identify the optimal APWP pole configuration for 16 major cratonic blocks minimising both plate velocity and velocity gradients characteristic of eccentric changes in predicted plate motions, producing a new global reference frame for the Phanerozoic consistent with physical geodynamic principles. In the final chapter of my thesis I identify palaeo-tectonic environments on earth through a machine learning approach using global geochemical data, deriving a set of first-order discriminatory tectonic environment models for mid-ocean ridge (MOR), subduction (ARC), and

oceanic hotspot (OIB) environments. Key discriminatory geochemical attributes unique to each first-order tectonic environment were identified, enabling a data-rich identification of samples of unknown affinity. Applying these models to Neoproterozoic data, 56 first-order tectonic palaeo-boundaries associated with Rodinia supercontinent amalgamation and dispersal were identified and evaluated against published Neoproterozoic reconstructions.

**Roger Clifton**, The University of Western Australia: *Inversion for depth and forward modelling of magnetically heterogeneous bodies.*



A formula has been derived to provide depth estimates from a greater length of the magnetic power spectrum than by using the classic Spector-Grant formula. Consequently, magnetic depths have been profiled at intervals of 5 km across the Northern Territory, giving depths of up to three bodies at each station. Shallower bodies can be located using flightline data, the ubiquitous interference being addressed by seeking coherent patches in a spread of depth estimates across space and spectrum. Ground work for real-time calculation of interference is set out. Fast modelling of highly detailed bodies using 3-D Fourier convolution is also demonstrated.

**Jeremie Giraud**, The University of Western Australia: *Integration of geological uncertainty into geophysical inversion by means of local regularisation.*



We introduce a workflow integrating geological modelling uncertainty information to constrain gravity

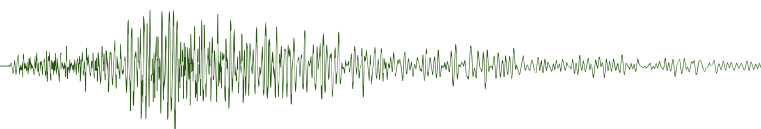
inversions. We test and apply this approach to the Yerrida Basin (Western Australia), where we focus on prospective greenstone belts beneath sedimentary cover. Geological uncertainty information is extracted from the results of a probabilistic geological modelling process using geological field data and their inferred accuracy as inputs. The uncertainty information is utilised to locally adjust the weights of a minimum-structure gradient-based regularisation function constraining geophysical inversion. Our results demonstrate that this technique allows geophysical inversion to update the model preferentially in geologically less certain areas. It also indicates that inverted models are consistent with both the probabilistic geological model and geophysical data of the area, reducing interpretation uncertainty. The interpretation of inverted models reveals that the recovered greenstone belts may be shallower and thinner than previously thought.

**Heta Lampinen**, The University of Western Australia: *Basement architecture for the polymetallic sediment-hosted Abra (cadabra).*



The 1590 Ma polymetallic Abra deposit, 170 km south west of Newman in Western Australia, is adjacent to an orogen parallel listric fault and hosted in Mesoproterozoic sediments. The Edmund Group sediments cover a fairly unknown Archean to Paleoproterozoic basement architecture, which must have controlled the mineral system resulting in the Abra deposit. Geology constrained combined gravity and magnetic forward modelling across the deposit was carried





out to understand the composition and the architecture of the mid-crust (4–10 km) at the deposit. Results suggest an anomalously dense and magnetic mid-crust composition in the intersection of the orogen parallel listric faults and a possible intersecting vertically accretive basement structure.

### MSc theses

**Stephanie Hawkins**, Macquarie

University: *Investigating an igneous dyke swarm using applied field magnetics.*



Did rifting on the eastern coast of Australia produce igneous rocks on either side of the Sydney Basin? A dyke swarm near Oberon in central-western New South Wales has been investigated using magnetics to determine its relationship to the Permian-Cretaceous rifting that allowed the extensional rift basin that became known as the Sydney Basin to deposit unconformably on top of the Lachlan Fold Belt. A secondary research question addressed is that of the relationship between the granites and the dykes themselves, and whether they are related or independent events. This research uses magnetic modelling of the Edith dyke swarm from aeromagnetic data and from a ground traverse magnetometer survey. Magnetic modelling was completed using ModelVision 15.0 and shows groups of thin (~4–8 m thick), vertically dipping tabular bodies successfully fit the anomalies. The modelling is accompanied by analysis of thin sections from a section of the swarm along Fish River at Evan's Crown Reserve, as well as geochemical data from a previous thesis analysing a portion of the swarm outcropping around Tarana. Both these locations are around 35 km north of the survey area, and represent the northern

reaches of the dyke swarm. This project has combined geophysical modelling with geochemical data to understand the structures causing the north-south striking magnetic anomalies that intrude the Carboniferous Bathurst Batholith.

**Alice Van Tilburg**, Macquarie

University: *Exploring lithospheric scale structure in the Eastern Yilgarn Craton with 3D magnetotellurics.*



The electrical structure of the Eastern Yilgarn Craton is of interest in building understanding of the pathways for mineralisation at the lithospheric scale. This project uses three dimensional inversion of magnetotelluric data from both broadband and long period stations to investigate an east-west traverse of the Youanmi and Kalgoorlie terranes. These data are from the Southern Cross Magnetotelluric Survey. Previous studies in the region focus on two dimensional modelling, however, phase tensor analysis of these data show a predominantly three dimensional subsurface that varies in strike across the profile. Models were produced using 26 stations from the Southern Cross data set, and show several conductive regions spanning a predominantly resistive subsurface.

**Joshua Grover**, The University of

Melbourne: *Palaeogene – Neogene deep lead sediments of the Stawell Zone: Evaluation of geophysical techniques for mapping deep leads.*



Deep lead sediments, known for their relatively large abundances of alluvial gold and potential for groundwater flows, were deposited in the Stawell Zone throughout Palaeogene-Neogene, when extensive palaeodrainage systems eroded through substantially older Cambrian bedrock. They were subsequently overlain by Quaternary sediments until recent re-exposure at the surface from erosional processes. The distribution of deep leads has been approximated using the Victorian Aquifer Framework (VAF), which interpolates drill hole data from mining records and groundwater databases from as early as the 1880's. This study aimed to rectify the key shortfall of the VAF – irregular spacing of drill holes – and improve the constraints on the model by using geophysical data to image the geometry of deep lead palaeochannels in the subsurface.

High-resolution land-based gravity as well as horizontal to vertical spectral ratio (HVSr) passive seismic datasets were acquired near Stawell, western Victoria. Geophysical interpretation of passive seismic data was found to accurately image the geometry of the deep lead palaeochannels, as well as differentiate between the Palaeogene – Neogene deep lead sediments at the base of the overlying Quaternary cover sediments. Conversely, it was not possible to identify the response of the deep lead sediments in the land-based gravity data, attributable to a lack of density contrast between the fill and cover sediments within the palaeochannels and the surrounding Cambrian bedrock. Because of the success of the HVSr method, further application of this form of geophysical data to enhance mapping of deep lead sediments may reduce the need for expensive drilling projects. This may increase economic viability for mining companies to target alluvial gold deposits, as well as improve access to groundwater, as the distribution of deep lead sediments becomes more accurately identified.

### BSc Honours Theses

**Adrian Eiffe**, University of Adelaide:

*Assessing Geophysical Model Uncertainty: Bootstrap and Pareto-Optimal Approaches.*

This project was undertaken to gain a greater understanding of what we can learn about the conductivity structure within the earth's crust from ground-based measurements. We can

measure the effects of telluric currents induced under the surface, and learn about the conductivity beneath with this information. However, there are limitations to how well this can be achieved. The MT technique is preferentially sensitive to more conductive structures, where current densities are highest. Surface measurements are of finite bandwidth and subject to random noise. They cannot be mapped uniquely to a single best model. Instead, an infinite range of models are consistent with the measurements, to a degree defined by the error of the measurements taken. The first aim of this project was to investigate what could be learned from a single set of MT data by applying a bootstrap resampling approach. By resampling the original data, a group of subsets of the data are obtained, from which we can produce new models. These models should be sufficiently independent to apply some simple statistics and assess the sensitivity of the model to the data. The second aim was to investigate how the integration of two EM surveying techniques that measure the same physical property of resistivity can be used to better constrain the produced models, reducing the issues of non-uniqueness.

The bootstrap resampling method is shown to be highly effective as it can be run in parallel with little additional computational cost. We show that suites of two-dimensional inversions with subsets of data can effectively provide insight into the uncertainty of different regions of a model. The approach is scalable to any dimension, and easy to implement. We demonstrate the utility using a 100 km long transect of 55 stations spaced approximately 2 km apart collected in the Curnamona Province, on the border of South Australia and New South Wales. Secondly, we demonstrate a proof of concept for using a Pareto-optimal approach to determine the overlapping acceptable model spaces of two EM techniques (MT and time domain EM), thus narrowing the range of determined model parameters. The combination of defining model uncertainty for one technique and reducing the model space using two techniques should significantly increase the confidence that the resulting models are representative of the real earth.

**Robin Keegan-Treloar**, Flinders University: *A multi-method hydrological study of Wither Swamp, in the Fleurieu Peninsula, South Australia.*

Springs are a crucial source of water to wetlands and are often sensitive

to drought cycles and changes in groundwater conditions. To effectively manage spring dependent wetlands there are three essential components to be considered: (1) the quantity of water discharging from the springs; (2) the origins of the waters contributing to the springs; and (3) the subsurface controls on the spatial distribution of the springs. This study applied several temperature-based, hydro-geophysical and hydro-chemical techniques to assess these three fundamental components of Wither Swamp, a spring dependent wetland system in the Fleurieu Peninsula, South Australia.

Analysis of water samples suggested that the springs derive water from a mixture of precipitation and groundwater. This finding was supported by geophysics, which indicated that the groundwater likely flows from a fractured rock aquifer into an overlying clayey sand layer where the groundwater mixes with recent rainfall. Springs were present in downslope regions where a clayey sand material breached an uppermost peaty clay layer. Three independent methods estimated the spring flux to be upwards on the order of  $10^{-6}$  m/s. As aquifers have a large storage capacity, groundwater may provide a vital source of water to Wither Swamp during periods of drought, ensuring the continuance of essential plant and animal habitat.

**Emily Birrell**, Monash University: *Significance of the Emu Shear Zone, Yilgarn Craton, Western Australia.*



The Emu Shear Zone is located in the Yilgarn Craton in Western Australia, one of the largest exposed sections of Archaean granite-greenstone terrane. The Yilgarn Craton is divided into a series of terranes and then further into domains by regional NNW trending faults and shear zones on the basis of distinct geological characteristics. The Emu Shear Zone, with a length of ~120 km, divides the Gindalbie domain to the west, and the Menangina and Bulong domains to the east and south-east of

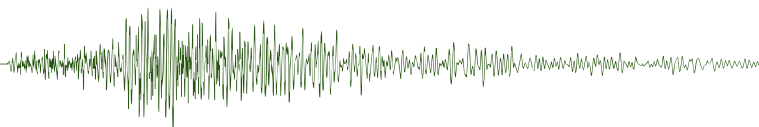
the Kurnalpi Terrane. Despite the Emu Shear Zone being a major NNW trending structure, there are limited structural observations and interpretations available regarding the geology of the system, with a major restraining bend associated with the shear zone only recently being identified in newer, higher resolution aeromagnetic images. Defining the structural evolution and kinematics of these major structures is important not only to determine potential constraints for gold mineralisation in the region, but also in reconstructing the tectonic evolution of the Yilgarn Craton.

A multi-scale approach was used for this study, combining geophysical interpretations, outcrop observations and thin section analysis with a focus on three locations; Camel Dam, Vertigo and North Brilliant. The restraining bend is shown to have three major splays. The easternmost of the three is the master shear zone, and is a major site of dilation allowing a large amount of fluids to migrate through the system. Hydrothermal alteration of host rock can be seen along all three splays, and likely resulted due to an increased permeability during deformation. Si and Fe-rich fluids resulted in the quartz-hematite banding seen in outcrop, with a sometimes 'cherty' siliceous appearance leading previous observations to believe this fault rock was a sedimentary unit. The Emu Shear Zone formed early in the regional deformation history, with the restraining bend evolving during a major NW-SE shortening event. This resulted in predominantly sinistral movement across all three splays, with the exception of dextral movement in Camel Dam. A dextral re-activation then resulted in hydraulic brecciation, and a minor sinistral shearing occurred during the final deformation event. Based on results collected during this study, it is theorised that gold mineralisation is most likely to occur in Vertigo, in the N-S oriented fault bend. This is due to the locality of the shear zone having a wide dilational potential, with over a kilometre of wide quartz-hematite banding seen. It is also suggested from results that gold was deposited during a D4 event, which is later than the principally D3 mineralisation recorded in literature for the Yilgarn Craton.

**Christina Boundy**, Monash University: *Structural Controls Influencing the Emplacement of the Dargo Tonalite, Using AMS, Geochemistry and Gravity*

Anisotropy of magnetic susceptibility, geochemistry and gravity were used to study the Dargo Tonalite, a late Silurian





– early Devonian intrusion located in the Tabberabbera Zone in eastern Victoria. Studying this intrusion is significant, because the orientation of the pluton does not fit the pattern of the many other intrusions in the broader area of the Lachlan Fold Belt. By analysing the geochemistry of the igneous rocks, a deep source of melt has been indicated, as well as an association with subduction processes and the fractionation of the melt. It is suggested in this thesis that the multiple deformation events in this region have created crustal scale structures that allow the transportation of deep melts, as well as shallower features that have influenced the plutons orientation during emplacement in the upper crust. The structure influence the Dargo Tonalite orientation would have formed during the Bindian event in the early Silurian.

