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Australian Society of Exploration Geophysicists

PREVIEW

NEWS AND COMMENTARY

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LIN approximation

Too good to be true

Spectral decomposition

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FRONT COVER

Andrew Pearson, a MSc student at the University of Melbourne, collecting gravity data over the Wentworth Trough in Victoria (see *Education matters* in this issue). Photo by P Skladzien.

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Editor's desk

We are delighted to present you with this Christmas issue of *Preview* and to inform you that, once again, we have been blessed by Don Emerson. He has crafted a feature on Haematite – the bloodstone, and is challenging our thinking about the physical properties of this most common but elusive mineral. On a more prosaic note, Michael Asten (*Education matters*) has put together a mini-feature on theses completed by geophysical students in Australia in 2017. This compilation is a compelling read for all of us interested in the future of our profession, and it would seem that our President (*President's piece*) is not alone in thinking that a broad-based training in the geosciences is important for job security in the exploration industry. We also say goodbye to Marion Rose (*Vale Marion Elisabeth Rose*). David Denham (*Canberra observed*) takes the opportunity to share his concerns about the decline in Australian research investment. Mike Hatch (*Environmental geophysics*) ruminates on low induction number approximation. Terry Harvey (*Mineral geophysics*) reminds us that if something appears to be too good to be true, it probably is, and 'Santa' Mick Micenko (*Seismic window*) introduces, or in some cases re-introduces, readers to spectral decomposition.

As this is the last issue for 2017 I would like to thank all *Preview* contributors and, in particular, the *Preview* editorial team for their unflagging support over the past 12 months. Your magazine would be nothing if not for their efforts. I would also like to thank the *Preview* production team, particularly for their patience – it can't be easy working with a bunch of amateurs who have difficulty staying focused on the job at hand. I think Helen has heard just about every imaginable excuse for missed deadlines. I am not sure, but I think she may have even heard the one about the dog…

Whilst on that topic, *Preview* may have made it onto your screens and into your letterboxes a little later than you have come to expect, but this time around I really do have a good excuse. I had only intermittent internet connection for most of November as I was trekking in Nepal with a group of colleagues interested in the ongoing evolution of the Annapurna Range and the consequent development of natural hazards, particularly landslide hazards – that was our rationale anyway! The group was led by Professor Monique Fort from the Université Paris, Diderot. Monique has been working in Nepal for over 40 years. When she started she had to walk for days, if not weeks, to reach areas that we were able to reach in days courtesy of the 'new silk road' being built from Tibet across Nepal and into India by the Chinese. The road is being hacked out of the mountains and is under constant threat from landslides, which are often triggered by earthquakes. After being bounced over rocks at an average speed of 10 km/h and then facing daunting climbs up steep mountainsides, it struck me that this was a terrain in which drone technology could really come into its own – particularly if that technology borrowed from Mars research and incorporated some sort of sampling mechanism. Now there is a Christmas challenge for the gadget builders amongst you!

A safe and happy festive season to you all!!

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

The Editor at Tatopani in Nepal at the start of a trek into the Higher Himalaya.

President's piece

Andrea Rutley

With barely one month left of the year, it never fails to amaze me at just how quickly every year seems to pass by. Once Christmas is past the New Year will be upon us and, all too quickly, so too will be our conference. This year we join with the Australian Institute of Geoscientists Ltd and the Petroleum Exploration Society of Australia Ltd to run a geosciences conference – the *First Australasian Exploration Geoscience Conference* – incorporating the *26th International Geophysical Conference and Exhibition*.

What does this mean? There are Members who have wondered, 'What happened to the *26th ASEG Conference* and why did it became the *First Australasian Exploration Geoscience Conference*?' The short answer is that our conference is still happening, it is just wearing a different label. As time progresses, and as our industry develops, we must become broader in our skills and, whilst still being technically strong geophysicists, we must also be fully integrated members of exploration teams. Exploration companies are actively searching for the integrated geoscientist and we need to be able to help our Members become educated in areas that were once considered outside of their scope.

As members from each organisation formed a Conference Organising Committee, the drivers to develop an integrated conference became stronger. Some of these drivers are:

- Broadening the scope of the conference to attract a wide range of geoscience papers from all corners of the industry
- Involving geologists and geophysicists in one conference
- Reducing the number of individual, small conferences, all targeting the same audience and targeting the same support funds.

As a result of the considerable work that the Committee has been undertaking, we will have the opportunity to attend a conference that includes geology, geophysics, engineering, groundwater, minerals and petroleum exploration – a truly integrated event. This conference aims to be the premier event for our region, drawing wide range of delegates, and so a new name was initiated – the *First Australasian Exploration Geoscience Conference* or *AEGC 2018*. The themes for the event are 'Exploration-Innovation-Integration'.

At the time that I am writing this update the conference delegate numbers are continuing to grow, with ASEG Members forming about half of the total number of delegates. I know that there are plenty of you that have not yet registered, so I would encourage you to head to the conference website http://www.aegc2018.com.au/, or to ASEG website https://www.aseg.org.au/ where you will see the conference advertised on the home page.

Don't delay, please register today and join all your colleagues in Sydney for yet another great collaborative event.

Andrea Rutley
ASEG President
president@aseg.org.au

Welcome to new Members

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

First name	Last name	Organisation	State	Country	Membership type
Antonia	Alvarado	Geofisica Austral Ltda.	Santiago	Chile	Active
Steve	Boucher	Geofisica Austral Ltda.	Santiago	Chile	Active
Marcello	Imaña		Storuman	Sweden	Associate
Unnikrishnan	Karumathil	Department of Primary Industry and Resources	NT	Australia	Active
David	Marchant	Computational Geosciences Inc.	West Vancouver	Canada	Associate
Rami	Matar	Mansoura University	Dammam	Saudi Arabia	Student
Matthew	Musolino	The University of Adelaide	SA	Australia	Student
Gabriel	Owowa	Synterra Energy	Abuja	Nigeria	Associate
Sofya	Popik	Curtin University	WA	Australia	Student
Greg	Staples	Earth Signal Processing Ltd	Calgary	Canada	Active

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Executive brief

The Federal Executive of the ASEG (FedEx) is the governing body of the ASEG. It meets once a month, via teleconference, to see to the administration of the Society. This brief reports on the last monthly meeting, which was held in October.

Society finances

The Society's financial position at the end of October 2017:

Year to date income $351 390
Year to date expenditure $305 711
Net assets $1 122 519

Membership

The FedEx have reviewed results of the membership survey as published in *Preview* 190 pp. 6–14. Several Member suggestions have been actioned. We will endeavour to keep you informed on the latest enhancements to membership benefits to ensure you're getting the most from your ASEG membership.

Communication was highlighted as an area with room for improvement; many Members indicated that they don't receive electronic notices from the ASEG, or that they're not receiving their copy of *Preview* Magazine. You may have noticed that in October we asked you to update your Currinda Profile. It is very important you keep your details up-to-date so we can continue to contact you if you change jobs (and therefore email address) or move house! If you haven't already done so, please check your profile by following the steps appended below.

Additionally, if you hear a colleague mention that they have not received something that you have received tell them to check their profile – and whether their membership fees have been paid!

Several Members used the Membership survey to volunteer to assist with the running of the Society, and President Elect Marina Costelloe has successfully recruited these individuals to positions within local branches or on federal committees. The FedEx is still recruiting, in particular we are interested in candidates willing to take on the position of Education or Publications Committee Chair. Please contact secretary@aseg.org.au if you're interested in helping to direct the future of our Society.

Finally, the year is fast coming to an end – don't forget to register for the upcoming *First Exploration Geoscience Conference* http://www.aegc2018.com.au/. This is the *26th ASEG Conference and Exhibition*, it is just labelled differently.

There are strong geophysics streams, as we have come to expect from our conferences, and also strong earth science streams – reflecting our integrated industry.

Megan Nightingale
Secretary
fedsec@aseg.org.au

Steps to access your ASEG membership profile details:

Step 1: Go to www.aseg.org.au and click 'Login' at the top right

Step 2: Log in with your email and password. If this is your first time logging into the website or if you have any trouble please contact the secretariat – secretary@aseg.org.au

Step 3: You will be redirected to your Profile page

*If your details are correct, there is nothing more to do

**If you need to make any changes, proceed to Step 4

Step 4: Click on 'Update Details' and make any changes required and click 'Save' at the bottom of the page

If you have any problems please contact the secretariat – secretary@aseg.org.au.

News from the ASEG Young Professionals Network

In the past few months we've really kick-started our activities, most notably launching a mentoring scheme with PESA in Victoria (see report below). A LinkedIn group and Facebook page were rebooted as a means of more rapidly disseminating information on career development opportunities between the network's members. Our Members should think of these social media platforms as noticeboards and are encouraged to make posts, 'like' or share. In this way, we feel that we can build a greater critical mass to make early career training more accessible, more affordable and of better quality.

A call for Young Professionals (YPs) to head up networks in their home state was answered quickly and enthusiastically and we'd like to welcome Elyse Schinella (NSW), Jeremy Lee (VIC), Tavis Lavell (WA), Chris Li (SA), who will take on leadership roles in their respective states by helping roll out mentoring schemes and/or running seminars and local training sessions (with a bit of help from their State Committees). We're still looking for state reps for Queensland, Tasmania and the ACT.

On a federal level, we've been trying to establish contacts and protocol for interacting with PESA to better coordinate joint YP activities between ASEG and PESA. The relationship with AIG seems to be working well already, and eventually we may also find common ground with other geoscience professional societies such as GSA and SPE. Such relationships may serve us well at joint conferences, and also enable local training initiatives to run economically.

For the upcoming AEGC conference please stay tuned for more information on a social event, to be held at a classy Sydney watering hole, which promises to be a relaxed opportunity to meet other YPs. Subject to sufficient registrations the Presentation skills workshop will go ahead, but we would like those interested to book ASAP so that the best possible venue can be secured in advance. For logistical reasons there is a cap on the number of attendees for this course and registrations will be taken on a first-come, first-served basis. We've had interest from 'not so young' professionals and would like to stress that everyone is welcome to attend this course.

Further down the pipeline we are hoping to offer a decision analysis workshop at the AGCC conference in Adelaide in October 2018. Also, the Victorian YPN (ASEG & PESA) is currently developing a foundation-level E&P workflow seminar series to be held on a monthly basis during 2018 and beyond.

Jarrod Dunne and Megan Nightingale
ASEG Young Professionals Network
ypadmin@aseg.org

Launch of the PESA/ASEG (VIC) Young Professional's Network

On Tuesday 17 October the PESA/ASEG (VIC) Young Professional's Network and mentoring programme was launched at Melbourne University's Earth Sciences Building. Prior to this event we had invited YPs and potential mentors to nominate themselves by completing a small survey that enabled us to optimise pairings to some degree. We received 10 mentee applications and to our great surprise we had a slight surplus of mentors. Not everyone could attend the launch event, but those who didn't quickly made plans to meet their assigned mentor at a more convenient time.

The launch event was kept very informal to encourage discussion. Some great wines, cheese and antipasti were consumed whilst introductions made. Jarrod Dunne then gave an overview of the development of the YPN within ASEG, PESA and other geoscience societies. For example, the YPN was promoted by the ASEG FedEx and it is currently being rolled out to the states, whereas PESA now has networks established in a few states but no transparent federal oversight (at present).

In a federal sense, YPN events and workshops are being planned around conferences, often involving equivalent YPNs from sister societies, such as the AIG. In the states where PESA currently has YPNs the focus to date has been on mentoring, and some branches have elected to only pair with SPE at this stage. Ultimately these pairings will allow an economy of scale, which over time should enable YPs (guided by their mentors) to have more control over their training opportunities, both in terms of content and cost.

Discussion amongst the group after Jarrod's presentation was initially focused on the type of training that both mentors and mentees felt would most benefit YPs. Foundation technical courses are hard to

Jarrod Dunne facilitating the launch of the ASEG/PESA YPN in Victoria.

come by in tough times, especially if you aren't part of a large company's graduate programme. However, it can be difficult to find course topics that are relevant to a diverse group. Soft-skills courses appeared to get more traction with the group and may benefit most from the 'economy of scale' idea.

Savings might also be had by running workshops or training courses in conjunction with conferences, or using low-cost venues such as universities during semester breaks. Local field trips were also considered highly relevant to all disciplines and can provide a great opportunity for local networking. Mentor networks might be leveraged to organize opportunistic tours to drill sites, mines, or seismic vessels.

The secret for success for the YPNs in each state may be the adoption of the old mantra first made famous by Woodside's former CEO Don Voelte: Focus…Decide…Attack! It was suggested that social media apps such as a LinkedIn could be used to focus ideas about training opportunities. It was further suggested that perhaps Survey Monkey could be used to canvas views of both mentees and mentors so that a democratic decision could be made as to which courses to offer each year. This will only work if the mentees…you guessed it…attack their career development when opportunities present themselves.

Peter Stickland, CEO of Melbana Energy and APPEA Board Member, then gave a presentation on the state of the play in the petroleum sector. His overview was very well received, especially as the red wine and Furphy ales had started to kick in and the mentors assembled had become more vocal. They chimed in with insights on the industry; with perspectives dating back over 30 years and looking forward just as far. Peter's charts showing forecasts of sustainable growth, and the positivity expressed by all (in the face of ever increasing societal pressure), left mentees feeling more confident about planning a long future in this business.

The evening wound up with a discussion about setting expectations for the mentoring scheme. In pairing mentees and mentors we have tried to accommodate the wishes of the mentee as much as possible. Society affiliation and similar career paths were also strong considerations, but ultimately a balance was sought and time will tell if we made the right calls. Issues around confidentiality were also touched on.

During 2018 we intend to informally review mentoring relationships and assist if challenges arise. We would also anticipate a small intake of new mentees and mentors each year.

Finally, there was some housekeeping on upcoming training or networking opportunities. Those that are listed here may be relevant to YPs in other states:

- A presentation skill workshop to be held (pending sufficient numbers) at the AEGC conference in Sydney on 18 February, 2018. For more info see: https://www.aseg.org.au/presentation-skills-workshop
- Also at the AEGC conference, a combined YPN (ASEG/PESA/AIG) social evening
- 2 soft-skills courses to be floated at the AGCC conference (October 2018, Adelaide) and the Greenhouse Gas Control Technologies conference (also October 2018, Melbourne)

Please keep an eye out for a YPN LinkedIn group that you can join to stay informed about upcoming events.

Jarrod Dunne (Karoon Gas) and Sara Morón-Polanco (Melbourne University)
ypadmin@aseg.org

Peter Strickland presenting at the launch of the ASEG/PESA YPN in Victoria.

ASEG Branch news

Western Australia

The WA Branch has had another busy period hosting technical events for our Members. In October the Branch hosted **Bill Peters** presenting on the use of geophysical methods for Ni-Cu exploration. This presentation was used to test webcasting technology, which would enable the presentations at the ASEG's busiest Branch to be shared with Members based regionally in WA, across Australia, and overseas. It is intended to continue to trial this live webcasting service through 2018 with a view to making it a regular offering for our non-Perth based Members.

In November we hosted our annual student presentations with four students presenting from Curtin University and two from UWA. Again this year the quality of the presentations and the work being undertaken by the students was outstanding. The Members voted on which presentation they felt was the best, with **Chanel de Pledge** taking out the honour of best presentation.

We will be hosting the Branch AGM and Christmas Party on 13 December 2017. It is planned to have an informal BBQ function at Kings Park, in the Old Tea Pavilion. All of the statutory positions (President, Secretary and Treasurer) are open for nomination and anyone interested in joining the ASEG WA Branch Committee as a member or in one of these statutory roles are encouraged to lodge a nomination form ahead of the AGM. Further information will be circulated to Members shortly.

I would like to take this opportunity to thank the WA Members for their active participation in our events this year. If there are any events Members would like to see in 2018 please let the Committee know! It has been an honour to serve as Branch President for the last 3 years. Thank you for entrusting me with this responsibility.

Kathlene Oliver
wapresident@aseg.org.au

The student presentation night in Western Australia.

Australian Capital Territory

In October the ACT Branch enjoyed a guided tour of one of Geoscience Australia's geomagnetic and seismic observatories. Those who attended leant about the intricacies of the geomagnetic instrumentation and its use in space weather prediction, along with the seismic station that forms part of Australia's earthquake and tsunami warning system. The ACT Branch would like to extend a big thank you to **Craig Bugden**, **Andrew Lewis** and **Bill Jones** from Geoscience Australia for organising and running the tour, it was thoroughly enjoyed by all!

Two students, **Marcus Haynes** and **Taimoor Sohail**, are congratulated for receiving Student Scholarship Awards from the ACT Branch. In November Marcus presented a talk describing his PhD work to date titled 'Predicting Surface Heat Flow' and Taimoor presented his current research on 'The Impact of Wind and Temperature on Southern Ocean Circulation', both of which were well received by the Branch.

To finish off the year the ACT Branch is looking forward to a Christmas party at the Canberra Yacht Club. This end of year celebration will be accompanied by a technical presentation and guided star-gazing from astronomers of the Australian National University.

Merry Christmas to everyone from the ACT Branch! We look forward to hosting more exciting events in 2018.

James Goodwin
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 Branch meeting and to attract as many students along as possible. They did an excellent job, with over 40 people attending the meeting, it being the largest held since the last student organised event.

The abstract for the meeting was:

Completing your degree at university is an exciting time; however, it can also follow with uncertainty. The transition from student to professional life in industry or academia can be tough. This sometimes makes the change from being a university student to securing a job and then becoming professional in the industry a bit daunting. This month's technical talk has been organised by the Macquarie University ASEG Student Chapter and will provide students and professionals alike with a broader understanding of what opportunities industry can provide.

The Speakers were: **Cindy Giang** – Junior Geophysicist at GBG Australia, **Olivia Penlington** – Project Geophysicist at Coffey International Limited, and **Cara Danis** – Senior Hydrogeologist at SMEC.

The students and the 'students at heart' thoroughly enjoyed the evening.

In October we had our annual student night, where Honours and Masters students present their research. This year we had three speakers all giving great talks with much discussion and hand gesturing afterwards. The speakers and topics were: **Lauren Harrington** (Sydney University) – 'Modelling the evolution of the Eromanga Sea in the context of tectonics, geodynamics and surface processes', **Anthony Finn** (Macquarie University) – 'Tracing shallow lateral preferential pathways of fluid movement using electrical geophysics', **Luke Smith** (Macquarie University) – 'Precision Positioning in UAV Geophysics'.

ACT Branch Members enjoying a tour of the Canberra Geophysical Observatory.

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

Mark Lackie
nswpresident@aseg.org.au

Queensland

An invitation to attend Queensland Branch meeting is extended to all ASEG Members and interested parties. Details of all upcoming Queensland events can be found on the Qld Events tab on the ASEG website. A night of student presentations is planned for December so keep an eye out for that one!

Fiona Duncan
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South Australia & Northern Territory

The SA/NT Branch has been quite busy holding two technical evenings and our annual Melbourne Cup Luncheon since the last update. In September we were lucky to be joined by **Laszlo Katona** and **Matthew Hutchens** from the South Australian Government Department of the Premier and Cabinet, who gave the Branch an update on the current Gawler Craton Airborne Survey; a joint initiative by the Department of State Development, Geoscience Australia, and the Plan for Accelerating Exploration (PACE) programme. Laszlo and Matthew gave a review of the world's largest high-resolution airborne geophysical and terrain imaging programme, and the survey's aims to set the foundation for the next generation of exploration in the Gawler Craton. We thank Laszlo and Matthew for joining us to go through the preliminary results and currently available data and I am confident the SA/NT resource explorers will be looking forward to a further update on completion of the survey.

Our second technical evening was the Annual Sponsors Industry Night, at which we were joined by representatives from three of our state branch sponsors, **Johann Soares** from Beach Energy, **Louise L'Oste-Brown** from Minotaur Exploration, and **Kelly Keates** from Zonge. Each speaker gave an interesting overview of some of their past and current projects and some potential future work identified from some interesting results. This included a run down by Johann on some of Beach Energy's recent gas exploration efforts in the Cooper Basin, some new work by Minotaur Exploration around the Eloise Copper-Gold mine, including a new major EM ground survey, and finally some trials of new real time leak monitoring equipment presented by Kelly. Thanks again go to Johann, Louise and Kelly for taking the time to come and join us.

Finally, the annual Melbourne Cup Luncheon was a great success, a perfect way to celebrate the 30th anniversary if the event. With the Calcutta Sweep producing some very happy winners, prizes for the best dress colt and filly and a great atmosphere in the packed venue, much fun was had throughout the day and into the evening. I would like to thank our Branch sponsors, the Pullman Adelaide for holding this year's event and **Sam Jennings, Adam Davey** and **Phil Heath** and all the committee members who lent a hand, without whom the day would not have come together. I would also like to thank **Neil Gibbins,** who once again joined us and ran the proceedings throughout the day. There is also an incredibly large amount of work done behind the scenes by **Alison Forton** from TAS, so thanks must be given to her for bringing all the bookings, advertising and the website together. Finally a big thankyou to **Steve Tobin, Leeton McHugh** and **Geoff Dunn** from Terrex Seismic who generously kept the celebration going following the official proceedings, I can't think of a better way to see out the 30th year of the event, with hopefully many more to come in the future.

Our technical meetings are made possible by our very generous group of sponsors, including the Department of the Premier and Cabinet, Beach Energy, Minotaur Exploration, and Zonge. Of course, if you or your company are not in that list and would like to offer your.

As usual, further technical meetings will be held monthly, at the Coopers Alehouse on Hurtle Square in the early evening. We invite all Members, both SA/NT and interstate to attend, and of course any new Members or interested persons are also very welcome to join us. For any further information or event details, please check the ASEG website under SA/NT Branch events and please do not hesitate to get in touch at joshua.sage@beachenergy.com.au or on 8338 2833.