**Matthew Paul Burgess**, Monash University: *Archean magmatic evolution: LA-ICPMS U/Pb and trace element analysis of zircons from the eastern Yilgarn superterrane.*

Field mapping was undertaken 19 km NNW of Kalgoorlie-Boulder, Western Australia, at the Scotia-Kanowna dome, the core of which is an Archean TTG-affinity high-Ca monzogranite batholith. Numerous quartz-phyric porphyry intrusions protrude from the batholith proper into the surrounding greenstone stratigraphy and are associated with NW/SE trending dextral faults. Geophysical and geochemical datasets, and field reconnaissance indicate a magmatic-hydrothermal transitional environment conducive to Sn, W, Cu, Au and Mo mineralisation, extending N-S from the batholith proper. These observations are characteristic of Intrusion Related Gold, Porphyry Cu-Mo-Au and Orogenic Au systems. Further study of the field area

is warranted to constrain which system is prominent. During field mapping, first order, low angle ductile fabrics within quartz porphyry units at the southern dome margin were identified. This D1, ENE/WSW shortening event has been regionally dated to 2680 Ma, consequently this field observation suggests these porphyritic intrusions have been emplaced prior to the Scotia batholith, which has been thrice dated by sensitive high-resolution ion microprobe to 2660 Ma. Representative samples were collected for whole rock geochemistry and laser ablation – inductively coupled plasma mass spectrometry (LA-ICPMS) for U/Pb and simultaneous in-situ trace element analysis. Cathode luminescence enabled scanning electron microscopy of 248 zircon grains collected from both units reveal homogenous, clear, inherited zircon cores within significantly recrystallised oscillatory zones, some sector zoning and metamorphic rims. Of the 581 laser points analysed, the inherited cores were the only concordant (>90%) U/Pb datapoints across the  $U^{238}/Pb^{206}$ ,  $U^{235}/Pb^{207}$  and  $Pb^{206}/Pb^{207}$  isotopic systems, yielding an approximate inherited age population of 2791.8 Ma ( $\pm 4.3$ , N: 31).

Trace element analysis and Ti-in-zircon thermometry of these inherited cores demonstrate protracted growth within the feldspar stability field at approximately 650°C from a reduced, HREE enriched magma with a consistent, negative Eu/Eu\* anomaly ( $< 0.7$ ), and a low Ce/Ce\* anomaly of ( $< 30$ ). The oscillatory growths enveloping the cores are increasingly affected by Pb-loss and increasing  $Pb^{206}/Pb^{207}$  discordance. However, the REE signatures, and Th/U ratios evolve coherently from the innermost oscillatory rims, outwards. An Eu/Eu\* anomaly (consistently  $> 1$ ), increasingly positive Ce/Ce\* anomaly, from 50 to 250, and complete HREE depletion, suggests increasingly oxidised, prograde conditions reaching 950°C, describing a complete transition of the magma from the feldspar to garnet stability field. The most coherent population from this prograde environment ( $> 80\%$  concordance) are the innermost oscillatory zircon growths, at 2694.2 Ma ( $\pm 3.6$ , N: 26). Beyond these inner oscillatory growths, the U/Pb isotopic system becomes decoupled.

The geological transition that these zircons record indicates periods of fertility for both the Intrusion Related Gold system and the Porphyry Cu-Au model. It also coincides with the protracted period

of continental rifting, east-west extension, mafic and ultramafic volcanism that are accepted to have commenced earlier than 2720 Ma in the Kalgoorlie Terrane, and have terminated by 2692( $\pm 4$ ) Ma. This zircon record begins in the lower continental crust, within an extensional setting, likely an evolving back-arc basin. The continuously prograde conditions can then be explained by either lower crustal/mantle interaction encouraged by the weakening continental crust and protracted volcanism, interaction with exsolving fluids from de-watering of hydrous subducted mafic material, or a diapiric mechanism whereby this section of lower crust descends and assimilates with the upper mantle.

**Mrinal Denis Deane**, Curtin University: *Derivation of seismic sequence attributes from VSP data as proxy lithological parameters for Harvey, WA.*



The South West Hub Project is an initiative of The Government of Australia and The Government of Western Australia to counter carbon emissions through Carbon Capture and Storage. The Lesueur Sandstone formation of the Perth Basin has been identified as a potential CO<sub>2</sub> reservoir. The formation is close to the surface, through an uplifted block, near the town of Harvey in Western Australia. The interpretations from geological and geophysical data revealed that no conventional seal is present, but other trapping mechanisms like palaeosols might exist that slow down CO<sub>2</sub> migration.

This thus, became of great importance to characterise both the reservoir and overlain sedimentary sequence in terms of shale/sand volume that is likely to play a crucial role in slowing down upward migration of injected CO<sub>2</sub>. To advance our understanding of the Yalgorup member that overlays the reservoir – high-density 3D seismic, Vertical Seismic Profiling (VSP) and borehole seismic measurements were acquired by Curtin University at Harvey 4 and Harvey 3 wells. The later one is the subject of this study. These data provided a possibility for an in-depth study of Yalgorup.



Vertical Seismic Profiling (VSP) measurements showed a sudden variation of both quality factor (Q-factor) and total energy which correspond to an increased shale volume just above the Wonnerup member. These observations inspired my investigations with the final aim of extrapolating it away from the borehole. One way of doing so was through the utilisation of seismic attributes that can be computed from the 3D surface seismic data and have a relationship to VSP observations. However, such attributes have to be robust enough to allow their computation not only on the high-resolution 3D surface seismic data around Harvey-3 well but also across a large area covered by the regional 3D seismic data.

Thus, the choice was seismic sequence attributes as they allow averaging of wavefield properties over a selected sequence that is the time interval. The investigation then reduced to the selection of the relevant sequence attributes that may be used to separate shaly from sandy intervals or equivalently determine the spatial extent of the palaeosols and in that way characterise the CO<sub>2</sub> holding or 'sealing' capacity of Yalgorup member.

The final methodology adopted was to compute the sequence attributes first on the transmitted VSP wavefield and select the specific attributes, called 'proxies', which correlated attenuation measurements and stratigraphy derived from borehole logs of H-3 well. Three attributes were identified from the VSP analysis – Energy half time, Effective Bandwidth and Zero Cross-Frequency which showed some relationship to the volume of palaeosols. These attributes were subsequently computed on 3D seismic data with the help of interpreted 3D horizons.

Anomalous attribute values were found for a thicker (in terms of spatial extent) unit of palaeosol above the Wonnerup member that corresponds to a high attenuation zone determined from the transmitted VSP wavefield. The resultant attribute maps showed a good correlation with the Harvey-3 logs. This methodology may be applied to the regional seismic cube to enable the creation of an improved static model and subsequent CO<sub>2</sub> injection simulation studies.

**Alejandro Sanchez**, Curtin University: *DHI for gas prospecting and lithology discrimination for the Otway Basin (Victoria).*



The Port Campbell Embayment Area is the most important gas producing region in the onshore portion of the Victorian sector of the Otway Basin. In the last century, more than one hundred exploration wells have been drilled in the region, which resulted in the discovery of nineteen natural gas and CO<sub>2</sub> fields. As is typical for gas bearing sediments, the prospective drilling sites were identified based on intense seismic amplitude anomalies –bright spots –at the target interval.

We believe that the success rate of the drilling and effectiveness of the production might have been improved if a more advanced seismic characterisation had been done. This thesis project focuses on quantitative seismic characterisation of the Eastern part of the Port Campbell Embayment Area, which has accumulated extensive set of geological and geophysical data thanks to the Otway project –the main Australian in-research project for carbon dioxide storage. We use data from seven petroleum wells and one CO<sub>2</sub> geo-sequestration well, in conjunction with a post-stack time migrated three-dimensional seismic volume. Having these data, we performed acoustic impedance inversion, rock physics transforms, and seismic modelling to study the feasibility of using bright spot amplitude signatures in the Waarre Formation for gas prospecting and lithology discrimination.

Our workflow began with seismic to well correlation, where satisfactory ties were obtained at the target interval – the Waarre and Eumeralla Formations. Secondly, we created low frequency models for post-stack acoustic impedance model-based inversion, and iteratively excluded one of the wells from the model generation to validate the robustness of the model and set up its parameters. The second important component of the seismic inversion –seismic wavelet – was obtained through an iterative process: (1) extract a statistical wavelet at the target interval for each well, (2)

extract a Roy-White wavelet at the well with the highest seismic to well correlation quality, (3) obtain the final wavelet through an inverse modelling. We inverted the data and obtained an absolute acoustic impedance volume that yielded global P-impedance and seismic misfits of 545.5 (m/s) (g/cc) and 6.97% respectively at the well locations. Later, we carried out fluid substitution and seismic modelling to analyse the effect of gas saturation and reservoir thickness in seismic amplitudes, and created crossplots to study the behaviour of porosity and seismic properties of the Waarre sediments with depth

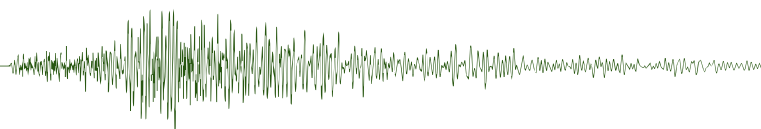
During the inversion stage, we found that deterministic post-stack acoustic inversion can be effectively utilised to estimate the acoustic impedance changes at the Belfast-Waarre and Waarre-Eumeralla interfaces, where it was observed that the Waarre Formation is characterised by a strong decrease of the absolute acoustic impedance with respect to the overlaying Belfast Mudstone.

Our rock physics analysis suggests that acoustic impedance inversion can be utilised for porosity computation, sand prediction and the identification of potential gas reservoirs at the Waarre level; having a post-production well, CRC-1, helped us to verify the rock physics model for the formation. Lastly, we showed that the application of relative acoustic impedance cut-off filters resulted in the prediction of sand geobodies and identification of at least five gas prospects.

From this project we concluded that, even though there are challenges posed by the fact that the seismic data was acquired onshore and that the imaging flow might have been imperfect, quantitative seismic interpretation methods showed to be valuable for reservoir mapping, lithology discrimination and the identification of potential gas reservoirs in the Waarre Formation.

**Anshuo Yang**, Curtin University: *Depth to the basement estimate from seismic data – a comparative study.*

Seismic reflection method can provide very precise images of the underground. One of the key issues is that this method becomes more expensive as the target under investigation becomes shallower. Hence this study investigates the potential of alternative seismic methods as well as the utilisation of other than the primary (P) waves to characterise the near surface at Ravensthorpe mine site. The results are



to be compared to a more conventional P-wave reflection survey. Our study deploys reflection, refraction, and Multichannel Analysis of Surface Wave (MASW) along a pre-selected transect. Three different types of sources: 45 KG weight drop, shear plate and Betsy gun were recorded by three different receiver types: 3C geophones with spikes, single component nodal geophone acting as a buried receiver and optical fibre. Data processing included P-waves in vertical component, as well as P-wave with converted SV-wave in in-line component and Raleigh (R) waves. Each wave mode samples the underground differently as its propagation is governed by different equations. Hence joint analysis of these waves might have a potential to better characterise complex near surface at Ravensthorpe where both geological and geotechnical information are needed

for optimisation of mining operations. My objective was to create accurate images of near surface structures that can provide information on the basement depth, structures and discontinuities and lithology that is rock properties. Each method utilised is evaluated against these objectives. The study also aims to assess the effectiveness of each method in terms of execution time, expenses related to the field operations, degree of operation difficulty.

Data processing included all body waves and reflection, refraction and inversion methods. Reflection survey in both vertical component and horizontal component with 45 kg weight drop showed significant depth of penetration (over 400 m). However, data processing is not trivial and requires very accurate static corrections and velocity field

estimation in the regime of low signal to noise ratio (SNR). The mix of P-wave and SV-wave reflected images are also processed and analysed (P-S-S-P mode). P-wave refraction data processing included plus-minus method, Generalised Reciprocal Method (GRM), and refraction tomography. Produced P-wave velocity field is evaluated together with the S-wave velocity field produced from the inversion of surface waves (MASW method). Inverted P-wave velocity field provides information within first 100 m while S-wave field covers 1/3 of that depth. Two wavefields correlate well over first 20–30 m. Joint analysis of all waves help delineate several structural features. The combined value of all methods exceeds each individual approach. Hence near surface investigations should be optimised for all wave modes but conducted efficiently at minimal expense.

## Highlighting the importance of earth sciences in our schools



Andrew Squelch  
ASEG Education Committee Chair  
[a.squelch@curtin.edu.au](mailto:a.squelch@curtin.edu.au)

Earth Science Western Australia (ESWA) continues to improve the quality of earth sciences and STEM education for students, teachers and the wider community. This exciting and important work is possible thanks to the long-standing support of a number of organisations, such as the Australian Society of Exploration Geophysicists.

ESWA works to create, produce and deliver innovative, valuable earth sciences education materials and experiences. Geophysics is included where it fits best with several activities across the Year 7, 8, 9 and 12 curricula. Education materials are all curriculum-linked and promote student engagement. These include teacher resource packages full of hands-on activities and online interactive

exercises. For senior school students, ESWA has produced textbooks for Earth and Environmental Science, as well as geological field guides for Perth and the Capes region of south-west WA. In support of these materials, ESWA delivers engaging and hand-on incursions across Western Australia and geological field activities across Perth, the south-west and Kalgoorlie. In 2017 alone, 5102 students, from Kindergarten to Year 12, were engaged in these activities.