Josh Sage
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Tasmania

By the time *Preview* readers see this report, there will have been a couple of notable events hosted by the University of Tasmania with geophysical contributions. On Thursday 16 November several talks of geophysical (including geodetic) interest will be contributed by postgraduate students to the first GSA Earth Sciences Student Symposium held in Tasmania. These include **Nahidul Samrat** on using interferometric SAR to look at bedrock uplift in Antarctica and thereby infer Earth rheological properties, and **Anna Riddell** on employing GPS observations in Australia to look particularly at vertical tectonic motion and thus improve sea level change estimates for the Australian coastline. In more classical exploration geophysics, **Tom Ostersen** will present aspects of

ASEG news

his fieldwork and resulting three dimensional conductivity model development work on the AusLAMP magnetotelluric deployment in Tasmania, while **Steve Kuhn** (Tasmania branch secretary) is covering his research on machine learning applications to lithology prediction from geophysical, geochemical and remote sensing data.

Later, on 26 and 27 November, the Earth Science (formerly Geology) Department of the University of Tasmania will celebrate its 70th anniversary. A commemorative symposium will include contributions from geophysics staff members **Michael Roach** and **Matt Cracknell** presenting highlights of current and recent geophysical research and teaching. Matt will also touch on elements of the history of geophysics at the University of Tasmania, which has been part of the Department's endeavours since its founding.

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 programme 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.

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Victoria

The Victorian branch of the ASEG has seen another eventful few months. During September we had the pleasure of welcoming **Dr Tom Whiting** as guest speaker at our technical meeting night. Tom is the non-executive Chairman of the board of the Deep Exploration Technologies Cooperative Research Centre (DET CRC) and proudly presented 'Prospecting Drilling: A Technology-Enabled Revolution in Mineral Exploration', at the Kelvin Club to a very welcoming audience. The talk was largely focussed on one of the CRC's key programmes – Coiled Tubing drilling or CT drilling – with impressive results from recent field trials. The significant time and cost saving benefits afforded from CT drilling is compelling and undeniable. Pardon the pun, but this ground-breaking technology, which is being immediately commercialised, has the potential to revolutionise the way explorers drill. We thank Tom and the DET CRC for their visionary approach to exploration drilling and wish them all the best for their stage 2 bid for funding of the MinEx CRC.

At our October technical meeting, we were delighted to have **Suzanne Haydon** of the Geological Society of Victoria entertain our members with her talk, bewilderingly titled 'Free Data, Free Drinks, Free Food', also held at the Kelvin Club. Suzanne has been a staunch campaigner for freely accessible geological data in Victoria. Her presentation introduced the voluminous archive of Victorian geological data available online, from ground and airborne geophysical survey data to geological maps and to open-file exploration reports. Suzanne also offered an update of data acquisition programmes that were recently undertaken as well as provide an overview of published interpretations and models produced by the GSV. Thank you, Suzanne for your dedicated support in promoting Victorian minerals and oil and gas exploration!

October also saw the launch of the Victorian ASEG-PESA Young Professionals Network (YPN), which was hosted at The University of Melbourne. **Dr Jarrod Dunne**, who is a committee member of the YPN, has been relentless in its promotion. Jarrod has written a separate article in this edition of *Preview* (see ASEG News Committees). Please take the time to read up on what's been happening with your Victorian YPN.

In early November the ASEG Student Night was held in partnership with the 2017 Victorian University Earth and Environmental Sciences Conference (VUEESC), hosted by The University of Melbourne. This event was an opportunity for all Victorian students to present their research work to the local geoscience audience. The ASEG student night awards this year were associated with the Economic Geology and Geophysics session. A well-deserved congratulation is extended to **Martin Nguyen**, from Monash University, who won first prize for his comprehensive and enthusiastic presentation of 'A structural and litho-geochemical prospectivity characterization of the Depot domain'. The second prize was awarded to **Andrew Pearson** from Melbourne University, for his contribution to 'Redefining the structure and timing of the Wentworth Trough, northwest Victoria'. The ASEG Victorian Branch acknowledges the contribution of all participating students at the VUEESC this year. Well done!

As we approach the silly season, the Committee would like to express its sincerest gratitude to all the speakers who took time out of their demanding schedules to present to our Members at our monthly technical meetings – thank you immensely! The Victorian Branch has had a tremendously eventful year. We thank all our Members for their ongoing support and hope to continue the rage throughout 2018 as we look forward to sharing further captivating geoscientific enlightenment. Please have a safe yet exciting festive season!

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ASEG national calendar: technical meetings, courses and events

Date		Branch	Event	Presenter	Time	Venue
13	Dec	NSW	Tech night	TBA	1730–1900	99 on York, 99 York Street, Sydney
13	Dec	WA	AGM & Christmas party	TBA	TBA	Kings Park, Perth
13	Dec	ACT	Christmas party	TBA	TBA	Canberra Yacht Club
	Dec	QLD	Student presentations	Various	TBA	TBA
18	Feb	National	YPN Presentation skills workshop	Doug Knight	0900-1600	TBA, Sydney
18–21	Feb	National	AEGC 2018	Various		International Convention Center, Sydney

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

Update from the AEGC 2018 Conference Organising Committee

AEGC2018
AUSTRALASIAN EXPLORATION GEOSCIENCE CONFERENCE
18-21 FEBRUARY 2018 • SYDNEY AUSTRALIA
EXPLORATION • INNOVATION • INTEGRATION
www.aegc2018.com.au

At the time of writing there are only three months until the conference (18–21 February) and there still seems to be a lot to do. Extended abstracts have (mostly) been reviewed, booths have (mostly) been sold, workshops are filling, delegates are registering and sponsors are being sought (it is never too late).

Standard registration is open (http://www.aegc2018.com.au/), so today is a good day to register if you have not already.

We are proud to announce that our Platinum sponsor is Australia Minerals and that our Sapphire Sponsor is the CSIRO and our Gold Sponsors are Oil Search and RioTinto and our Opal Sponsor is Geoscience Australia. Our Silver Sponsors are Bridgeport Energy, Geosoft, Horizon Oil, Kinetic and Velseis. Wireline Services Group will be our lanyard sponsor, while GBG Australia will sponsor one of our morning teas and First Quantum Minerals are sponsoring the best paper and poster awards. There are still sponsorship opportunities available if your company is looking for exciting promotion opportunities. Again, please do not hesitate to contact us if you are interested and would like further information.

At the time of writing our team of paper reviewers have almost finished reviewing around 300 extended abstract submissions, with just a few stragglers to complete. We are very impressed with the quality of the abstracts and are very excited by the program (see following pages). We have eight concurrent streams, three covering the Energy stream, three covering the Mineral Geoscience stream and two covering the Near Surface and Groundwater stream. In the Energy stream we cover a diverse range of topics from Basin Symposia (Western Australia, Central Australia and Eastern Australia), through to Non-Conventional, PNG and New Technologies in seismics. The Mineral Geoscience theme covers such topics as geophysics and geology case histories, airborne geophysics, magnetics and EM theory and Industrial and Strategic. The Near Surface and Groundwater theme has such topics as innovation, case studies and what is new in groundwater investigations. We will have over 80 posters on display for the three days of the conference in the foyer. Poster presenters will have a dedicated poster session after lunch giving delegates ample opportunity to discuss the science with the author.

The exhibition hall is almost full, please visit the website to see who has already secured a spot. If your company would like a booth, please get in contact with us ASAP. The prospectus is available for download on the conference website: (http://www.aegc2018.com.au/). The Conference Organising Committee has endeavoured to contact as many companies as possible – if your company hasn't been contacted please let us know ASAP!

We have 12 workshops associated with the conference, ranging from geophysical interpretation to exploration methodologies to basin analysis and prospect determination as well as learning presentation skills. Please book your spot soon as they are filling fast.

Please stay tuned to the website for any updates to the program.

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Max Williamson
Co-Chair Petroleum

Happy throng at the last ASEG conference in Adelaide – don't miss out this time around!

AEGC 2018 Draft Conference Program

Monday								
0730-0830	Registration							
0830-0940	Conference Welcome and Opening							
0940-1010	Plenary Speaker 1 Peter Botten, Managing Director, Oil Search							
1010-1040	**Morning tea**							
	CONCURRENT SESSIONS							
	Coal	**West Australian Basins Symposium**	**East Australian Basins Symposium**	**Geology Case History**	**IP From EM Surveys**	**Inversion Modelling Methods**	**Regional Tectonic**	**Geotechnical and Environmental**
1040-1105	Keynote Presentation Coal in NSW **Kevin Ruming**	Keynote Presentation Continental collision, wrenching and orogenesis in the Banda Arc **Peter Baille**	Tectonics and geodynamics of the eastern Tethys and northern Gondwana since the Jurassic **Sabin Zahirovic**	Keynote Presentation **Steve McIntosh**	Modelling IP effects in airborne time domain electromagnetics **Dave Marchant**	Cooperative inversion: A review **Brett Harris**	Palaeomagnetic test of oroclinal rotation in the Dundas Trough, Tasmania **Robert Musgrave**	Tracking the Diprotodon - microtremor passive seismic profiling as a tool for location of megafauna bone beds **Michael Asten**
1105-1130			Predicting and detecting carbonate cemented zones within Latrobe Group reservoirs of the Gippsland Basin **Mark Bunch**		A thorough synthetic study on IP effects in AEM data from different systems **Andrea Viezzoli**	Impact of uncertain geology in constrained geophysical inversion **Jeremie Giraud**	Mapping metasomatised mantle by integrating magnetotelluric, passive seismic and geochemical datasets – SE Australia **Karol Czamota**	An integrated analysis of geophysical data for landslide risk assessment **Koya Suto**
1130-1155	Discovery through the ages – a journey of coal resource discovery in Queenslands Bowen Basin from the 1960's and the 2000's **Darren Walker**	Mapping northern Australia's present day stress field: The Canning Basin **Adam Bailey**	Impact of sequence stratigraphy on static and dynamic reservoir models: Examples from the Precipice–Evergreen succession, Surat Basin, Queensland **Andrew La Croix**	Lithogeochemistry of pegmatites at Broken Hill: An exploration vector to mineralisation **Christopher Torrey**	Keynote Presentation Airborne EM and IP below 10 Hz **Jim Macnae**	Constraining an inversion to follow curving trends in an image **Andrew King**	Geoscience Australia's contribution to AusArray – Passive seismic imaging of Australia **Alexei Gorbatov**	The application of VSP in the Pilbara **Ashley Grant**
1155-1220	The use of FWI in coal exploration **Mehdi Asgharzadeh**	Regional Jurassic sediment depositional architecture, Browse Basin: Implications for petroleum systems **Nadege Rollet**	Organic geochemistry and petroleum potential of Permian outcrop and core samples from the southern Sydney Basin **Simon George**	Ore and gangue minerals of the Hera Au-Pb-Zn-Ag deposit, Cobar Basin, NSW **Angela Lay**		Exploring inversion solution space: A case study over a Cu-Ag deposit in the Kalahari copper belt **Robert Ellis**	Coordinating and delivering a 1.8 million line kilometre magnetic and radiometric survey – a state government perspective **Laszlo Katona**	Application of the passive seismic Horizontal-to-Vertical Spectral Ratio (HVSR) technique for embankment integrity monitoring **Regis Neroni**
1220-1320	**Lunch**							
1320-1345	**Poster Session**							
	CONCURRENT SESSIONS							
	Coal	**West Australian Basins Symposium**	**East Australian Basins Symposium**	**Geology Case History**	**EM & Deep Radar**	**Exploration**	**Regional Tectonic**	**Geotechnical and Environmental**
1345-1410	Seismic diffraction imaging for improved coal structure detection in complex geological environments **Binzhong Zhou**	Evolution of "Tres Hombres" - a large mid-crustal dome structure within the northern Beagle Sub-basin Western Australia: An integrated geophysical investigation **Gerry O'Halloran**	Targeting core sampling with machine learning: Case study from the Springbok Sandstone, Surat Basin **Oliver Gaede**	Keynote Presentation **Richard Hillis**	2.5D vs 1D AEM forward and inversion methods at a survey scale : A case study **Desmond Fitzgerald**	On-demand mineral exploration support systems **Ben Rippingale**	Evolving 3D lithospheric resistivity models across southern Australia derived from AusLAMP MT **Stephan Thiel**	How to build your own simple, low-cost, seismic system **Tim Dean**
1410-1435	Integration of downhole geophysical and lithological data from coal exploration drillholes **Brett Larkin**	Controls on Mesozoic rift-related uplift and syn-extensional sedimentation in the Exmouth Plateau **Hayley Rohead-O'Brien**	The influence of reverse-reactivated normal faults on porosity and permeability in sandstones: a case study at Castle Cove, Otway Basin **Natalie Debenham**		Otze – airborne EM inversion on unstructured model grids **Carsten Scholl**	Understanding geology and structure: An essential part of mineral resource estimation **Bert De Waele**	Imprints of tectonic processes imaged with magnetotellurics and seismic reflection **Tom Wise**	Feasibility study of near-surface dispersion imaging using passive seismic data **M. Javad Khoshnavz**
1435-1500	Quantifying gas content in coals using borehole magnetic resonance **Tom Neville**	Shelf-margin architecture and shoreline processes at the shelf-edge: Controls on sediment partitioning and prediction of deep-water deposition style **Victorien Paumard**	High frequency refraction/ reflection full-waveform inversion case study from North West Shelf offshore Australia **Xiang Li**	Pathfinder exploration techniques targeting porphyry and epithermal alteration systems in the Temora copper-gold belt **Bruce Hooper**	Realistic expectations for deep ground penetrating radar performance **Jan Francke**	Building 3d model of rock quality designation assisted by co-operative inversion of seismic and borehole data **Duy Thong Kieu**	Identifying lithospheric boundaries and their importance for mineral discovery **Stephan Thiel**	Refraction Microtremor method for delineation of layers and lenses, and assessing liquefaction potential within an alluvial setting – Morobe Province, Papua New Guinea **Aaron Tomkins**
1500-1530	**Afternoon tea**							