To ensure the earth sciences materials that are produced are implemented in the best possible way, ESWA provides professional development opportunities at teaching conferences, network meetings, school development activities and special events. As a result of this extensive engagement 1636 teachers were involved in professional development with ESWA in 2017.

Increasing awareness of the wide range of careers opportunities that earth sciences



*Teachers explore aspects of planetary science, including convection currents and static electricity, at a primary workshop at the Conference of the Australian Science Teachers' Association.*





provide is vital to ESWA's core business. In pursuit of this they provide careers-based incursions for students in secondary schools. They assist with and run related events in which geophysics is presented as a career opportunity for the benefit of students showing interest in learning more of our science.

With a growing focus throughout education and the resources industry on STEM education and skills ESWA continue to strive to further the recognition of earth sciences as an integral part of STEM. This has been grown through the creation of earth sciences-based STEM project packages.

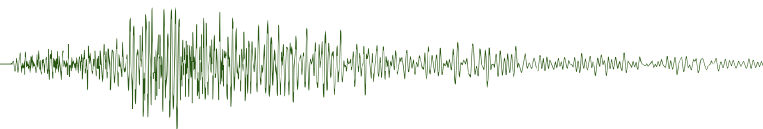
If you are keen to learn more about what is happening in this space or to partner with ESWA please visit [www.earthsciencewa.com.au](http://www.earthsciencewa.com.au) for more information.

*Staff and students explore for oil and gas in activities run by ESWA.*



*Students at Ashdale Secondary College, Perth, work together to classify a rock collection.*





## Environmental geophysics



Mike Hatch  
Associate Editor for  
Environmental Geophysics  
[michael.hatch@adelaide.edu.au](mailto:michael.hatch@adelaide.edu.au)

### Reflections on the 2018 SEG conference

Welcome readers to this issue's column on geophysics applied to the environment. In October I had the pleasure of attending the 2018 SEG conference in Anaheim, California. I attended to report on a Geoscientists without Borders grant that some colleagues at Flinders University and I received for work in Laos on the use of geophysics to help characterise the depth to groundwater in the Vientiane Basin (more on that in a future column). I have been pretty involved with ASEG conferences over the years, as many of you know, but this was my first SEG conference. I enjoyed attending if for no other reason than to compare how the SEG do conferences to how we do them.

So, the most obvious difference is ... scale, the SEG conference is quite a bit bigger than an ASEG conference (that might change now that we are holding our combined AEGC conferences) – but this one was apparently only about two-thirds the size of any SEG conference held in Texas (home to so many of the big energy companies – see accompanying photo for the obligatory shot of a large device used to shake the Earth).

As with ours, the Ice Breaker was on Sunday (one free drink only, hmmm), but talks didn't start until midday Monday and then finished at midday on Thursday – so the same three days of conference that we run, just in a slightly different format. By my count there were something like 768 talks presented over those three days in 16 parallel streams, with a morning set of talks and an



*Exhibition Hall 2018 SEG conference, Anaheim, California.*

afternoon set of talks, each just over three hours long. The good thing about this, is it left from about 11.45 am to 1.50 pm for lunch. Interestingly, the conference did not supply lunch (although some of the exhibitors did – I guess in the interest of keeping people in the venue). Being Southern California there was also an excellent Mexican restaurant within walking distance – so between exhibitors' lunches and good Mexican food the situation was more than acceptable. As far as I could make out, there were something like 96 sessions over the three days, and only two were dedicated to mineral exploration. Another session was about geophysicists in the workforce; one was about geophysics applied to medical imaging (unfortunately I couldn't go to this as it clashed with another session I wanted to go to at the same time – how does that always happen?). Eight more sessions were dedicated to engineering/near surface/hydrogeophysics. The rest (~84) were more or less dedicated to energy/petroleum.

So what were some of the interesting trends to note in the world of near surface / environmental geophysics? I am happy to see that fewer 'sounding based' resistivity surveys are being done in the developing world. I'm talking about those surveys where limited numbers of Schlumberger/Wenner array soundings (VES) are made over an area to characterise the hydrogeological setting; these surveys certainly have their place, but I think that they are too slow and therefore can't offer the data density that is needed to really characterise an area. I was pleased to see that more multichannel dipole-dipole etc. type resistivity arrays (often called 'tomographic surveys' or ERT) are being done in these settings. To

me, these efficiently provide much more information to depth over much large lateral areas than the individual sounding data. I suspect that this trend reflects that the results from multichannel systems are getting more exposure and, maybe, that system prices are coming down.

Other interesting talks included one by Esben Auken on a towed time domain EM system that his group at Aarhus University are developing (similar to, but a definite improvement on similar work that I have been involved in here in Australia). Burk Minsley of the USGS talked about how large scale geophysical surveys (think especially AEM) 'can inform key scientific and societal studies' as they are covering larger and larger areas with sufficient detail to really improve our understanding of the hydrogeology at both large and small scales. He stressed the importance of establishing uncertainty in these data sets and that this is carried through to the various 'products' that are derived from the base data sets. He showed data from an ongoing survey on the Mississippi Alluvial Plain (MAP) project <https://www2.usgs.gov/water/lowermississippigulf/map/>. This project will ultimately cover a huge swath of the central US (see map in link above for an idea of what's involved) with geophysical data including AEM, ground TEM, towed resistivity, and NMR data sets (this is just a partial list of the data sets being collected – including huge quantities of other hydrogeological information).

Overall, it was a very good meeting, with a nearly overwhelming number of talks to sift through – as I look through the program now I am actually disappointed in the number of talks that I missed. I guess I'll just have to read the papers...

## Minerals geophysics



Terry Harvey  
Associate Editor for Minerals geophysics  
[terry.v.harvey@glencore.com.au](mailto:terry.v.harvey@glencore.com.au)

### Mineral exploration and The Three Princes of Serendip

In 1754 Horace Walpole, English art historian, man of letters, antiquarian and Whig politician coined the term serendipity, prompted by 'The Three Princes of Serendip', the title of a fairy tale he remembered in which the heroes 'were always making discoveries, by accidents and sagacity, of things they were not in quest of'. Walpole's memory was a little selective, because in the fairy tale the princes actually made most (but not all) of their discoveries by deductive reasoning. So, it could be argued that Walpole's coining of the word serendipity was in itself somewhat serendipitous.

Serendipity can be compared and contrasted with luck, which may be defined as success or failure brought on by chance rather than through one's own actions. Depending on what your definitions are, there could clearly be overlap between the two. In this discussion I'll consider success through sagacity as serendipity, and success in the absence of one's own actions as luck. Like it or not, serendipity and luck can be significant factors in mineral exploration. The serendipity factor is at least something we might have some control over – luck probably not (unless you believe in the power of rabbits' feet, or the like).

The first stage in mineral exploration – ground selection – is arguably the most critical. No matter how good you are at exploration, if there's no orebody on your ground you won't be able to find one. You can do good work in demonstrating that nothing is down there, i.e. efficiently

sterilizing the ground, which will allow exploration to be directed elsewhere rather than wasting further time and money in fruitless effort. But there's no possibility of an exploration discovery – serendipity and luck are irrelevant.

So, to give success (and serendipity and luck) a chance, ground selection has got to be as good as it can be. Selection criteria might include one or more of the following: the presence of mineralisation or significant geophysical or geochemical anomalies, a perception that the geological environment is favourable for the targeted mineralisation, suitability for the application of a particular exploration technique, absence of previous appropriate exploration, or, perhaps, it's the only ground left near to someone else's discovery!

Even the existence of an unrelated anomalous feature might be a factor. Consider the discovery of the Century Zinc deposit in northwest Queensland. As I understand it, CRAE's interest in the area was first piqued by the presence of an extensive annular outcrop pattern of Cambrian sediments overlapping an area of known small-scale vein-type lead-zinc mineralisation. What was this 15 km diameter circular feature; was it perhaps evidence for an astrobleme? Two long lines of ground geochemistry in a cruciform pattern were undertaken. One line passed over one of the only two small surface expressions of the Century deposit zinc mineralisation, which was recognised as such. Luck or serendipity? Certainly the skill of the exploration team in recognising sphalerite and their persistence in having the target drilled were essential to the discovery.

The second stage in mineral exploration is the exploration itself. In the old days, if you didn't walk over the mineralisation outcrop or gossan (and recognise it for what it was) you missed out on a discovery. Prospectors got around this by thoroughly covering the ground, and in some cases using pathfinders, such as tracing surficial gold back to the shedding mother lode. Arguably they made their own luck, at least as far as exposed mineral deposits went. In modern times we strive to achieve the same result with systematic exploration, and where cover exists mineral geophysics plays a critical role. So far so good. We like to think the geophysical tools we employ are adequate for the task if we've done our homework about the nature of the target style and the environment.

Serendipity comes in to play in the recognition of something unexpected in all this systematic exploration. Consider the situation in a lead-zinc exploration program when airborne electromagnetics (with magnetics) is used to search for significant conductors beneath weathered cover. What if the survey turned up a small shallow circular conductor, perhaps with an attendant low-order magnetic anomaly? This is not the target you seek, but in the right environment – say a stable shield setting – it could be indicative of a kimberlite pipe. Surely it's worthy of further consideration? At the very least, if your company is not interested in diamonds, the prospect may be on-sold to help finance future exploration programs.

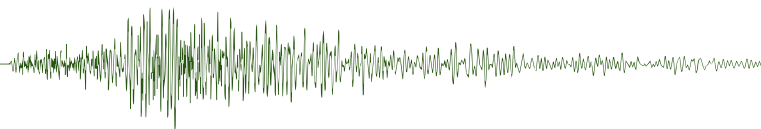
Ivanhoe Australia's discovery of the Merlin molybdenum rhenium deposit provides a good example of where lateral thinking and attention to detail resulted in an unexpected success. While drilling out the Mount Dore copper deposit, one drillhole passing below the main target intersected disseminated 'mafic's'. The exploration team's recognition that this disseminated mafic material was molybdenite (totally unexpected) was the turning point in the discovery process of the Merlin deposit.

So, luck and serendipity do play a part in mineral exploration success. Perhaps we should also be addressing these factors. Adding fortune tellers, astrologers and lucky people to the exploration team may be a step too far, but giving serendipity every opportunity, particularly where it eventuates through sagacity, definitely has merit. Employing and encouraging good observers and thinkers without fixed mind sets might be a good start. It's all about maximising your chance of success.



Horace Walpole by John Giles Eccardt 1747-8.





## Seismic window



Michael Micenko  
Associate Editor for Petroleum  
[micenko@bigpond.com](mailto:micenko@bigpond.com)

## Curvature, channels and compaction

Curvature is a measure of the amount of deformation of a surface such as a mapped seismic horizon. It is defined as the reciprocal of the radius of a circle that is tangent to the surface, and will be large for a tightly folded surface and zero for a planar surface. An anticlinal structure has a positive curvature and a synclinal shape has negative curvature. Commonly curvature is used to identify faults or channel edges, but it can also identify folds where there is no discontinuity. It is this characteristic that I want to pursue in this article.

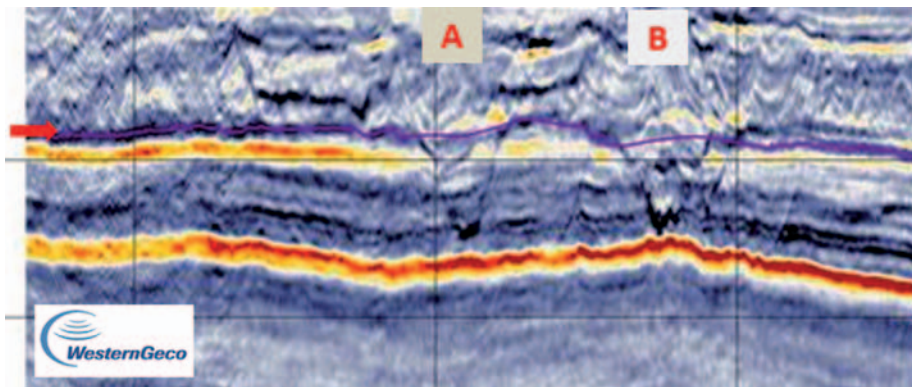
Channels, canyons, incised valleys, regardless of what they are called, can be quite spectacular and produce artistic displays, but they may also host hydrocarbons if the channel fill has good reservoir properties. So, how can we identify a sand filled channel from one that is shale filled? Figure 1 is a vertical seismic section with two major incisions cutting into the sediments. The channel labelled A is interpreted to be shale filled while channel B has a sandy fill.

The horizon based similarity attribute displayed in Figure 2 shows that each incision is not formed by a single event, but by several events within a broad channel belt. The properties of the channels appear to be varying temporally and spatially. Shale filled channels have a concave shape because the deposited muds in the thickest section compact more than the thinner muds near the edges. On the other hand, sandstones have relatively low compaction compared to the surrounding shales and retain a positive relief. These differences in shape and intensity of deformation can be detected by an appropriate curvature attribute.

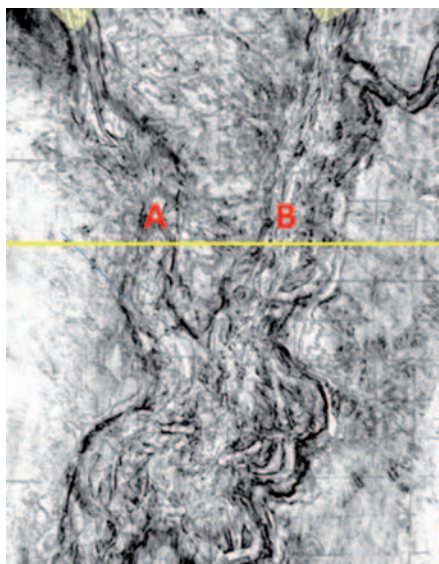
It should be possible to distinguish a convex up feature, such as the top of a sand filled channel, by displaying the positive curvature attribute, while shale filled channels should display a negative curvature – just calculate and display the positive curvature attribute to highlight all the convex up reflectors. This sounds simple and Figure 3 is an example of an early attempt. It's not as convincing as I'd hoped, but the sand filled channel seen in Figure 1 does have a positive curvature anomaly whilst the interpreted shale channel has no positive curvature (perhaps I need to apply a some kind of filter to enhance the areas of positive curvature).

Figure 3 is also an example of using colour blending to show multiple attributes in a single map. In this case I have assigned similarity to black, positive curvature to blue, curvedness to red and entropy to green, which results in sand prone channels having a purple hue (similarity highlights the channel edges and other discontinuities while entropy is a measure of chaos and highlights the channel belts).

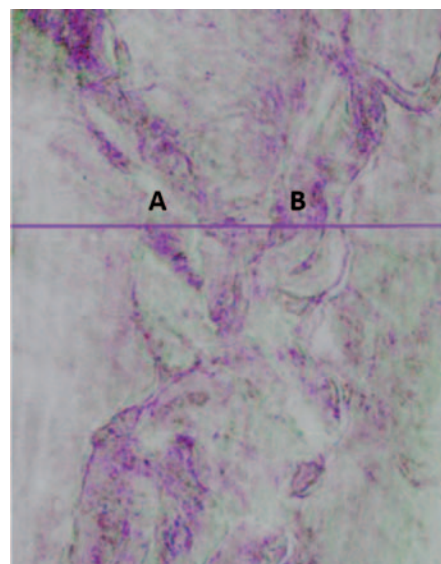
While not perfect, this technique can be refined to allow rapid identification of sand prone areas within complex channel systems. Good hunting!



**Figure 1.** Seismic line across an interpreted shale filled (A) and sand filled (B) channel. The reflectors above channel A are concave whereas those above channel B are convex. The display in Figure 2 is extracted just below the purple horizon. The red arrow indicates the level of the display in Figure 3. Data courtesy of WesternGeco Multiclient.



**Figure 2.** Similarity attribute displayed along a horizon near the top of the channel system showing the location of channels A and B and the seismic line from Figure 1. Each channel belt consists of numerous meandering features that move spatially over time. Data courtesy of WesternGeco Multiclient.



**Figure 3.** Colour blend display along a horizon above the channelized section. Positive curvature is in blue and curvedness is in red (other channels are green – entropy, and black – similarity). Areas where there is drape over a sand fill have a positive curvature and appear purple such as location B. It appears the left hand channel at location A is more shale prone. Data courtesy of WesternGeco Multiclient.



## Data trends



Tim Keeping  
Associate Editor for geophysical data  
management and analysis  
[Tim.Keeping@sa.gov.au](mailto:Tim.Keeping@sa.gov.au)

### Exploring passive seismic file formats for data exchange

Passive seismic is emerging as an exciting field with new applications in mineral exploration and stratigraphy modelling. State surveys are now building archives of passive seismic data with lots of subsurface detail and, as a

consequence, the exchange of passive seismic data has been on our minds at the ASEG. An informal ASEG group contacted known academic, government and industry users for the how and why of their favourite passive seismic file formats. It turns out that it is not just a local problem, with Moho, the Italian manufacturers of the widely used Tromino™, interested in finding a better output format for their devices.

Successful candidate formats should have the following parameters:

- Broad software support for acquisition formats
- Broad software support for end users
- Compaction for data exchange without ‘lossy’ compression
- Metadata

An additional stipulation is that data should be at least in time series, if not also in the frequency domain.

The most common acquisition formats are SEED (Standard for the Exchange of Earthquake Data) and SAC (Seismic Analysis Code). SEED has a long history of use in earthquake monitoring, while SAC has the advantages of both binary and text formats. Both formats are effectively software and files, with the data produced by a program of the same name. SAC appears to be favoured by academic users, despite the considerable

volume of historical data in SEED. Conversation with IRIS (Incorporated Research Institutions for Seismology) showed a preference for SEED.

Other text file formats (GeoCSV, Simple ASCII) lack the metadata and popularity to warrant consideration.

SEG2 is used for the passive Rayleigh wave format ReMi in engineering, but is believed to be restricted to time series data. SEG-Y was originally out of favour due to storage size restrictions. Various SEG-Y ‘flavours’ sprung up as work arounds, and the recent revision (SEG-Y r2) in 2017 was generally welcomed by end users. It has arguably the widest software support of any geophysical format.

IRIS supply various utilities for transforming between SEED and SAC. Tim Dean of Curtin University mentioned a possible tool to convert between the various formats as a by-product of a passive wave project, possibly adding a SEG-Y output.

Do you have an opinion on the path we should take? Should the ASEG prefer one or two formats for passive seismic data, or pursue software conversion? The formats under consideration are summarised in Table 1. Please reply with your opinion and suggestions/ideas to [technical-standards@aseg.org.au](mailto:technical-standards@aseg.org.au).

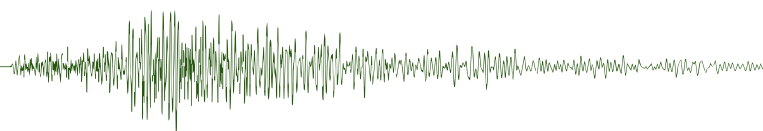
Table 1. Passive seismic data formats under consideration

Name	Original purpose	Channels	Software support	Stations per file	File or software	Known distributors	Metadata
SEED	Earthquakes	Single	Institutions	Single	Software	Most seismic institutions	Yes
SAC	Earthquakes	Single	Academic	Single	Software	USGS, academics	Yes
SEG-Y r2	Seismic	Multi	Wide	Multi	File	Petroleum	?
SEG2	Engineering	Multi	Engineering industry	Multi	File	Civil engineers	?



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## Webwaves



Dave Annetts  
ASEG Webmaster  
[david.annetts@csiro.au](mailto:david.annetts@csiro.au)

## Endings and a new beginning

A total of 89 votes were received for the 51 entries in the ASEG's 2018 photo competition. This competition was held to seek images for use on the Website and in newsletters. First place, with seven votes, was #43, reproduced here as Figure 1. Entitled 'Watching the Milky Way rise as the sun sets just off the Barkly Highway. Road side seismic camp, NT', this was submitted by Richard Barnwell (Terrex Group). Second place was #22 ('EM Surveying, Disko Island, Greenland' submitted by Bill Peters of SGC). Third place was a tie between #34 ('Milky Way lighting the way Birdsville Track, QLD'), #37 ('Seismic fleet, expedition Mars frontier...somewhere along the Birdsville track, QLD') and #41 ('The eye of the storm, Camerons Corner, QLD'), all submitted by Richard Barnwell (Terrex Group). All entries can

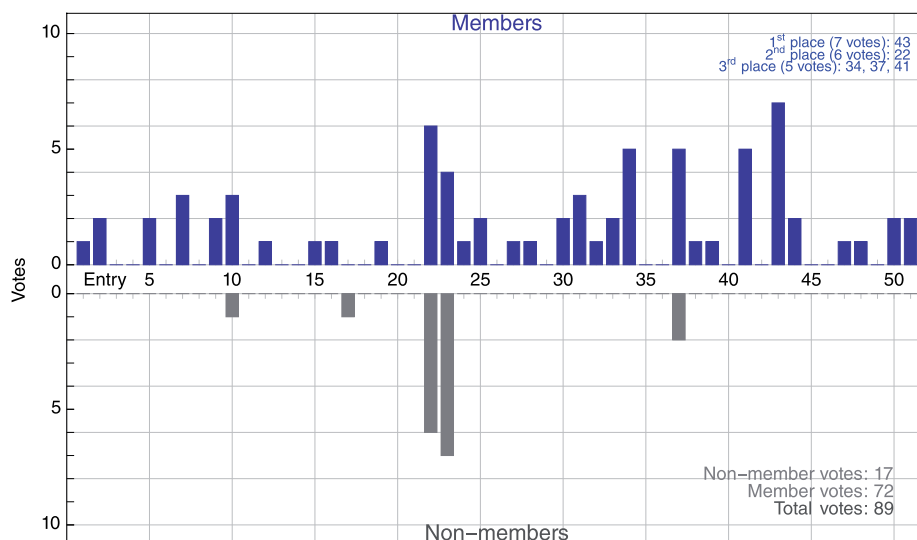


Figure 2. Tally of votes in the ASEG 2018 photo competition.

be seen at <https://www.aseg.org.au/about-aseg/2018-photo-competition>. Over the next few months, some of 2018 entries will be used on the website and in the monthly newsletter. Figure 2 shows results of the 2018 photo competition. It is noteworthy that had the six non-members joined the ASEG before submitting their votes, the competition would have been won convincingly by #22. As a consolation, all non-members will receive invitations to join the ASEG so that their votes will count in the next competition. Until that time, as Members they can take advantages of other benefits such as discount conference registration and access to *EG*.

The second web-related event to end in November, was the annual wine offer.

This offer, organised by the SA/NT Branch, goes from strength to strength each year, and the 2018 addition of a third variety, the NV Adelaide Hills Sparkling K1 by Geoff Hardy, was well-received by Members. Members may be pleased to note that, at the time of writing, there are less than 10 months before the 2019 Wine offer commences.

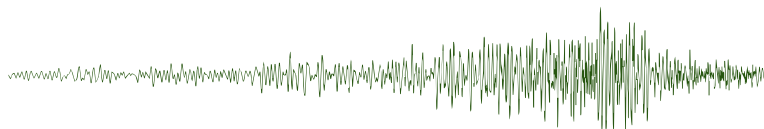
The final web-related topic to end in November was support for user Forums. Conceived as a mechanism for information exchange between ASEG Members in the website's previous incarnation, and carried over into the current incarnation, these never really captured Members' imagination. There are several reasons for this, one of which is the popularity of alternatives such as reddit (e.g. <https://www.reddit.com/r/geophysics/>) and Geosoft's SEGMIN mailing list (<https://bit.ly/2OthqCm>). In any case Members, through their silence, have spoken, and the ASEG Forums are no more.

As noted by the Editor in the last issue of *Preview*, 2019 marks the beginning of the ASEG's relationship with a new publisher, Taylor & Francis. T&F have strong ties to the European Union and will require Members' permission to use data. This permission will be given as a seamless part of the usual membership renewal process, which is expected to begin in January 2019. The ASEG's Data Policy can be viewed at <https://www.aseg.org.au/data-collection-policy>.



Figure 1. The winning photo in the ASEG 2018 photo competition; Richard Barnwell 'Watching the Milky Way rise as the sun sets just off the Barkly Highway. Road side seismic camp, NT'.





## Pyrolusitic supergene manganese oxides: inductive properties, EM conductivity and magnetic susceptibility



Don Emerson  
[systemsnsu@gmail.com](mailto:systemsnsu@gmail.com)



Phil Schmidt  
[phil@magneticearth.com.au](mailto:phil@magneticearth.com.au)

### Introduction

Manganese is a significant industrial metal, after iron, aluminium, and copper, it is the most widely used – finding application in steel alloys, oxidising treatments, glassmaking, and dry cell batteries. It has an atomic weight (54.94) similar to iron (55.85) and some similarity of chemical behaviour, but it is more mobile and soluble than iron and less readily precipitated, so that deposits of Fe and Mn oxides are usually separated in oxidation zones.

The earth's crust contains about 1000 ppm Mn (compare Fe: 53 000 ppm) giving it 12th rank in element abundance. Dark manganese minerals are everywhere in nature. Manganese has five oxidation states +2, +3, +4, +6, +7 (compare Fe +2, +3) allowing it to form a large variety of oxides such as occur in rock dendrites where they crystallise in attractive branching patterns on bedding or fracture planes (Figure 1). The rock varnish seen in outback outcrops comprises a very thin coating of manganese oxides, iron oxides, and clay (Voynick, 2017, 2018). The impressive building sandstones of the Sydney Basin Triassic sequence, if sideritic, can be discoloured after quarrying and exposure of the blackened stone surfaces to the atmosphere (Franklin, 2000). Small amounts of manganese, centred in the siderite, are released into solution upon oxidation and crystallise on the surface as black manganese dioxide, thus blackening the stone.

Primary manganese minerals occur in sedimentary, hydrothermal, and metamorphic environments. The largest primary deposits are to be found in sedimentary beds; the major secondary deposits are residuals derived by oxidation of primary sediments (Bateman, 1959). The former include vast low-grade manganese carbonate (rhodocrosite) beds that, after diagenesis and weathering, generate the latter, sometimes in the form of high tonnage (100 Mt+), high grade (Mn 46%+) supergene deposits, in suitable cavities or on suitable surfaces in the zone of oxidation. Manganese oxides are quite dense. Manganese

dioxide, pyrolusite, is often the major component of secondary deposits. Details of residual Mn deposits in Queensland, Northern Territory, New South Wales, and Western Australia may be found in McLeod (1966), McAndrew (1970), Knight (1975), Hughes (1990), and Phillips (2017).