	CONCURRENT SESSIONS							
	Coal	**West Australian Basins Symposium**	**East Australian Basins Symposium**	**Geology Case History**	**Airborne Gravity**	**Electrical Methods**	**Regional Mapping Methods**	**Groundwater**
1530-1555	Cooper Basin deep coal – the new unconventional paradigm: Deepest producing coals in Australia **Bronwyn Camac**	Influence of Permian and Carboniferous extensional history on the northern Carnarvon basin and its influence on Mesozoic extension **Amy I'Anson**	Petroleum plays of the Bowen and Surat basins **Alison Troup**	Cargo Porphyry Cu-Au deposit – where is the high grade core? **David Timms**	Validating the Gedex HD-AGG™ airborne gravity gradiometer **David Hatch**	Laboratory confirmation of non-linear electrical effects in mineralised rocks **Alan Oertel**	Characterising the subsurface architecture and stratigraphy of the McArthur Group through integrated airborne EM and gravity inversion **Teagan Blaikie**	Using microgravity to characterise water storage and usage at Kings Park, Perth, WA **Alan Aitken**
1555-1620	Predicting structural permeability in the deep coal play, Tirrawarra-Gooranie fields, Cooper Basin **Cameron Bowker**	Interpretation of a Permian conjugate basin margin preserved on the outer northwest shelf of Australia **Christopher Paschke**	Borehole gravity in horizontal wells **Andrew Black**	Implicit modelling of the Las Bambas deposits, Peru **Anthony Reed**	Airborne gravimetry takes off in the Western Australia 'Generation 2' reconnaissance gravity mapping project **David Howard**	Field trials of the Biassed Heterodyne method of exploration for sulphide minerals **Bob White**	Self organising maps - a case study of Broken Hill **Tasman Gilfeather-Clark**	Microgravity surveys on the Nullarbor **Philip Heath**
1620-1645	Towards understanding phosphorus distribution in coal: A case study from the Bowen Basin **Brooke Davis**	New insights into early Triassic rifting in the NW shelf help explain regional structural styles and associated deposition model **Malcolm MacNeill**	The stratigraphic significance of paralic deposits in the Precipice–Evergreen succession, Surat Basin, Queensland **Andrew La Croix**	What is down plunge of the Dobroyde Hill high-sulphidation epithermal deposit, near Junee, NSW? **Glen Diemar**	Gravity gradiometer design comparison by three different methods **James Brewster**	Getting a better control of IP acquisitions with GDD's new IP post-processing software **Circe Malo-Lalande**	The utility of machine learning in identification of key geophysical and geochemical datasets: a case study in lithological mapping in the Central African Copper Belt **Stephen Kuhn**	Application of magnetic resonance data for groundwater prospectivity in the Fitzroy Basin, Western Australia **Kok Piang Tan**
1645-1710	Evidence for glacial and polar impacts in the Permian coal measures of the Sydney basin **Malcolm Bocking**	Modelling reservoir deliverability within the northern Beagle Sub-basin, Western Australia **Christopher Hurren**	Next generation reservoir engineering **Klaus Regenauer-lieb**	The Discovery of the Edna Beryl Deposit - A journey with a destination! **Rob Bills**	Terrain correction correction Tasmania – results and implications **Mark Duffett**	The effective use of forward modelling and petrophysical analyses in the application of induced polarisation surveys to explore for disseminated sulphide systems in the Paterson province, Western Australia **Nikhil Prakash**	An overview of tensors, gradient and invariant products in imaging and qualitative interpretation **Matthew Zengerer**	Uncertanty analysis of faulting and folding on near surface aquifers **Titus Murray**

Tuesday								
	CONCURRENT SESSIONS							
	PNG and NZ	**West Australian Basins Symposium**	**Non Conventional**		**Strategic and Industrial**	**Magnetotellurics**	**Regional Mapping**	**Case Studies**
0830-0855	Keynote Presentation Innovative exploration in Papua New Guinea; past, present and future **Kevin Hill**	Onshore inventory – targeting new basins (Officer, Perth, Canning Basins) **Lidena Carr**	Integrated Seismic (IS) for shale gas exploration and management **Shastri Nimmagadda**		Keynote Presentation Strategic & industrial minerals leading the next production revolution **Richard Flook**	Particularities of 5-component magnetotelluric soundings application for mineral exploration **Igor Ingerov**	Keynote Presentation **Richard Blewitt**	Characterizing the Spiritwood Valley Aquifer, North Dakota, using helicopter time-domain EM **Jean Legault**
0855-0920		Linear trends of paleo-pockmarks and fluid flow pipes in the Jurassic and Triassic sediments of offshore northwest Australia **Tayallen Velayatham**	Using multiazimuth seismic data for anisotropy estimation in an unconventional reservoir **Surabhi Mishra**			Sferic signals for lightning sourced electromagnetic surveys **Lachlan Hennessy**		Reinterpretation of wireline log data in the eastern Galilee Basin, Queensland: stratigraphic and hydrogeologic implications **James Hansen**
0920-0945	Resource growth through petroleum exploration in PNG **John Warburton**	The effect of flexural isostasy on delta architecture: Implications for the Mungaroo Formation **Sara Morón-polanco**	A new computational model to predict breakdown pressures in cased and perforated wells in unconventional reservoirs **Mohammed Kurdi**		ALTECH is meeting a sapphire future **Iggy Tan**	Keynote Presentation What is new in magnetotellurics? **Graham Heinson**	An integrated approach to mapping crustal geology and structures in the NE Capricorn Orogen, Western Australia: Implications for uranium exploration **Ashley Laurence Uren**	Keynote Presentation **Katarina David**
0945-1010	Structural and reservoir development of the western Papuan Basin gas and condensate fields **Michelle Spooner**	Mesozoic to Cenozoic depositional environments & fluid migration within the Caswell Sub-basin: Key insights from new interpretation & modelling of the Schild phase 2 3D **Jarrad Grahame**	An optimised hydraulic fracturing treatment on challenging Rizq Field **Muhammad Asad Pirzada**		Rare earth element deposits – aspects of their evaluation, diversity, geochemistry and genesis **Phil Hellman**		Archean controls on basin development and mineralisation in the southern Capricorn Orogen **Sandra Occhipinti**	
1010-1040	Morning tea							
	CONCURRENT SESSIONS							
	PNG and NZ	**West Australian Basins Symposium**	**Non Conventional**	**General Geology**	**Strategic and Industrial**	**EM Inversion Modelling**	**Regional Mapping & Thomson Orogen**	**Case Studies**
1040-1105	Plio-pleistocene river drainage evolution in New Guinea **Gilles Brocard**	Canning Basin – petroleum systems analysis **June Then**	Transform faulting - an unseen problem to resource plays **Trevor Brooks**	Keynote Presentation Geophysical detection of the hydrothermal alteration footprints of ore deposits **John McGaughey**	Industrial minerals - evaluation and profitability **David Turvey**	Trans-dimensional Monte Carlo inversion of short period magnetotelluric data for cover thickness estimation **Ross Brodie**	AusAEM; acquisition of AEM at an unprecedented scale **A.Yusen Ley-Cooper**	Rate of success for a groundwater drilling program planned from AEM, Gascoyne River, WA **Aaron Davis**
1105-1130	Geophysical and geological characterisation of dredge locations from RV Southern Surveyor voyage ss2012_v06 (ECOSATI): Hotspot activity in northern Zealandia **Maria Seton**	The Ungani oil field, Canning Basin - evaluation of a dolomite reservoir **David Long**	A new system for efficiently acquiring vertical seismic profile surveys **Tim Dean**		Mineral deposits in the Ontario Cobalt Belt **Ian Pringle**	Comparative analysis and joint inversion of MT and ZTEM Data **Wolfgang Soyer**	Increasing prospectivity in a covered terrain – the southern Thomson Orogen, northwestern NSW **Rosemary Hegarty**	Geophysical investigation to support characterisation of structurally controlled groundwater flow into an open pit mine **Regis Neroni**
1130-1155	Compressional evolution of the PNG margin from an orogenic transect from Juha to the Sepik **Kevin Hill**	Depositional, diagenetic and mineralogical controls on porosity development in the Ungani Field, Canning Basin **June Then**	What we know, what we don't know, and things we do not know we don't know about hydraulic fracturing in high stress environments **Raymond Johnson**	Creating a new frontier in detection and data integration for exploration through cover **Robert Hough**	The Sinclair Zone Caesium Deposit, Pioneer Dome, W.A. **David Crook**	1, 2.5 and/or 3D inversion of airborne EM data - options in the search for sediment-hosted base metal mineralisation in the Mcarthur Basin, Northern Territory **Timothy Munday**	Estimating cover thickness in the southern Thomson Orogen – a comparison of applied geophysics estimates with borehole results **James Goodwin**	Uncovering the Musgrave Province in South Australia using airborne EM **Camilla Soerensen**
1155-1220	Tectonic and geodynamic evolution of the northern Australian margin and New Guinea **Joanna Tobin**	Laurel gas play, Canning Basin - recent stratigraphic learnings **June Then**	The role of diagnostic fracture injection testing to improve reservoir evaluation and stress characterisation in compressive stress regimes **Raymond Johnson**	Episodic mineralising fluid injection through chemical shear zones **Thomas Poulet**	The Pilgangoora Lithium-Tantalum Deposit - Geological overview and evolution of discovery **John Holmes**	Spatially and conductivity log constrained AEM inversion **Ross Brodie**	Application of AEM for cover thickness mapping in the southern Thomson Orogen **Ian Roach**	A multidisciplinary study of groundwater conditions in sedimentary strata at Thirlmere Lakes (NSW) **Katarina David**
1220-1320	Lunch							

1320-1345	**Poster Session**							
1345-1410	SOCIETY PLENARIES							
	CONCURRENT SESSIONS							
	PNG and NZ	**International**	**Non Conventional**	**Geochemistry**	**Brine Deposits**	**EM Inversion Modelling**	**Regional Cobar**	**Innovation**
1410-1435	A method for assessing earth model uncertainty in the Taranaki Basin, New Zealand **Edward Lewis**	On the geothermal potential of the Heyuan Fault, South China **Lisa Tannock**	The use of coring-induced petal fractures in coal to supplement and ground truth the interpretation of image logs **David Titheridge**	Keynote Presentation 21st century exploration geochemistry – the good, the bad and the ugly **Ryan Noble**	Lithium: fundamental supply/demand, the lithium brines of South America and exploration/development methodologies **Steve Promnitz**	Large scale 3D airborne electromagnetic inversion – Recent technical Improvements **Mike McMillan**	Metamorphism and skarn mineralisation in the Cobar Basin: Implications for exploration **Joel Fitzherbert**	Source Assisted Marine Refraction Microtremor (ReMi) for marine material strength assessments – New Ireland Province, Papua New Guinea **Trent Bowman**
1435-1500	Modelling and visualizing distributed lithospheric deformation of Australia and Zealandia using GPlates2.0 **Dietmar Muller**	The discovery and development of oil rim fields in the Beibu Gulf, China **Andrew Fernie**	Automatic fracture identification using x-ray images **Ankita Singh**		Evaluating brine deposits using borehole magnetic resonance **Tom Neville**	3D time-domain airborne EM inversion with finite-volume method **Xiuyan Ren**	Cobar Deposits – structural control **Vladimir David**	Bootstrapping reliable noise measure in time-gated nuclear magnetic resonance data **Trevor Irons**
1500-1530	**Afternoon tea**							
	CONCURRENT SESSIONS							
	PNG and NZ	**International**	**Non Conventional**	**Geochemistry**	**Industrial and Borehole**	**New Airborne EM Techniques**	**Regional Gawler Isa Halls Creek**	**Innovation**
1530-1555	Investigation of possible shallow gas accumulations associated with pockmarks on the Otago slope southeast of New Zealand **Jasper Hoffmann**	Hydrocarbon source potential of Tertiary carbonaceous mudstones, shales and sandstones of eastern Chenor, onshore Penyu Basins, Pahang, Malaysia **Yousif Makeen**	Fraccing onshore Australia **Maxwell Williamson**	Field analysis of low ppb gold using pXRF and new detectORE technology **Melvyn Lintern**	Frac sand supply & demand Australia **Murray Lines**	Passive EM processing of megatem and helitem data **Daniel Sattel**	A hidden Palaeoproterozoic ocean-continent transition in the northern Gawler Craton **Tom Wise**	Low noise, multichannel surface NMR receiver system with wireless connections to receiver coils **Jakob Juul Larsen**
1555-1620	Characterisation of focused gas hydrate accumulations from the Pegasus Basin, New Zealand, using high-resolution and conventional seismic data **Andrew Gorman**	Sedimentary characteristics and lithological trap identification of distant braided river delta deposits: A case study on the Upper Cretaceous Yogou Formation of Termit Basin, Niger **Zhao Ning**	Impact of artificially matured organic matter on the dielectric and elastic properties of compacted shales **Matthieu Cauchefert**	Cassiterite and rutile as indicator minerals for exploring the VMS system **Walid Salama**	High-grade silica sands in the Eastern Murray Basin NSW **Graham Lee**	Sub-Audio Magnetics (SAM) – Ground-based and HeliSAM FLEM trials at the Forrestania EM test range **Malcolm Cattach**	Thermochronological history of the northern Olympic Domain of the Gawler Craton; correlations between cooling ages and mineralising systems **James Hall**	ECloud – Magnetotelluric Webapp **Andrew Pethick**
1620-1645	Comparing shale gouge ratio and juxtaposition analysis using stochastic trap analysis: Examples from Gippsland, Taranaki, Otway and Southern North Sea Basins **Titus Murray**	Airborne gravity gradiometer survey over the Pelarang Anticline onshore Kutai Basin Indonesia **Asbjorn Norlund Christensen**	The stratigraphic architecture, distribution and hydrocarbon potential of the organic rich Kyalla and Velkerri shales of the Upper Roper Group (McArthur Basin) **Mattilda Sheridan**	Can geophysics and geochemistry combine to detect mineralisation under transported cover? **David Cohen**	Scintillators for PGNAA in mineral exploration **Snezana Petrovic**	CGG'S new Helitem-C AEM systems **Adam Smiarowski**	Tectonic framework of the southern Mount Isa Province **Janelle Simpson**	Groundwater assessment in a coal measures sequence using borehole magnetic resonance **Tom Neville**
1645-1710	New method for monitoring steam injection for Enhanced Oil Recovery (EOR) and for finding sources of geothermal heat **Gordon Stove**	The effect of deep burial and folding on sandstone reservoirs in Giant Gas Fields, South America **Gregory Smith**	Geomechanical prestack depth migration of the Kraken 3D (Browse Basin, Australia) **Jarrod Dunne**	A new blasthole xrf probe for mining grade control **Phil Hawke**		Square-wave processing of megatem data **Daniel Sattel**	Magma evolution in the Halls Creek Orogen; insight from geodynamic numerical modelling and geochemical analysis **Fariba Kohanpour**	Geologically-constrained interpretation of airborne electromagnetic data for definition of prospective groundwater resources, Albany Hinterland, Western Australia **James Reid**

Wednesday								
	CONCURRENT SESSIONS							
	New Technology Seismic	**New Technology CO_2**	**Central Australian Basins Symposium**	**History**	**Geophysical Case History**	**Hardrock Seismic**	**Groundwater**	**Groundwater**
0830-0855	Broadband least-squares wave-equation migration **Andrew Long**	Rock-physics based time-lapse inversion in Delivery 4D: Synthetic feasibility study for CO_2CRC Otway Project **Anton Egorov**	Evolving exploration methods in the hydrocarbon play within the Patchawarra Formation on the Western Flank, Cooper Basin **Johann Soares**	Keynote Presentation Ocean and atmosphere chemistry drive cycles of basin-hosted ore deposits through time **Ross Large**	Constrained 3D modelling and geochemical analyses of the Horseshoe Range BIF: tools for evaluating magnetic signatures under cover **Ben Patterson**	Potential of full waveform inversion of vertical seismic profile data in hard rock environment **Anton Egorov**	Impact of airborne electromagnetic (AEM) surveys in groundwater management in the Lower Platte South natural resources district, Nebraska, USA **Jared Abraham**	Utilization of AEM methods for cost-effective mapping of shallow Neogene intra-plate fault systems in Eastern Australian coal seam gas basins **Donna Cathro**
0855-0920	A new system for efficiently acquiring vertical seismic profile surveys **Tim Dean**	Application of time-lapse full waveform inversion of vertical seismic profile data for the identification of changes introduced by CO_2 sequestration **Anton Egorov**	Stromatolite construction, biofacies and biomarkers in the Lower Cambrian Hawker Group, Arrowie Basin, South Australia **Bronwyn Teece**		Comparing responses from different AEM systems and derived models at the Sunnyside Nickel Project, Botswana **Andrea Viezzoli**	The rise of 3D seismic in hardrock mineral exploration **Frank Bilki**	Aquifer delineation using the tempest AEM system **Adam Smiarowski**	The 'exploring for the future' groundwater programme: a multi-physics, inter-disciplinary systems approach for de-risking investment in agriculture in northern Australia **Ken Lawrie**
0920-0945	Quantitative Interpretation: Use of seismic inversion data to directly estimate hydrocarbon reserves and resources **James Shadlow**	3D vertical seismic profiling acquired using fibre-optic sensing DAS – results from the CO_2CRC Otway project **Julia Correa**	Reservoir modelling, structural history and volumetrics of the Jerboa Area, Eyre Sub-Basin **Jordan McGlew**	Quest for the Holy Grail; BHP' s Geophysical Research Program 1985-2005 **Ken Witherley**	What is ZTEM seeing over this tropical porphyry? **Chris Wijns**	Fast-tracking gold exploration below 300m – 3D seismic case history from Darlot gold mine **Greg Turner**	Resolving changes to freshwater lens systems in a "sea of salinity" using multi-date airborne EM **Timothy Munday**	An integrated hydrogeophysical approach to exploring for groundwater resources in southern Northern Territory **Laura Gow**
0945-1010	Solid substitution: Theory versus experiment **Yongyang Sun**	Geochemistry of storing CO_2 and NOx in the deep Precipice Sandstone **Julie Pearce**	Tertiary deep-water coral supports cold seeps in the Ceduna Sub-Basin **Laurent Langhi**	Ten years in the wild: The P223 experiment **David Annetts**	Airborne geophysics over the Dolly Varden VMS and low sulphidation epithermal silver deposits, northwestern BC, Canada **Jean Legault**	Distributed acoustic sensing for mineral exploration: Case study **Andrej Bona**	Stretching AEM near-surface resolution limits related to low- and very high resistivity contrasts **Andi Pfaffhuber**	Using AEM AND GMR methods for non-invasive, rapid reconnaissance mapping and characterisation of groundwater systems in the Kimberley region, northern Australia **Neil Symington**
1010-1040	**Morning tea**							
	CONCURRENT SESSIONS							
	New Technology Seismic	**New Technology CO_2**	**Central Australian Basins Symposium**	**Exploration Strategy**	**Geophysical Case History**	**Petrophysics**	**Groundwater**	**Groundwater**
1040-1105	Keynote Presentation Multi-component seismic: Applications and new developments **Natasha Hendrick**	Feasibility of Seismic monitoring of CCS in Perth Basin **Andrej Bona**	Regional migration and trapping frameworks in the frontier Ceduna Sub-Basin: New insights from stratigraphic forward modelling and 'triangle juxtaposition' diagrams **Laurent Langhi**	Keynote Presentation **Mike McWilliams**	Imaging high quality conductors at Golden Grove **Neil Hughes**	The use of petrophysical data in mineral exploration: A perspective **Michael Dentith**	The use of airborne EM to investigate coastal carbonate aquifer, seawater intrusions and sustainable borefield yield at Exmouth, Western Australia **Karen Gilgallon**	Comparative evaluation of 1D, 2.5D and 3D inversions for resolving tectonic elements in floodplains and near-surface inverted sedimentary basins **Ken Lawrie**
1105-1130		A double double-porosity model for wave propagation in patchy-saturated tight sandstone with fabric heterogeneity **Mengqiu Guo**	Could the Mesoproterozoic Kyalla Formation emerge as a viable gas condensate source rock reservor play in the Beetaloo Sub-Basin? **Carl Altmann**		Woodlawn revitalised by DHEM **Kate Hine**	Practical considerations & good protocol for the interpretation of ultramafic & mafic rock physical property data **Cameron Adams**	Developing water supplies from Saprolite Regolith **Kevin Morgan**	Using hydrogeophysical techniques to characterise and map sea water intrusion and preferential flow paths in Howards East Aquifer, Darwin rural area, Northern Territory **Laura Gow**