Manganese ores are an important component of Australia's mineral production. Demonstrated reserves amount to ~200 Mt, i.e. 10% of the world's resources. When beneficiated, Mn ore is worth ~\$200 per tonne, similar in value to coal. The total tonnage mined is about twice the beneficiated tonnage owing to yields of 50% after treatment<sup>1</sup>.

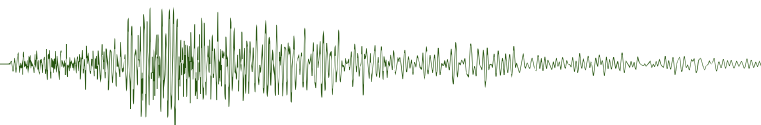
Dentith et al. (1994) note that magnetic anomalies may be associated with some Australian manganese mineralisation. For regional scale exploration, airborne EM can be used for conductive manganese ores. At prospect or local scale, gravity generally offers a cheaper alternative for the direct detection of manganese mineralisation.

Hashemi et al. (2005) carried out Sub-Audio Magnetic (SAM) surveys over known EM-responsive Mn deposits. They compare



**Figure 1.** Manganese is a mobile element and manganese oxides are very widely distributed. They are quite commonly observed precipitated in bedding planes and flaws in host rocks where they occur in a dendritic i.e. branching pattern. A ferruginous claystone, from the Sydney Basin, has dendrites on a fracture plane. Galvanic microprobing indicates that the black oxides, which presumably here include pyrolusite, are slightly conductive, ~ 1 S/m. The fracture face view is 50 x 40 mm.

<sup>1</sup>Approximate values, subject to grades and price fluctuations.



SAM results with high-resolution gravity, HoistEM, gradient-array induced polarization (GAIP), dipole-dipole induced polarization (DDIP), and ground time domain electromagnetic (TEM) surveying over five EM-responsive manganese deposits, which varied in size and burial depth. They conclude that the SAM technique detects conductive manganese occurrences at shallow depths (<40 m), adding that the use of multiple geophysical techniques is more reliable.

Murthy et al. (2009) give examples of geophysical exploration for manganese deposits from the Keonjhar district, Orissa (India). In terms of magnetic properties the pyrolusite and psilomelane varieties showed paramagnetic (antiferromagnetic) responses comparable to that of hematite. Within a background of phyllite, shale, conglomerate or quartzites the manganese ores can be expected to show detectable magnetic responses. They emphasise the need for gravity and magnetic surveys supplemented by physical property studies of host rocks and ores.

Harvey (2018) identifies pyrolusite (along with pyrite and graphite) as a mineral of significance in electrical geophysics.

This article gives the results of preliminary experimental work on the mesoscale physical properties of some secondary Mn ores containing two common black/dark grey supergene Mn oxides, pyrolusite, mainly, and cryptomelane. The crystalline hardness of these oxides is comparable to that of haematite i.e. H ~6 on Moh's scale.

## Mineralogy

Pyrolusite ( $\beta$  MnO<sub>2</sub>, 63% Mn), a paramagnetic semiconductor, is one of the most common Mn oxides to occur in oxidation zones where, in supergene concentrations, it can form all or part of economic Mn deposits. Geophysically, pyrolusite is of particular interest owing to its conductivity, a property most, if not all, other Mn minerals lack. Cryptomelane (KMn<sub>8</sub>O<sub>16</sub>, 60% Mn) is another common supergene Mn mineral, which frequently occurs intergrown with pyrolusite in microcrystalline or cryptocrystalline aggregates of high tensile strength, i.e. very tough. Some details of these two important secondary Mn oxide minerals are given in the notes to Table 1.

Thirty secondary manganese oxide samples were tested from a variety of locations in Australia and overseas (Table 1). The sample constituents are mainly pyrolusite and cryptomelane. Minor or trace amounts of other manganese oxides, such as braunite, may be present along with silica and iron oxides such as goethite. Summaries of Mn minerals may be found in Read (1970) and Klein and Hurlbut (1993). Extensive detail is provided by Frenzel (1980) who documents the variety and complexity of many Mn oxides. If the American Geosciences Institute is to be followed (Neuendorf et al., 2011), the sample test suite would be broadly classified as psilomelane: 'a general term for mixtures of manganese oxide minerals'. However, psilomelane is also the name applied for many years to hydrated manganese oxide containing varying amounts of barium and potassium oxides, so it is not used here.

The physical properties of semiconducting pyrolusite and the alkali bearing Mn oxide cryptomelane are not very clear, even regarding density. Both have porosity at lattice scale (tunnel structures), microscale, and mesoscale. Both can be hydrated with chemisorbed water. Common pyrolusite is  $\beta$  MnO<sub>2</sub> with a theoretical density of 5.23 g/cc, but field densities are

usually taken as ~4.8 g/cc owing to the submicroscopic porosity<sup>2</sup>.

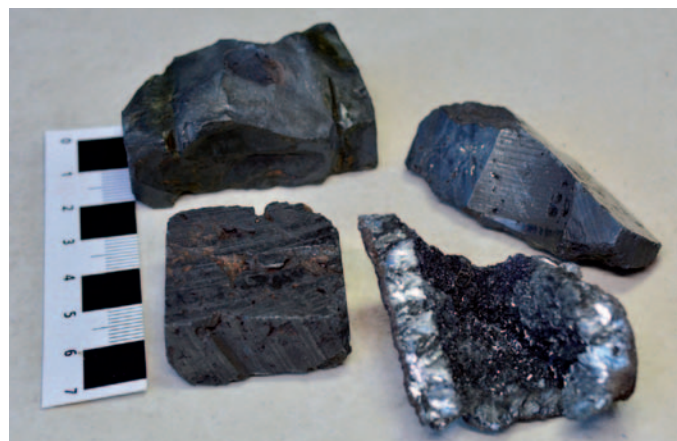
Pyrolusite's magnetic susceptibility is low ( $\sim 125 \times 10^{-5}$  SI), as would be expected for a paramagnetic mineral. Kropáček and Krs (1975) report a range of values. Subordinate amounts of iron oxides can affect the magnetic properties of manganese oxides. Gutzmer and Beukes (1995) describe a magnetic form of hausmannite (Mn<sub>3</sub>O<sub>4</sub>) from the giant Kalahari deposit in South Africa which is hydrothermally altered and strongly magnetic. These workers found up to 11% ferric oxide in their more magnetic samples. Non-magnetic hausmannite contains less than 3% ferric oxide.

Shuey (1975) cites electrical conductivity measurements from 0.1 to over 100 S/m for natural pyrolusite; Olhoeft (1981) gives 1 S/m; Bertin and Loeb (1976) 0.2–50 S/m; Keller (1982) 0.03–143 S/m, and Harvey (1928) up to 1000 S/m. Quite a range.

Not much is known about the physical properties of cryptomelane. Its density is ~4.3 g/cc, but its magnetic susceptibility and conductivity appear not to have been investigated. Cryptomelane's chemical formula can vary considerably depending on its formative environment (Frenzel, 1980). We were not able to locate test specimens of pure cryptomelane.

To try to clarify the physical properties of pyrolusite, four collector grade samples from Morocco, USA, and the Philippines; of coarsely crystalline (#1, 2, 29), and finely crystalline (#30) materials were tested. The pyrolusite crystals are acicular (needle shape) and aggregated haphazardly or obliquely in fibrous bundles imparting an open texture. The hard, though brittle, crystalline material contains pockets and seams of softer, sooty pyrolusite.

Samples #3–28 from Queensland, Western Australia, and Northern Territory are quite different. They comprise



**Figure 2.** Three offcuts from the very finely crystalline, supergene Mn oxides tested (cm/mm scale shown): tight (low porosity 1%), relatively conductive 68 S/m material from Qld, sample 3 in Table 1, top left; porous (8%) low conductivity, 19 S/m, material from NT, sample 4, top right; vuggy quite porous (14%) marginally conductive, 2 S/m, ferruginous material from WA, sample 12 bottom left; also included is an offcut of coarse grained crystalline, very porous (37%), pure pyrolusite with sooty pyrolusite coatings and pockets, low conductivity, 11 S/m, material from Morocco, sample 1, bottom right.

<sup>2</sup>The battery active manganese oxide is nsutite,  $\gamma$  MnO<sub>2</sub> (hydrated), sometimes called ramsdellite. Nsutite is extremely hard, H = 8½, with a density ~4.6 g/cc; it is not thought to be present in the sample suite.



heterogeneous, microcrystalline to cryptocrystalline mixes of Mn oxides, dominantly pyrolusite and cryptomelane. Tough textures are imparted by tight intergrowths of extremely fine grains.

Some samples are shown in Figure 2.

## Measurements

This study focussed on the inductive properties of magnetic susceptibility ( $k$ ) and conductivity ( $\sigma$ ) as they are quickly and conveniently measured. Following Yang and Emerson (1997), the responses of cored subsamples were measured over a frequency range in induction coils to give  $k$  and  $\sigma$  (Figure 3). Remanence measurements were also carried out at CSIRO North Ryde using a 2G Enterprises 755R three-axis cryogenic magnetometer. As an aid to interpretation mass properties were determined following Emerson (1990). Galvanic measurements, carried out at microprobe and core scales, corroborated the EM conductivities, allowing for differences caused by texture. The samples were measured in the 'as received' air dried condition with residual pore water as this was thought to approximate oxidised zones in the field. Vacuum saturation with fresh water was applied in the mass property measurements.



**Figure 3.** An induction coil of the type used in the conductivity measurements. The wire winding is 70 mm long  $\times$  30 mm internal diameter. A conductive core inserted in the coil causes a change in its resistance,  $\Delta R$ , which is measured on an impedance bridge. If the core is magnetic it also causes a change in the coil inductance,  $\Delta L$ . From these quantities electromagnetic conductivity and magnetic susceptibility are derived (Yang and Emerson, 1997). The measurements are usually run in the kHz to MHz range (below the onset of skin effect). An air gap correction would be necessary if this method is used for a mag  $k$  measurement. The 54 mm long, 25 mm diameter Mn oxide test core shown is sample 9 with an 8 S/m EM conductivity and  $114 \times 10^{-5}$  SI mag  $k$ . The core is porous and siliceous.

## Results

The data set for the mass and inductive physical properties measured is given in Table 1.

The bulk density, BD, is the preferred reference parameter for viewing the results. This is regarded as the field density near surface or shallow depth materials above any water table – as would be the case in many supergene Mn oxide deposits. The density, BD, includes residual pore moisture, as quantified by  $S_w$  in Table 1; it is not the dry bulk density, DBD, which is 105°C oven dried density ( $S_w \rightarrow 0$ ) also given in Table 1.

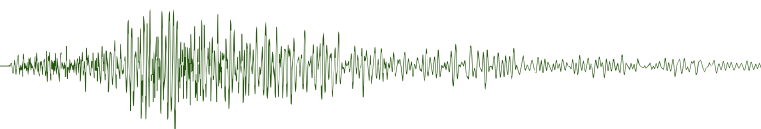
A perspective of the mass properties is provided in Figure 4 where porosities are plotted against dry bulk density. Substantial porosities are evident. The overtly crystalline samples #1, 2, 30 have an apparent grain density of  $\sim 4.8$  g/cc and clearly plot in the pyrolusite field. Sample #29 has quartz grains interstitial to the acicular pyrolusite crystals and plots to the left of the pyrolusite field. Samples #3 to 28 are massive cryptocrystalline, hard, tough, heterogeneous aggregates of Mn oxides (mainly pyrolusite and cryptomelane) together with quartz, clay, and iron oxides in various, usually minor, proportions. This results in a spread of densities with respect to the reference mineralogy. The average porosity of the four coarser crystalline pyrolusites is very high, 31%. The range of microcrystalline pyrolusite/cryptomelane porosity is 1–19%, average 7.5%, for the 26 samples.

Magnetic susceptibility is plotted against bulk density in Figure 5. This has three interpreted features. An envelope of 21 relatively low susceptibility samples manifesting a low angle trend and regarded as representing mixtures of pyrolusite, cryptomelane, and other mineralogies. Above this are two groups thought to contain Fe oxides. Kropacek and Krs (1975) note that mineral aggregates of natural Mn-oxides, generated under the influence of atmospheric agents, bind Fe-oxides. So many natural aggregates of Mn-oxides display weak ferromagnetism.

The conductivity results are conveniently viewed in Figure 6 where EM conductivity is plotted against bulk density, both quantities are for the air dried state.