1130-1155	Marine vibrator concepts for modern seismic challenges **Andrew Long**	Application of passive seismic in determining overburden thickness: North West Zambia **Nikhil Prakash**	Isotope constraints on intra-basin correlation and depositional settings of the mid-Proterozoic carbonates and organic-rich shales in the Greater McArthur Basin, Northern Territory, Australia **Juraj Farkas**	Budget allocation and the stopping problem in mineral exploration **Andy Green**	Mineral exploration in the Mount Lyell region of Tasmania with the Helitem35C® System **Adam Smiarowski**	Petrophysics and exploration targeting: The value proposition **Barry Bourne**	Focused attributes derived from AEM surveys using the continuous wavelet transform **Niels Christensen**	Rapid assessment of groundwater salinity and seawater intrusion hazard in the Keep River floodplain, Northern Territory, Australia **Ken Lawrie**
1155-1220	Methods for reducing unwanted noise (and increasing signal) in passive seismic surveys **Tim Dean**	Portable XRD for unconventional and conventional petroleum exploration **Dane Burkett**	Ranking DHI attributes for effective prospect risk assessment applied to the Otway Basin, Australia **Sebastian Nixon**	How a systems thinking approach to mineralising geosystems is opening new search spaces for ore discovery **Tim Craske**	Combined gravity and magnetic studies of satellite bodies associated with the giant Coompana reverse magnetic anomaly in South Australia **Clive Foss**	Defining petrophysical properties of ultramafic and mafic rocks in terms of alteration **Cameron Adams**	Structural analyses aiding identification of water conductive fracture zones in crystalline rock **Kevin Morgan**	VTEM ET: An improved helicopter time-domain EM system for near surface applications **Jean Legault**
1220-1320	**Lunch**							
1320-1345	**Poster Session**							
	CONCURRENT SESSIONS							
	New Technology Seismic	**New Technology CO2**	**New Technology Minerals**	**Strategy & Geological Models**	**Geophysical Case History**	**Magnetics**	**Groundwater**	**Groundwater**
1345-1410	Least square Q-Kirchhoff migration: Implementation and application **Joe Zhou**	CA-IDTIMS and biostratigraphy: Their impact on exploration **Tegan Smith**	Mathematical properties and physical meaning of the gravity gradient tensor eigenvalues **Carlos Cevallos**	Dykes, synclines and geophysical inversion - Is geology important? **Desmond Fitzgerald**	An assessment of Geotem, Falcon® and ZTEM surveys over the Nebo Babel deposit, Western Australia **Ken Witherley**	Extending magnetic depths past 1000 m **Roger Clifton**	Gaining insight into the T2*-T2 relationship through complex inversion of surface NMR free-induction decay data **Denys Grombacher**	Novel methods for near-surface hydrogeological feature enhancement from high-resolution airborne magnetic data **Peter Milligan**
1410-1435	Fibre-optic VSPS: Borehole seismic revolution in Australia **Konstantin Galybin**	Analysis of time-lapse seismic and production data for systematic reservoir model classification and assessment **Rafael Souza**	Application of frequency domain induction EM soundings with controlled source (FDEMS method) for precise tracing of boundaries in geoelectrical sections **Igor Ingerov**	Common uncertainty: Research explorer uncertainty estimation in geological 3D modelling **Evren Pakyuz-Charrier**	Geophysics for sediment hosted copper and gold mineralisation, the role of 3DIP **Barry Bourne**	Using AMS and palaeomagnetic data to assess tectonic rotation: A case study from Savannah Nickel Mine, WA **Jim Austin**	Magnetotelluric inversion for characterisation of complex aquifer systems **Ralf Schaa**	Recent advancements and applications of logging and surface magnetic resonance for groundwater investigations **Elliott Grunewald**
1435-1500	Modelling complex near-surface features to improve shallow seismic exploration **Shaun Strong**	Integrating geophysical monitoring data into multiphase fluid flow reservoir simulation **Trevor Irons**	Enhanced reservoir characterization using machine learning **Amir Hashempour Charkhi**	Multidimensional topology transforms **Mark Jessell**	Geophysics of the Patterson Lake South Uranium Deposit, northwestern Saskatchewan **Jean Legault**	Magnetic field surveys of thin sections **Suzanne McEnroe**	Loupe - a portable EM profiling system **Gregory Street**	Improved groundwater system characterization and mapping using hydrogeophysical data and machine-learning workflows **Michael Friedel**
1500-1530	**Afternoon tea**							
1530-1630	Closing Plenary							

Vale Marion Elizabeth Rose (1947–2017)

Marion Rose (*nee* Tom), a pioneering female geophysicist, passed away in July this year after a difficult few months of ill health. Marion was born in 1947 into a family with a strong rural background. She grew up on a farm in country Victoria near the town of Romsey, north of Melbourne, where she had a happy childhood with three sisters and a brother and an extended family of cousins. Marion's mother, Jean Marion Tom, was a scientist in her own right, having graduated with a MSc in physiology from Melbourne University in 1944. She was a great inspiration and role model in Marion's life, an exceptional woman who for 23 years of service to the CWA and women in the community, was recognised with an Order of Australia in 1993. Sadly, Marion's beloved mother passed away during the time of Marion's own health challenges.

Marion attended the PLC boarding school in East Burwood, Melbourne from the age of 11. She completed her matriculation in 1965 with a focus on mathematics and science, perhaps somewhat unusual for a woman of her generation. She went on to attend the University of Melbourne where she studied science and majored in geophysics and mathematics, studying under Colin Kerr-Grant, Lindsay Thomas and Garry Gibson.

One of Marion's ancestors from the Gold Rush days was William Tom who pioneered and gave his name to the original Australian version of the gold cradle (Tom's cradle). Many also claim that William Tom and J. H. A. Lister made the original discovery on the Ophir goldfield for which John Hargreaves took credit. Not surprisingly then, over a century later, Marion chose mineral exploration for her career in science.

In 1969 Marion joined BHP as a geophysicist in the Exploration Department, based in Melbourne. This was a time during the 60s 'nickel boom' when geophysics was flavour of the month and geophysicists were a somewhat rare breed, to say nothing of a female geophysicist. It was in the 'analogue' days before PCs, mobile phones and advanced communication. Nevertheless, Marion was undeterred and enjoyed rolling up her sleeves and going into the field in a day when the only contact with the outside world was on daily radio skeds. In those days it was a rare thing to see women in the exploration group participating in the male dominated world of field work, nevertheless, Marion and one or two of her other female colleagues in the exploration group, pioneered the way for the many women who joined the minerals exploration world in later years.

Marion was trained in classical geophysics, in the days before coloured images. She was comfortable with profiles and contour maps and developed a real skill interpreting magnetics and gravity maps and making observations about significant relationships in them. She was also excellent at compiling geophysical data sets and turning them into an exploration story.

When the Olympic Dam deposit was discovered in the early 1970s it caused a great flurry of geological head scratching throughout the BHP exploration group about what sort of deposit it was. Marion ignored the geological musings about 'the model'. She assembled and interpreted the relevant regional aeromagnetic and gravity data and made several observations about the setting of deposit that led to the identification of new targets on open ground.

In the early 1970s Marion met and married her husband Howard, a financial manager with BHP Melbourne.

After 10 years with the BHP Minerals Exploration group, Marion moved into BHP Petroleum where she was able to bring her potential field interpretation skills to a group dominated by seismic geophysicists. It is testament to her that she became a valued member of the team.

In 1992 Marion re-joined the BHP Minerals group when she moved to the San Francisco based head office along with her husband Howard. On her return to Melbourne, at the end of the overseas posting, Marion joined the Falcon airborne gravity gradiometer deployment group as an interpreter. Her well-honed skills in the interpretation of potential field data was a valuable asset and she was a mentor to the younger geophysicists working in the Falcon team at that time. The Falcon team was nominated and awarded the ASEG Graham Sands Award in 2001.

Marion retired from BHP and geophysics about 10 years ago to enjoy the next stage of her life with her husband Howard, their daughter Christine and son Alistair and their grandchildren. Even so, as a longtime member of the ASEG, she still attended the occasional local Melbourne branch meetings and served the ASEG as a reviewer for *Exploration Geophysics.*

In retirement Marion enjoyed a wide range of interests including catching up with her friends, photography and compiling her family history. She developed a passion for international travel as a young woman when she travelled to South East Asia, and she and Howard travelled extensively throughout their life together. During their travels they visited north Africa, England, South America (the highlight trip for her) and other places. They were both looking forward to further travelling in the future.

Marion was a highly competent geophysicist, however those who knew her and worked with her know that she was much more than that. She was very kind, compassionate and friendly and always had time to help out her work colleagues. She valued her family and friends and was looking forward to seeing her grandchildren grow up. She loved to watch Essendon play a good game of footy and was an avid reader with wide interests.

Marion was quiet and determined and managed to get her message through in the nicest possible way, a consummate quiet achiever. In a world that, in her early days in exploration, was dominated by men, she never apologised for being a woman. She would probably be embarrassed to hear herself referred to as a pioneer. She was just doing what she loved both professionally and personally. She will remain an inspiration for women in mining and exploration and will be fondly remembered by all whose lives she touched.

Phil Harman, Geoff Pettifer, Terry Lee, Lindsay Thomas, Asmita Mahanta and Cory Williams

AGU Medal for Brian Kennett

Brian Kennett, Emeritus Professor of Seismology at the Research School of Earth Sciences at the ANU, will be presented with the Inge Lehmann Medal at the December (Fall) meeting of American Geophysical Union. The Inge Lehmann Medal recognises 'outstanding contributions to the understanding of the structure, composition, and dynamics of the Earth's mantle and core'.

Congratulations Brian!

Ceremony to celebrate ASEG Gold Medal award to Richard Lane

The ACT Branch of the ASEG celebrated Richard Lane's ASEG Gold Medal award in September 2017.

The ASEG Gold Medal is awarded from time to time for exceptional and highly distinguished contributions to the science and practice of geophysics by a Member, resulting in wide recognition within the geoscientific community. In June the ASEG announced the 2017 awardee was Richard Lane from Geoscience Australia. The award recognises Richard's significant and distinguished contributions to the profession of geophysics in Australia and overseas through his practical research and contributions to the understanding and application of geophysical methods in both mining and petroleum, for his frequent contributions at conferences both in Australia and overseas, and through his outstanding professional work in applied geophysics for over 30 years.