The interpreted plot has four features:




1. The crystalline pyrolusites show an increasing conductivity with density #1 $\rightarrow$ 2, #29 $\rightarrow$ 30, up to a maximum of  $\sim 10$  S/m, which seems a reasonable limit given the unfavourable crystallinity (needles), the poor crystal to crystal suturing, the very high porosities, and the sooty pyrolusite vughs and lenses. Galvanic microprobing suggests that the sooty pyrolusite is about three times less conductive than the crystalline material, which, as mentioned, in aggregate is not very conductive. It is emphasised that these comments obtain for secondary, sooty and acicular pyrolusites. Hydrothermal pyrolusite and rare large prismatic pyrolusite crystals have not been investigated. Polianite is an uncommon variety of pyrolusite with well formed tetragonal crystals. Suitable samples of such material could not be obtained for testing.
2. Most of the micro/cryptocrystalline, low to moderate porosity, samples plot in a broad belt of conductivity increasing with density. The variability within the envelope is a consequence of the main Mn and minor Fe oxide mineralogy, texture, and the occurrence of silica and clay impurities. The NT samples have more silica and clay and plot on the left side of the envelope.
3. Sample #10 is very siliceous; samples #7, 9 are quite clayey/siliceous. These three samples plot in a lower density trend to the left.
4. An increase in density is regarded as reflecting an increase in pyrolusite content so the broad trend for the tough, extremely



## Feature

Table 1. Manganese oxides: mass and inductive physical properties

#	Code	BD	DBD	P <sub>A</sub>	WBD	GDA	S <sub>W</sub>	magk	Q	EM cond.
		g/cc	g/cc	%	g/cc	g/cc	%	SI x 10 <sup>-5</sup>		S/m
Morocco										
1		3.25	3.20	34.4	3.54	4.88	15	98	<0.01	11
2		3.09	3.06	37.1	3.43	4.86	9	100	<0.01	9
Queensland										
3		4.44	4.43	1.0	4.44	4.45	56	177	<0.01	68
Northern Territory										
4		3.90	3.87	7.9	3.94	4.20	43	160	0.18	19
5		3.89	3.87	6.0	3.93	4.12	33	138	0.01	12
6		4.08	4.07	10.3	4.18	4.54	9	140	0.06	57
7		3.75	3.74	2.5	3.76	3.84	50	143	0.05	27
8		3.53	3.50	8.3	3.58	3.82	38	137	0.15	4
9		3.59	3.57	3.5	3.61	3.70	50	114	0.04	8
10		2.95	2.93	11.1	3.04	3.30	18	68	0.03	4
Western Australia										
11		3.87	3.85	2.5	3.88	3.95	67	128	1.00	10
12		3.61	3.57	14.1	3.71	4.16	29	496	3.60	2
13		4.12	4.10	3.0	4.13	4.23	67	277	1.80	49
14		3.88	3.84	7.8	3.92	4.16	50	426	0.37	17
15		4.32	4.29	4.8	4.34	4.51	60	333	<0.01	18

#	Code	BD	DBD	P <sub>A</sub>	WBD	GDA	S <sub>W</sub>	magk	Q	EM cond.
		g/cc	g/cc	%	g/cc	g/cc	%	SI x 10 <sup>-5</sup>		S/m
Western Australia										
16		4.17	4.15	7.1	4.22	4.47	29	460	<0.01	10
17		4.15	4.12	7.6	4.19	4.46	43	181	0.01	20
18		4.60	4.57	5.6	4.62	4.84	60	185	0.01	35
19		3.91	3.90	19.3	4.09	4.83	5	127	<0.01	31
20		4.30	4.27	4.6	4.32	4.48	60	453	<0.01	28
21		4.16	4.10	8.4	4.18	4.48	75	138	0.02	67
22		3.82	3.81	3.3	3.84	3.94	30	94	0.01	7
23		3.42	3.40	6.5	3.46	3.64	33	97	0.03	2
24		3.67	3.60	8.4	3.74	3.99	50	133	0.05	4
25		3.80	3.76	10.8	3.87	4.26	37	297	1.06	17
26		4.10	4.08	9.9	4.18	4.53	20	148	<0.01	33
27		3.64	3.61	7.3	3.69	3.89	38	201	0.39	5
28		3.46	3.41	13.4	3.54	3.94	37	151	0.07	4
Arizona, USA										
29		3.08	3.06	26.6	3.33	4.20	7	93	<0.01	3
Philippines										
30		3.71	3.53	25.7	3.79	4.75	69	198	0.40	8

- Notes:
- BD – bulk density air dried, as collected; DBD – dry bulk density, 105°C dried; WBD – freshwater saturated density; P<sub>A</sub> – apparent (water accessible) porosity; GDA – inferred grain density; S<sub>w</sub> – residual water saturation level in pores in air dried state; measurements made @ 20°C temperature.
  - Magnetic susceptibility, magk, various methods including induction coil 460 Hz; Q Koenigsberger ratio modulus of J<sub>NRM</sub>/J<sub>IND</sub>, J magnetization intensity, NRM remanence, IND induction J = kF, F earth's field.
  - EM conductivity, EMσ, induction coil 2.5 MHz, air dried state.
  - Cited values rounded off.
  - MnOx is a collective term for mix of manganese oxides not specifically determined; These supergene test samples are mainly mixtures of pyrolusite and cryptomelane – two of the most common oxidation zone Mn oxides.
  - pyrolusite β MnO<sub>2</sub>, either crystalline, dark grey-black, silvery, metallic lustre, Moh's hardness >6; or soft, sooty fine grained, dull black, Moh's hardness ~2; blackish grey streak; theoretical density 5.23 g/cc, field density 4.8–5.0 g/cc (quite high).
  - cryptomelane K(Mn<sup>4+</sup> > Mn<sup>2+</sup>)<sub>8</sub>O<sub>16</sub> steel-grey, submetallic lustre, Moh's hardness ~6, black streak; in addition to K, this mineral can have other metal ions substituting in its lattice (e.g. Ba) and its formula can be quite complex; density 4.3 g/cc (lower than pyrolusite)
  - braunite, 3Mn<sub>2</sub>O<sub>3</sub>·MnSiO<sub>3</sub> (10% by weight silica) may be present in some of the WA samples #11–28, but was not positively identified at mesoscale, it is thought that braunite's mag k exceeds that of pyrolusite, however in the absence of suitable reference samples this could not be substantiated
  - pyrolusite, cryptomelane, braunite are paramagnetics and crystallise in the tetragonal system
  - samples 1, 2 from Imini mine Morocco are coarsely crystalline pyrolusites with sooty pockets and minor/trace quartz; sample 29 from Pima mine Arizona has coarsely crystalline acicular (needle) pyrolusite, sooty pyrolusite, and quartz; sample #30 from Larena, Siquijor Island, Philippines, fine grained crystalline pyrolusite and sooty pyrolusite bands
  - the Australian samples #3–28, generally hard, tough, extremely fine grained, and variably porous, are from various locations in Queensland, Northern Territory and Western Australia.
  - the crystalline pyrolusites are highly porous and comprise often haphazardly stacked, fibrous splays or bundles of acicular (needle) pyrolusite crystals a few microns in diameter and tens of microns in length; the open 'loose' textures in #1, 2, 29, 30 are in complete contrast to those in #3–28.
  - pyrolusite: nominally BD 5.0 g/cc, 100 S/m cond; 125 × 10<sup>-5</sup> SI mag k, reported values for pyrolusite show considerable variation especially in conductivity; sooty soft pyrolusite's conductivity is less than that of crystalline pyrolusite; cryptomelane: nominally 4.3 g/cc but mag k and conductivity not reported
  - samples #3–28 are heterogeneous in composition, they contain minor amounts of silica, clays, iron oxides, and MnOx other than pyrolusite and cryptomelane.

fine grained interlocked oxides, #3–28, suggest that 100 S/m would be a reasonable notional value to ascribe to a material comprising 100% pyrolusite of this nature.

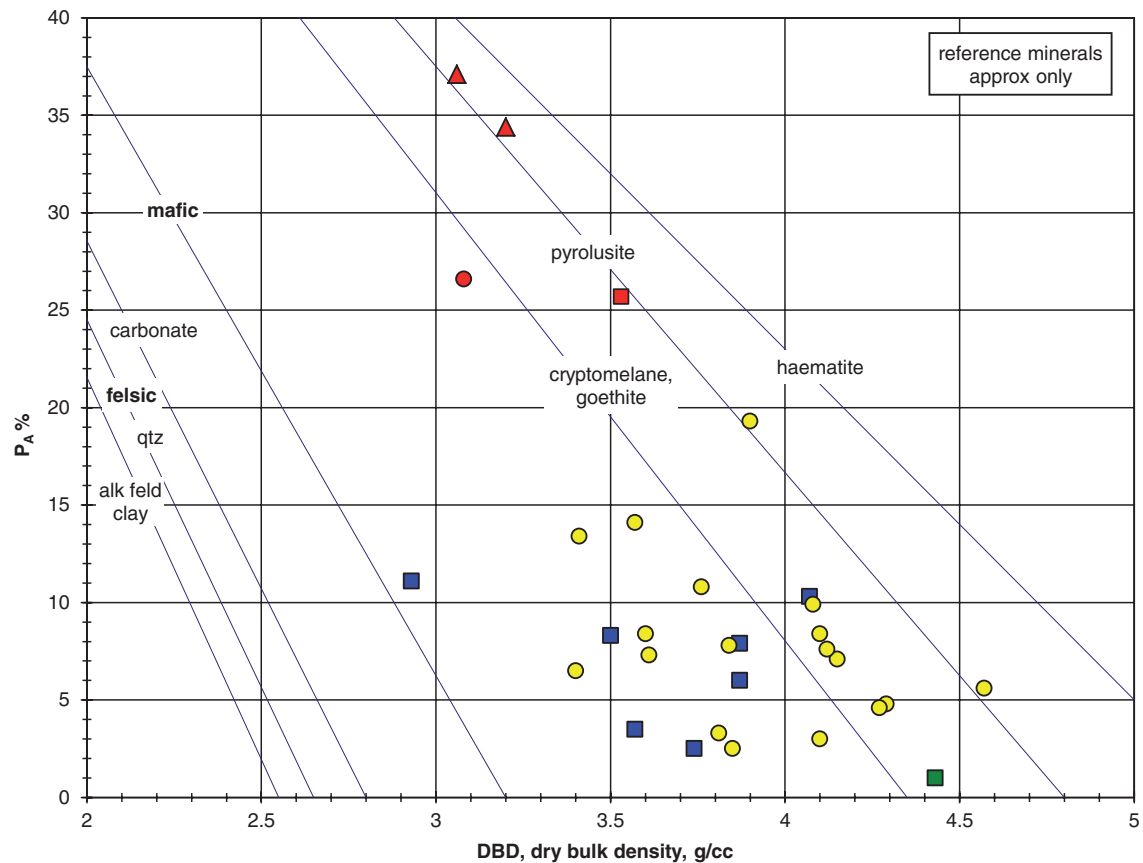
A plot of conductivity against inferred grain density (porosity removed) is given in Figure 7 where the features are similar to those in Figure 6.

Conductivity does not appear to depend on S<sub>w</sub>, the residual water saturation (crossplots for S<sub>w</sub> not shown here), this is to be

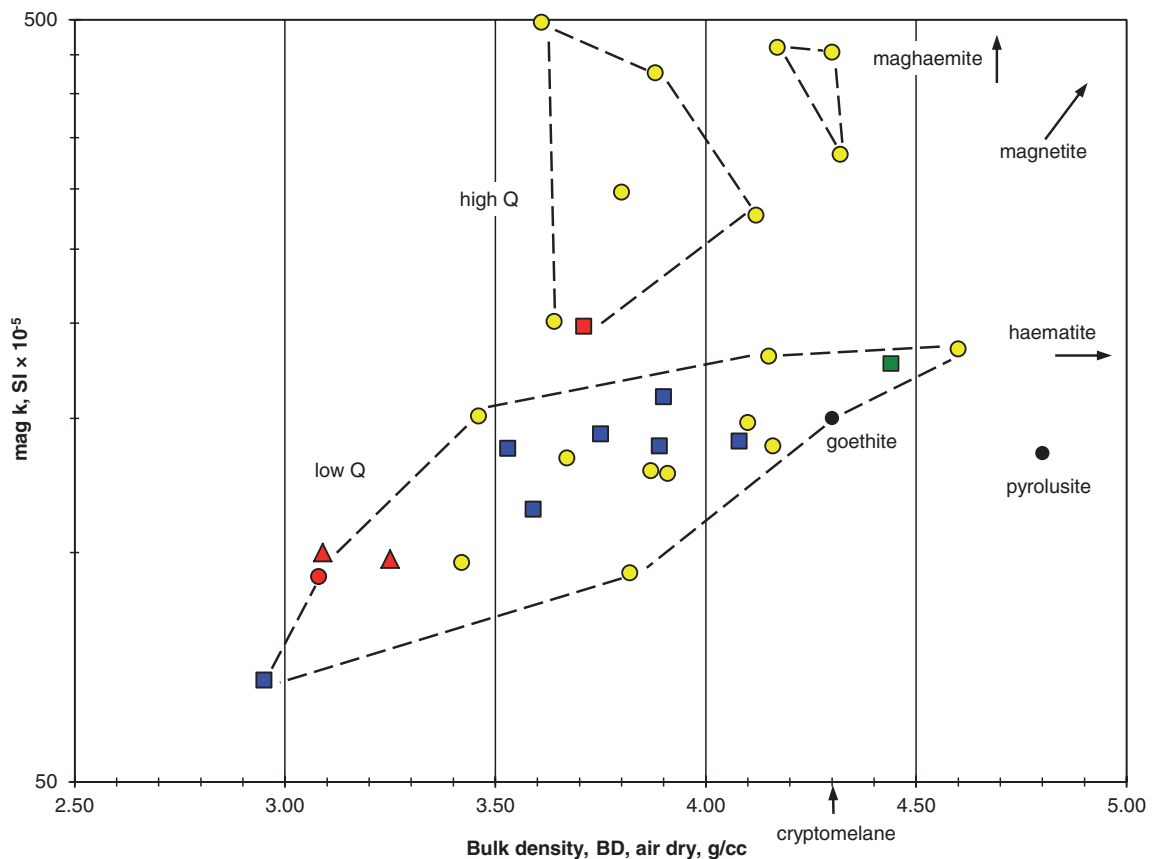
expected because the preferable mode of conduction would be through the pyrolusite content, either massive or networked, and not through relatively resistive residual pore moisture.