The President of the ASEG, Andrea Rutley, the current Geoscience Australia CEO; Dr James Johnson, past Geoscience Australia CEOs; Dr Neil Williams and Dr Chris Pigram, Bob Smith from Greenfields Geophysics and Dr Ted Tyne were some of the many distinguished guests to attend the award ceremony.

ASEG President Elect, Marina Costelloe, local Branch President, James Goodwin, Dr James Johnson and Bob Smith gave wonderful speeches. Thank you to all Members and friends of Richard and Leigha Lane who sent well wishes, they were included in a PowerPoint presentation that ran throughout the ceremony.

Congratulations Richard – from us, and from them!

CONGRATULATIONS RICHARD LANE, ASEG GOLD MEDALLIST!
(Melbourne Geophysical G.O.L.F.ers group)

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 10 November 2017)

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

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km^2)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Murloocoppie	GSSA	GA	MAGSPEC Airborne Surveys	11 Feb 2017	109 560	200 m 60 m E–W	19 540	25 May 2017	Oct 2017	183: Aug 2016 p. 34	Nov 2017
Warrina	GSSA	GA	MAGSPEC Airborne Surveys	11 Feb 2017	135 628	200 m 60 m E–W	24 140	25 May 2017	Oct 2017	183: Aug 2016 p. 34	Nov 2017
Andamooka	GSSA	GA	Sander Geophysics	23 Feb 2017	81 396	200 m 60 m E–W	14 560	6 Jun 2017	Final data QA/QC in progress	183: Aug 2016 p. 34	TBA
Barton	GSSA	GA	Thomson Aviation	22 Jan 2017	111 758	200 m 60 m E–W	20 560	11 May 2017	Final radiometric data QA/QC in progress	183: Aug 2016 p. 34	TBA
Fowler	GSSA	GA	Thomson Aviation	18 Feb 2017	95 009	200 m 60 m E–W	17 360	2 Jun 2017	Final radiometric data QA/QC in progress	183: Aug 2016 p. 34	TBA
Torrens	GSSA	GA	Sander Geophysics	4 Mar 2017	79 990	200 m 60 m E–W	14 800	15 Jun 2017	Final data QA/QC in progress	183: Aug 2016 p. 34	TBA
Coonabarabran	GSNSW	GA	UTS Geophysics	17 May 2017	50 827	250 m 60 m E–W	11 000	30 Jul 2017	Nov 2017	184: Oct 2016 p. 23	Nov 2017
Tasmanian Tiers	MRT	GA	TBA	TBA	Up to an estimated 66 000	200 m 60 m N–S or E–W	11 000	TBA	TBA	TBA	National Collaborative Framework Agreement between GA and MRT is being updated. The survey has been deferred to occur between Oct 2017 and Mar 2018
Isa Region	GSQ	GA	GPX	3 Jul 2017	120 062	100 m 50 m E–W	11 000	5 Nov 2017	TBA	188: Jun 2017 p. 21	TBA
Tallaringa N (1A)	GSSA	GA	TBA	26 Oct 2017	97 762	200 m 60 m E–W	17 320	6.7%	TBA	190: Oct 2017 p. 26	TBA
Tallaringa S (1B)	GSSA	GA	TBA	26 Sep 2017	145 042	200 m 60 m E–W	26 010	19%	TBA	190: Oct 2017 p. 26	TBA
Coober Pedy (8A)	GSSA	GA	TBA	18 Sep 2017	90 627	200 m 60 m N–S	16 140	55.1%	TBA	190: Oct 2017 p. 26	TBA
Billa Kalina (8B)	GSSA	GA	TBA	10 Oct 2017	90 625	200 m 60 m N–S	16 140	54.4%	TBA	190: Oct 2017 p. 26	TBA
Childara (9A)	GSSA	GA	TBA	5 Nov 2017	135 021	200 m 60 m N–S	23 910	3.6%	TBA	190: Oct 2017 p. 26	TBA
Lake Eyre (10)	GSSA	GA	TBA	2 Oct 2017	91 800	200 m 60 m E–W	16 180	25.3%	TBA	190: Oct 2017 p. 26	TBA

TBA, to be advised.

News

Table 2. Gravity surveys

Survey name	Client	Project management	Contractor	Start survey	No. of stations	Station spacing (km)	Area (km²)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Tanami-Kimberley	GSWA	GA	Thomson Aviation	16 Jun 2017	49 825	2500 m line spacing	110 000	31 Oct 2017	TBA	The survey area covers the Billiluna (all), and parts of the Lucas, Cornish, Mount Bannerman, Mount Ramsay, Noonkanbah, Lansdowne, Lennard River, Derby, Charnley and Yampi 1:250 k standard map sheets	TBA
Kidson Sub-basin	GSWA	GA	CGG Aviation (Australia)	14 Jul 2017	72 933	2500 m line spacing	155 000	TBA	70.7%	The survey area covers the Anketell, Joanna Spring, Dummer, Paterson Range, Sahara, Percival, Helena, Rudall, Tabletop, Ural, Wilson, Runton, Morris and Ryan 1:250 k standard map sheet areas	TBA
South Nicholson	GA	GA	Atlas Geophysics	30 Jul 2017	2724	4 km spacing	43 330	28 Jul 2017	1 Sep 2017	The survey area covers parts of the Mount Drummond, Ranken and Avon Downs standard 1:250 k map sheet areas	15 Sep 2017

TBA, to be advised.

Table 3. AEM surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
East Kimberley	GA	GA	SkyTEM Australia	26 May 2017	13 723	Variable	N/A	24 Aug 2017	Nov 2017	TBA	TBA
AusAEM (Year 1)	GA	GA	CGG	TBA	59 349	20 km with areas of infill	TBA	TBA	32.9%	186: Feb 2017 p. 18	TBA
Surat-Galilee Basins QLD	GA	GA	SkyTEM Australia	2 Jul 2017	4627	Variable	Traverses	23 Jul 2017	Nov 2017	188: Jun 2017 p. 21	TBA
Stuart Corridor, NT	GA	GA	SkyTEM Australia	6 Jul 2017	9832	Variable	Traverses	12 Aug 2017	Nov 2017	188: Jun 2017 p. 22	TBA
Olympic Domain	GSSA	GA	SkyTEM Australia	14 Nov 2017	3181	1.5 & 3 km E–W	33 200	TBA	TBA	190: Oct 2017 p. 27	TBA
Fowler Domain	GSSA	GA	SkyTEM Australia	Early Dec 2017	3057	5 km NW–SE	15 000	TBA	TBA	190: Oct 2017 p. 27	TBA

TBA, to be advised.

Table 4. Magnetotelluric (MT) surveys

Location	State	Survey name	Total number of MT stations deployed	Spacing	Technique	Comments
Northern Australia	Qld/NT	AusLAMP	150	50 km	Long period MT	The survey covers the area between Tennant Creek and Mount Isa

New seismic in the South Nicholson Basin region

In early August 2017 acquisition of deep crustal seismic reflection data was completed in the region between the southern McArthur Basin to the Mt Isa western succession, crossing the South Nicholson Basin and Murphy Province (Figure 1). Prior to this survey the region contained no seismic data and minimal well data.

Five seismic lines were acquired totalling 1100 line km with two of the seismic lines to the east linking with existing deep crustal seismic data in the Mt Isa western succession. The acquisition was designed to explore exposed and undercover sedimentary basins to better understand the location and scale of potential energy resources.

This data will also support mineral exploration through the improved understanding of the region's geological evolution and the identification of geological terrains with greater mineral potential. Initial field stack data are of excellent quality and image a variety of previously unknown features. The public release of processed data is expected in early mid-2018.

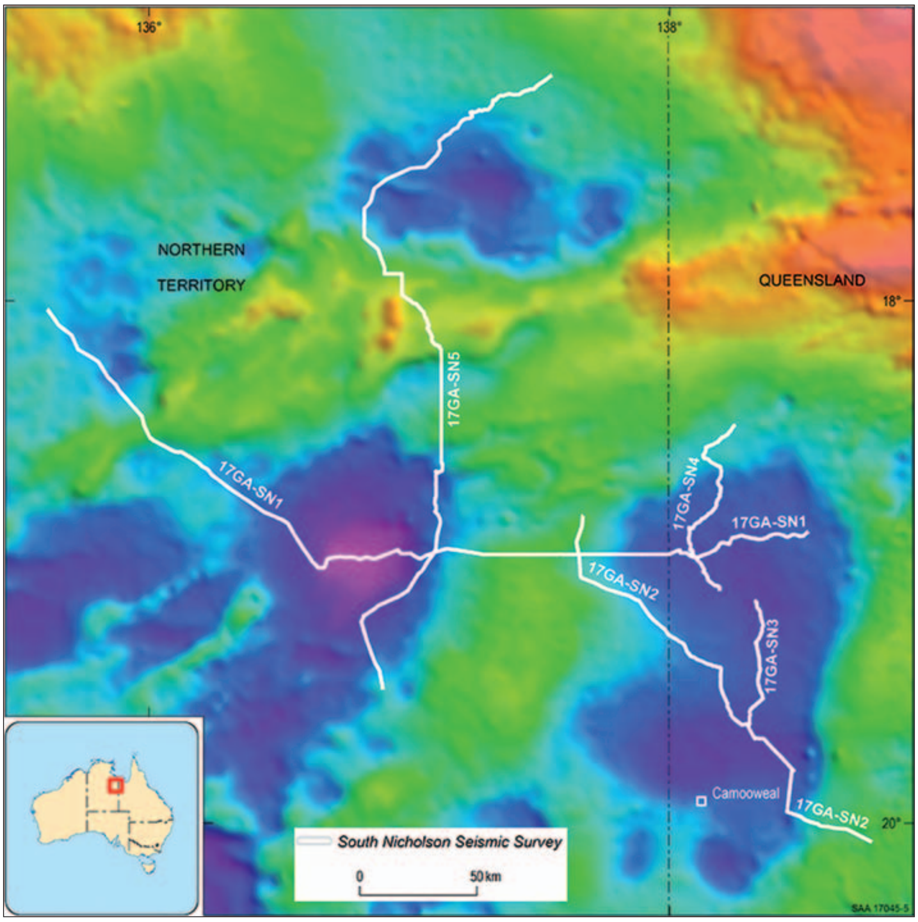

Figure 1. *Location of the South Nicholson seismic survey.*

Geological Survey of South Australia: Discovery Day

The Geological Survey of South Australia recently held Discovery Day, a one-day extravaganza on all thing minerals exploration related in South Australia. Four of the GSSA's geophysicists presented at the conference.

The GSSA's latest geophysical recruit, Kate Robertson, presented on 'Scale reducing MT exploration funded by PACE Copper'. This presentation updated participants on the AusLAMP project in South Australia, and included some exciting results from early inversion work. Kate used WinGLink software to demonstrate the conductive lower crust in the Curnamona Region.

Stephan Thiel also presented work on MT in South Australia. His presentation titled 'Evolving AusLAMP resistivity models in South Australia' showed depth slices of the state, illustrating the regional resistivity models. The inversion results showed resistivities from depths of 10 km to 150 km, giving a truly regional perspective on the subsurface of South Australia.