For the tough heterogeneous cryptocrystalline Mn oxide samples (#3–28) there are no clear correlations or features when conductivity is plotted against porosity (not shown here) so the relatively low porosities, average 7.5%, are not regarded as having a predictable influence when the group is

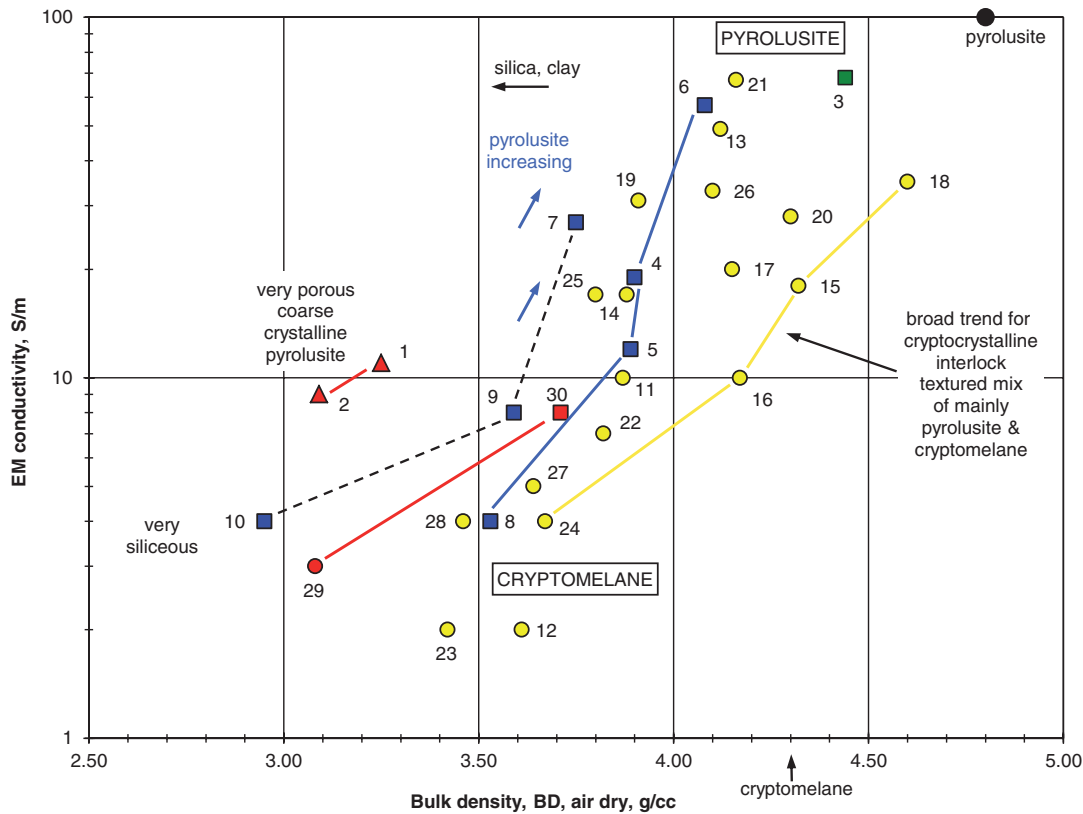
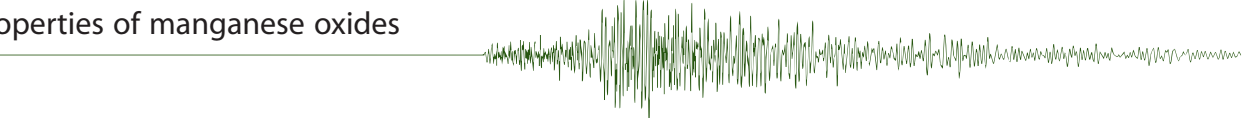




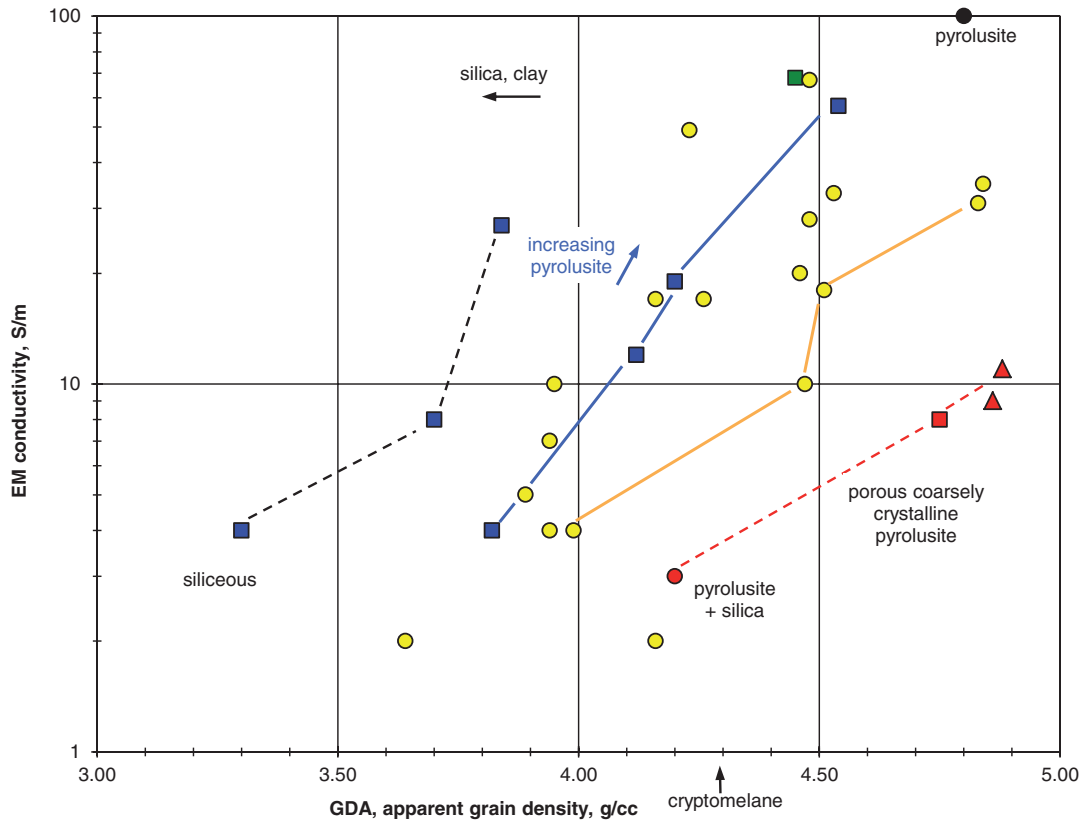
**Figure 4.** Porosity plotted against dry bulk density with reference mineralogy trends shown. The reference 'text book' mineral densities are approximate only, variations can occur. See Table 1 for plot point colour code.



**Figure 5.** Magnetic volume susceptibility plotted against bulk density (for the air dried state) showing three features interpreted from the data. Reference mineral values are approximate only, they can vary considerably.

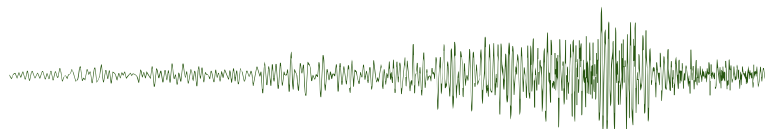


**Figure 6.** Induced (EM) conductivity plotted against bulk density (air-dry state) with features interpreted from the data. The reference value for pyrolusite is nominal. For the variably ferruginous cryptocrystalline materials, samples at the top of the plot are rich in pyrolusite, e.g. #3; those at the bottom are pyrolusite poor and have more cryptomelane, e.g. #28. Conductivity rises with increasing pyrolusite content, and also with improvement in pyrolusite networking. The coarser crystalline pyrolusites #1, 2, 29, 30 have quite different textures and exhibit a separate behaviour.



**Figure 7.** An adjustment of Figure 6 showing induced (EM) conductivity plotted against inferred grain density (i.e. porosity removed). See Table 1 for plot point colour.





considered as a whole. However, it would be expected that the conductivity of an individual sample would be boosted if the void space was occupied by semiconducting pyrolusite. So the crystalline pyrolusites (#1, 2, 29, 30) with large void spaces could show a significant increase in conductivity if filled with pyrolusite. However, even if conductivity doubled, to say around 20 S/m, it would not render these materials very conductive; their textures are simply not favourable for good electrical continuity.

### Concluding remarks

The results of the sample tests suggest that surficial or near surface, secondary, residual, porous Mn deposits comprising mainly pyrolusite and cryptomelane in massive, tough, cryptocrystalline form, have low to moderate conductivities, ~1 S/m up to ~70 S/m, and moderate to high densities, ~3.5–4.5 g/cc. The conductivities increase with pyrolusite content. Overtly crystalline, fibrously textured, very porous, quartz-free pyrolusite has a conductivity of ~10 S/m. About a third of the volume of these overtly crystalline samples is void space, and it is considered that this, the needle grain shape, and poor grain boundary suturing, account for the lower conductivity of the coarsely crystalline pyrolusite.

Frenzel (1980) states that manganese oxides are, as a rule, electrically non-conducting. Pyrolusite is the exception to this rule. It is not known whether cryptomelane is a conductor. We were not able to access literature values or obtain good samples of cryptomelane for testing. Tentatively, on the basis of galvanic microprobing of samples and the results presented here, a conductivity of ~5 S/m is ascribed to a compact microcrystalline Mn oxide mix comprising mainly cryptomelane with subordinate pyrolusite content (e.g. #27, 28), but it is likely that sparsely networked pyrolusite imparts the conductivity.

The air dried state conductivities of the tough microcrystalline Mn oxide assemblages are low to moderate and largely dependent on the pyrolusite content. The conductivities are not directly diagnostic of Mn grade as insulating or only slightly conductive Mn minerals other than pyrolusite, e.g. cryptomelane, can be present in high concentration. High grade secondary pyrolusite ore comprising by volume 60% pyrolusite, 20% cryptomelane, 10% felsics, and 10% porosity ( $S_w = 0$ ) would have an Mn content of ~58% by weight, a density of ~4 g/cc, and an expected conductivity ~55 S/m based on the analysis of the 26 samples in Table 1. If the ore is 10% pyrolusite, 70% cryptomelane, 10% felsics, and 10% porosity ( $S_w = 0$ ) then it would contain 56% Mn, its density would be ~3.8 g/cc, and its expected conductivity ~5 S/m. Similar Mn contents do not mean similar physical properties.

The lower than expected conductivities for the four overtly crystalline pyrolusites are surprising. The inductive data were checked with galvanic microprobing and four electrode core scale DC galvanic resistivity tests. All this data shows without doubt, that such pyrolusites, or at least the four tested, are not very conductive. This, for want of a better explanation, is ascribed to porosity, crystal shape and grain boundary effects, and to the frequent occurrence of pockets of sooty pyrolusite with conductivity below that of the crystalline material.

The results of this work are not definitive but they are indicative for the types of mineralisation documented here. The accuracy of the physical property measurements is better than 1%. If

samples #3 to #28 can be regarded as reasonably representative elementary volumes of oxidation zone Mn oxide deposits comprising a mixed, very fine grained pyrolusite – cryptomelane mineralogy, then such deposits are indicated by this study as likely having EM conductivities in the 1 to 100 S/m range and magnetic susceptibilities in the 100 to 500  $\times 10^{-5}$  SI range. The conductivities are dependent on the pyrolusite content and sensitive to the effects of texture and to the presence of other minerals such as silica. The susceptibilities depend on all the Mn oxides present, as all Mn oxides are paramagnetic and manifest low to moderate susceptibilities. Iron oxides, if present, would contribute to susceptibility. If magnetic effects derive from Mn oxides of the type documented here, it is probable that they will be low order ( $k \approx 100 \times 10^{-5}$  SI) and of limited, if any, use in exploration, especially in the magnetic noise of ferruginous weathered zones.

Mn oxide rock assemblages have other interesting properties: temperature effects, where pyrolusite shows behaviour typical of many semiconductors (Shuey, 1975) in that conductivity increases with temperature (about three-fold from room temperature to 100°C); saturated state resistivities (very dependent on saturant salinity); and IP effects (for saturated state pyrolusite typically ~100 mV phase lag @ 0.1 Hz). These aspects are not dealt with here, but some data on compressional (P) wave velocities are given in Appendix 1.

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The source of the image used in the title is 'Manganese dendrites on a limestone bedding plane from Solnhofen, Germany. Scale in mm.'. Public domain; <https://commons.wikimedia.org/wiki/File:Dendrites01.jpg>.

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**Don Emerson and Phil Schmidt** are geophysical consultants specialising in hard rock petrophysics.

Appendix 1. Compressional (P) wave velocity and porosity

Compressional (P) wave velocities were measured on ten air-dried samples (Table A1). Ultrasonic (200 kHz) transit times were recorded under 10 kN uniaxial load. Although the velocities are not indicative of conductivities (the rationale for the measurements) the results are included here as there appear to be little or no published velocity data for Mn oxides.

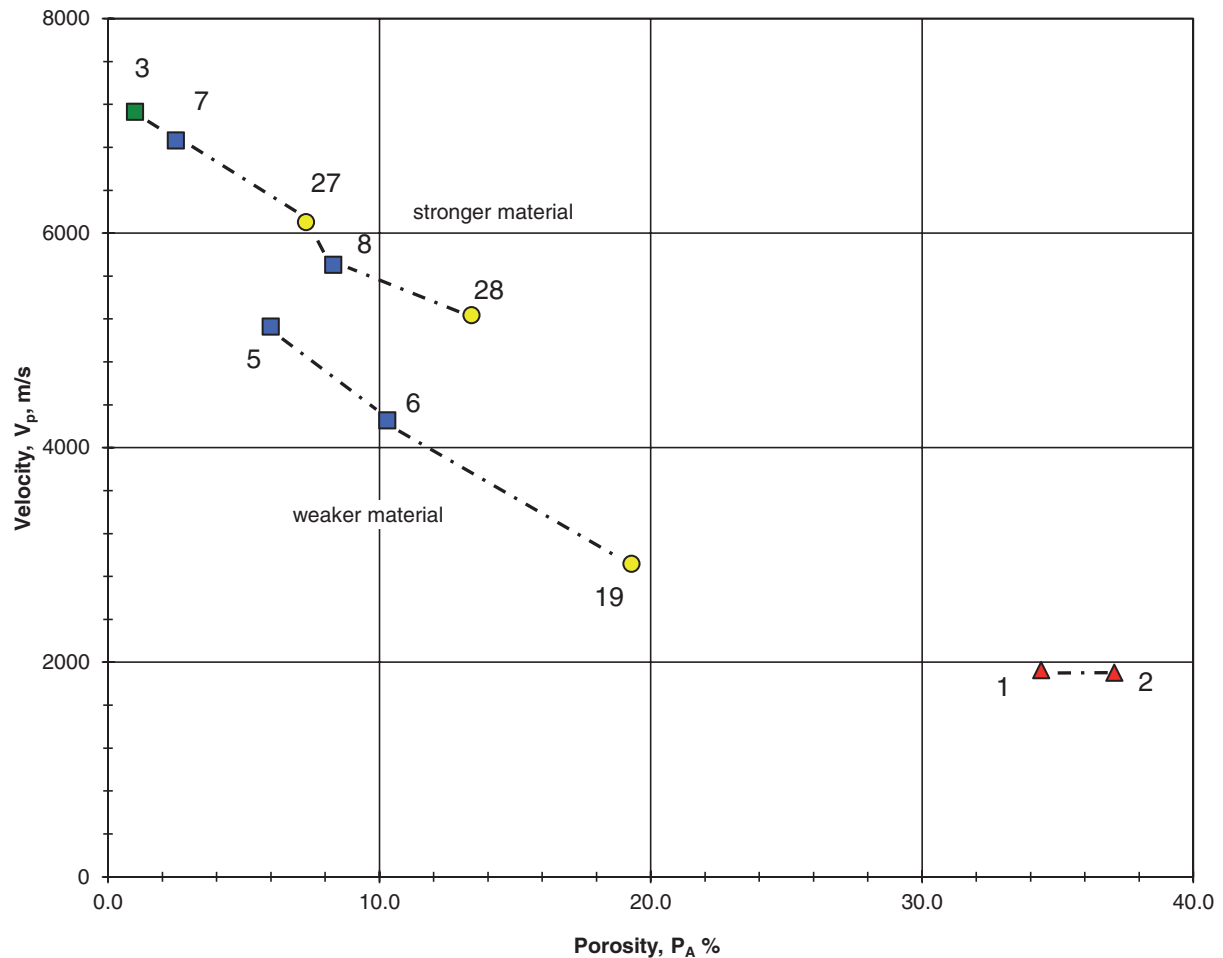
Velocities are seen to decrease as porosity increases (Figure A1), a behaviour commonly observed in all rock types, and on which an extensive literature exists (Mavko et al., 1998). The data do suggest that at zero porosity a velocity of about 7500 m/s may obtain, i.e. a high velocity similar to the other metal oxides such as haematite. However, here seven of the materials are not monomineralic, but rather very fine grained heterogeneous mixtures of pyrolusite, cryptomelane and a minor miscellany of other Mn oxides, with or without some silica and clay. The two pure coarse grained Moroccan pyrolusites have low velocities on account of their texture and very high porosities. The Pwave velocity depends on the elastic moduli and density of the whole mass of rock, on which porosity exerts a strong influence; the conductivity depends on the amount, distribution and networking of pyrolusite, and porosity, unless very high, exerts only a second order minor influence. The calculated acoustic impedances [ $Z_{ac} = V_p \times BD$ ] in Table A1 suggest the compact, tight (low porosity), high velocity microcrystalline Mn oxides (e.g. #3, 7) could present strong reflectivity contrasts to sedimentary host rocks.

Table A1. Compressional (P) wave velocities were measured on 10 air-dried samples. Refer to Table 1

#	BD g/cc	V <sub>p</sub> m/s	Z <sub>ac</sub> k $\text{tm}^{-2} \text{s}^{-1}$	P <sub>A</sub> %	EM cond S/m
1	3.25	1924	6.3	34.4	11
2	3.09	1902	5.9	37.1	9
3	4.44	7129	31.7	1.0	68
5	3.89	5129	20.0	6.0	12
6	4.08	4255	17.4	10.3	57
7	3.75	6864	25.7	2.5	27
8	3.53	5704	20.1	8.3	4
19	3.91	2918	11.4	19.3	31
27	3.64	6100	22.2	7.3	5
28	3.44	5233	18.0	13.4	4

A rough rule of thumb for an empirical relationship between P wave velocity (V<sub>p</sub>) and unconfined compressive strength (UCS) is:  $UCS \approx (V_p)^3$ , here UCS is in MPa and V<sub>p</sub> is km/s. So for sample #3  $UCS \approx 362 \text{ MPa}$  (very strong material), and for sample #1 it is much lower,  $UCS \approx 7 \text{ MPa}$  (quite weak, mechanically). These features were noted in core cutting: the tight cryptocrystalline samples, e.g. #3 were extremely difficult to drill, whereas the coarse, porous samples, e.g. #1 were easy to cut.





**Figure A1.** Ultrasonic compressional (P) wave velocity plotted against porosity shows a pronounced decrease in velocity as porosity increases in the very fine grained heterogeneous Mn oxides, a diminution in velocity is associated with fracturing in three of these (#5, 6, 19); the coarsely crystalline very highly porous pyrolusites (#1, 2) have quite low velocities.



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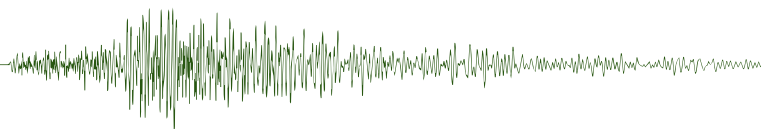
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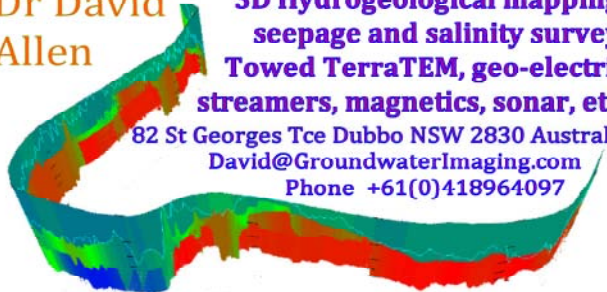
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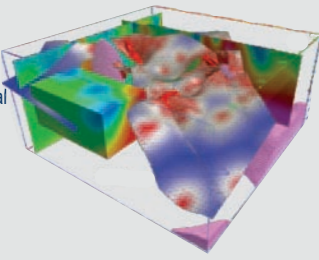


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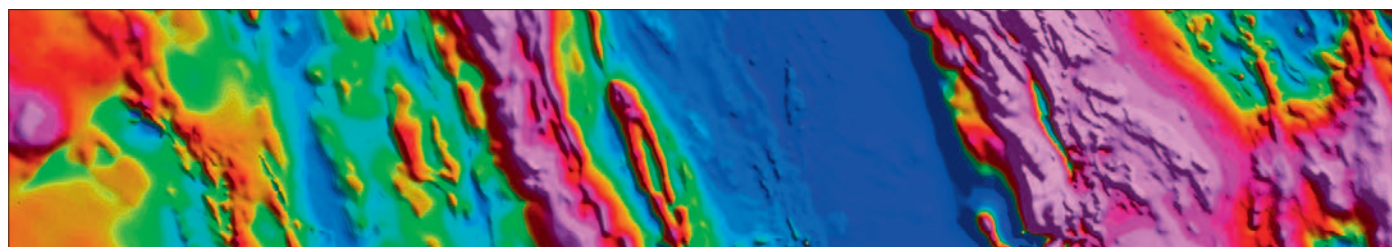
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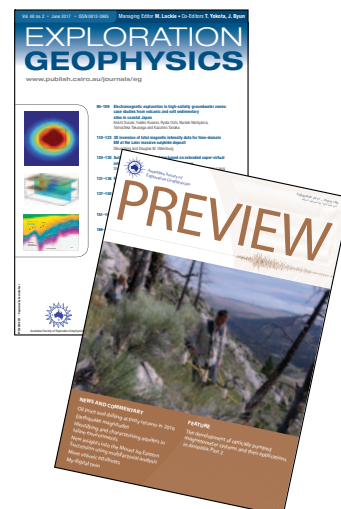
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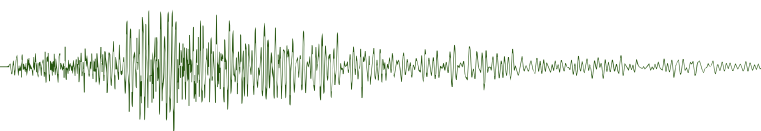
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December	2018		
6	South Australian Exploration and Mining Conference <a href="http://www.saexplorers.com.au/">www.saexplorers.com.au/</a>	Adelaide	Australia
10–14	AGU Fall Conference <a href="https://fallmeeting.agu.org/2018/">https://fallmeeting.agu.org/2018/</a>	Washington, DC	USA
February	2019		
14–15	GeoTHERM - Expo & Congress <a href="http://www.geotherm-germany.com/">http://www.geotherm-germany.com/</a>	Offenburg	Germany
March	2019		
17–21	SAGEEP 2019 <a href="https://www.sageep.org/">https://www.sageep.org/</a>	Portland	USA
26–28	International Petroleum Technology Conference <a href="http://www.iptcnet.org/19iptc/home/">http://www.iptcnet.org/19iptc/home/</a>	Beijing	China
April	2019		
7–12	EGU <a href="https://www.egu2019.eu/">https://www.egu2019.eu/</a>	Vienna	Austria
23–36	5th International Workshop on Rock Physics <a href="http://sgpnus.org/5iwrp.html">http://sgpnus.org/5iwrp.html</a>		Hong Kong
23–26	EAGE-GSM 2nd Asia Pacific Meeting on Near Surface Geoscience & Engineering <a href="https://events.eage.org/en/2019/eage-gsm-nsge-2019/">https://events.eage.org/en/2019/eage-gsm-nsge-2019/</a>	Kuala Lumpur	Malaysia
May	2019		
6–9	Offshore Technology Conference <a href="http://2019.otcnet.org/welcome">http://2019.otcnet.org/welcome</a>	Houston	USA
13–17	GeoConvention 2019 <a href="https://www.geoconvention.com/">https://www.geoconvention.com/</a>	Calgary	Canada
19–22	GEM 2019 Xi'an <a href="https://seg.org/Events/Events-Calendar/GEM-2019-Xian">https://seg.org/Events/Events-Calendar/GEM-2019-Xian</a>	Xi'an	China
June	2019		
3–6	81st EAGE Conference & Exhibition 2019 <a href="https://events.eage.org/2019/EAGE%20annual%202019">https://events.eage.org/2019/EAGE%20annual%202019</a>	London	UK
11–13	AGU/SEG Airborne Geophysics Workshop	Golden	USA
16–20	8th International Geosciences Student Conference	Uppsala	Sweden
September	2019		
2–5	AEGC 2019: Data to Discovery <a href="http://2019.aegc.com.au/">http://2019.aegc.com.au/</a>	Perth	Australia
8–12	Near Surface Geoscience Conference and Exhibition 2019 <a href="https://events.eage.org/2019/Near%20Surface%202019">https://events.eage.org/2019/Near%20Surface%202019</a>	The Hague	The Netherlands
15–20	SEG International Exposition and 89th Annual Meeting	San Antonio	USA
22–25	2019 GSA Annual Meeting <a href="https://www.geosociety.org/GSA/Events/Annual_Meeting/GSA/Events/gsa2019.aspx">https://www.geosociety.org/GSA/Events/Annual_Meeting/GSA/Events/gsa2019.aspx</a>	Phoenix	USA
October	2020		
6–9	SAGA 16th Biennial South African Geophysical Association Conference and Exhibition <a href="http://sagaconference.co.za/">http://sagaconference.co.za/</a>	Durban	South Africa
11–16	SEG International Exposition and 90th Annual Meeting	Houston	USA
21–24	Fifth International Conference on Engineering Geophysics (ICEG) <a href="https://seg.org/Events/ICEG-2019">https://seg.org/Events/ICEG-2019</a>	Al Ain	UAE
29–31	OTC Brazil <a href="http://www.otcnet.org/Brasil">http://www.otcnet.org/Brasil</a>	Rio de Janeiro	Brazil

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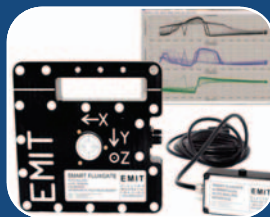
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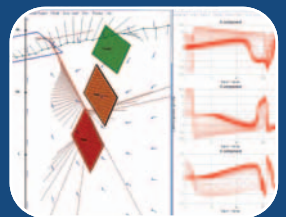
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