Laszlo Katona presented on the Gawler Craton Airborne Survey (GCAS), providing an update to the industry. The presentation provided an overview of the survey and covered many of the challenges that the GSSA have had to overcome. This is particularly true in terms of community engagement with the holders over 28000 land parcels within the survey region. Laz demonstrated how a website designed to inform the various stakeholders has been successful in engaging everyone concerned.

Finally, Philip Heath presented two posters. The first poster presented the results from the Coompana microgravity surveys. The microgravity surveys were designed to detect underground cavities prior to a drilling programme. The results clearly show underground areas of low density, which may correspond to caves and cavities. The second poster gave an update on new geophysical surveys available for downloading via SARIG. Some highlights included the Musgraves Tempest and SkyTEM surveys, as well as the Coompana regional gravity and the first tranche of GCAS data.

Philip Heath
Geological Survey of South Australia
Philip.Heath@sa.gov.au

Geological Survey of Western Australia: More aerogravity surveys in WA

The Geological Survey of Western Australia is proposing to continue its program of airborne gravity surveys over the north-eastern part of the state.

Within the framework of the Western Australia Reconnaissance Gravity Project National Collaboration Agreement, Geoscience Australia has released a public request for tender for new surveys in one or more of four potential project areas (Figure 1; http://tenders.gov.au, ATM ID 2017/4223, closing date 18 December 2017).

The proposal for these new surveys follows from the successful conclusion of the East Kimberley survey in 2016 and the progress of the aerogravity surveys being conducted in 2017 (Table 1). All surveys are being flown at 2.5 km line spacing.

A list of non-confidential private company surveys held by GSWA are listed in Table 2 with the locations shown in Figure 1. Data from these surveys are available for free download from GSWA's online delivery system at www.dmp.wa.gov.au/geoview (under the 'Company Airborne Surveys' layer in the 'Geophysical Surveys' group).

For more information contact geophysics@dmirs.wa.gov.au.

David Howard
Geological Survey of Western Australia
david.howard@dmp.wa.gov.au

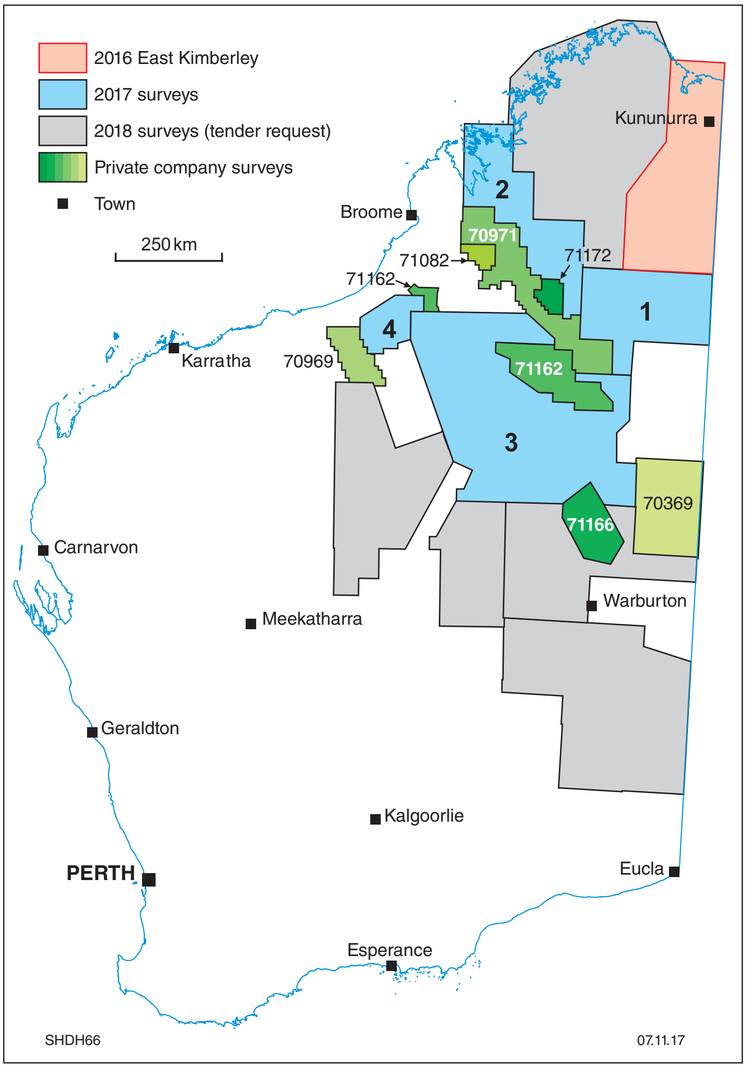

Figure 1. *Aerogravity surveys in Western Australia.*

Table 1. Status of GSWA aerogravity surveys in Western Australia

Survey name	Size (line km)	Contractor	Technology	Status
2016 East Kimberley	38 000	Sander Geophysics	AIRGrav	Complete; GSWA survey registration number 70156
2017 Surveys				
1. Tanami	25 000	Thomson Aviation	GT-2A	Data processing; release: Dec 2017 (est.)
2. NE Canning	25 000	Thomson Aviation	GT-2A	Data processing; data release: Feb 2018 (est.)
3. Kidson	70 000	CGG Aviation	Falcon/sGrav	Data acquisition; release Mar 2018 (est.)
4. Kidson extension (Anketell Shelf)	5500	CGG Aviation	Falcon/sGrav	Data acquisition; release Mar 2018 (est.)

Table 2. Exploration company aerogravity surveys (non-confidential)

Registration number	Survey name	Line spacing	Size (line km)	Technology
70369	Amadeus SPA704.5 AG	5000 m	7780	GT-1A
70969	SPA-055 Falcon AGG	3250 m	4065	Falcon
70971	Canning Basin Falcon AGG	1000 m	43 880	Falcon
71162	Canning Basin EP450_451 AG	2500 m	11 100	GT-2A
71166	Canning Basin SPA-A AG	1500 m	12 900	GT-1A
71172	Canning Basin 2434 AGG	1500 m	3560	Falcon

Geological Survey of Victoria: new airborne survey for Otway Basin

GSV are planning an 18 000 km^2 gravity/gravity-gradiometry survey over the Otway Basin as part of a pre-competitive data package to support a nearshore petroleum acreage release in 2018. The surveying is part of the $42.5 million Victorian Gas Program, which aims to produce a clear picture of the state's prospective onshore and offshore gas resources, as well as options for underground gas storage (https://www.premier.vic.gov.au/wp-content/uploads/2017/10/171031-Victorian-Gas-Research-In-Full-Flight-1.pdf).

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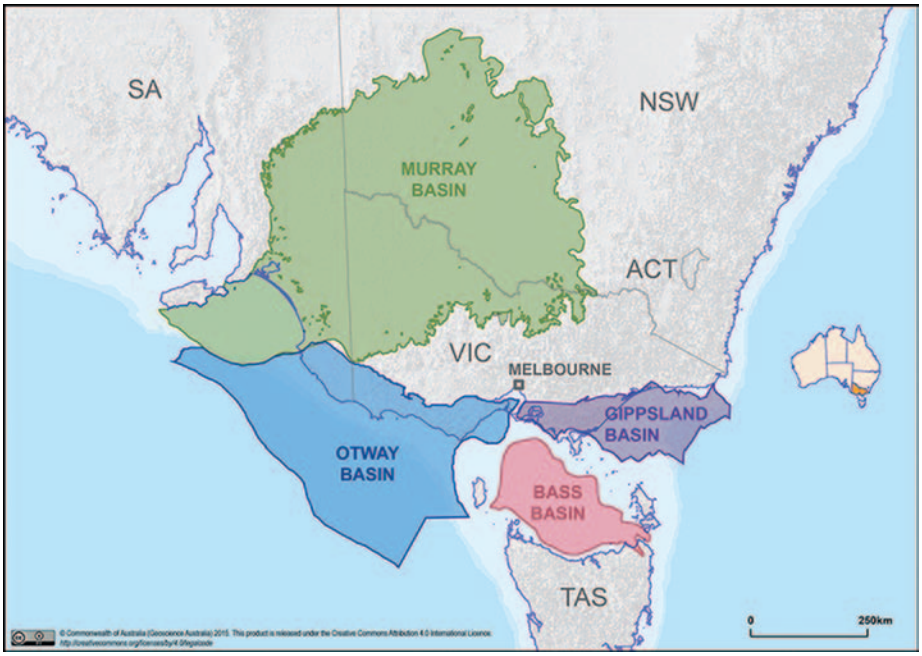

Victorian sedimentary basins; the Victorian Gas Program will focus on the Otway and Gippsland Basins.

Canberra observed

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Decline in Australian research investment a real concern

On 15 September 2017 the Australian Bureau of Statistics published the Australian Gross Domestic Expenditure on Research and Development (GERD) for the year 2015–16.

It does not make for happy reading. The 2015–16 GERD is estimated at $31.2 billion, a decrease of $2.3 billion (7%) from 2013–14 investment. The GERD value as a percentage of GDP also continues to decline, from the peak of 2.25% in 2008–09. Table 1 shows the results from 2006 to 2016. The GERD/GDP ratio fell from 2.25% to 1.88% in 2015–16 and is now at its lowest level since 2004–05, when it was 1.73%.

In a country where governments have spruiked innovation and research, there is a lot of work to be done to restore our place as a clever country. Even though government investment has been reasonably constant over the last five years, the smaller science based agencies are suffering. For example, the ABS does not have the resources to properly measure these research investment parameters on an annual basis. In its September report (ABS 8104.0) it states: 'Following changes in the ABS work program for R&D statistics, it is no longer possible to derive a comparable estimate of GERD in the same manner'. This is code for 'We don't have the resources to do this properly'.

The agency had to use a predictive model to estimate the numbers for 2015–16, rather than actively gathering the raw data. This is better than nothing, but not an outcome to be proud of and is a situation that should never have been allowed to develop.

Table 1. GERD, by sector and as %GDP

	2006–07	2008–09	2010–11	2011–12	2013–14	2015–16
	$billion	$billion	$billion	$billion	$billion	$billion
Business	12.64	17.29	18.01	18.32	18.85	16.66
Government	3.10	3.42	3.83	3.55	3.75	3.96
Higher education	5.43	6.85	8.16	8.89	9.92	9.55
Private non-profit	0.61	0.74	0.91	0.94	0.95	1.01
Total	**21 78**	**28 30**	**30 91**	**31 70**	**33 47**	**31 18**
GERD/GDP %	***2.00***	***2.25***	***2.19***	***2.12***	***2.11***	***1.88***

Data from: http://www.abs.gov.au/ausstats/abs@.nsf/mf/8104.0?OpenDocument.

It was revealed at Senate Estimates in October that over the next three years the ABS's funding will fall by approximately 10 per cent, at the same time as the demand for statistics is rising. Accessible, reliable, statistics form the basis for all future planning at the national, state and council levels and are crucial for any nation aspiring to prosper in the 21st century. The government should be increasing its funding, not inflicting death by a thousand cuts.

The GERD numbers in Table 1 cover the four main sectors. The key message is that while investment by the governments, Higher Education and Private Non-profit sectors has remained reasonably constant in dollar terms over the last few years, investment by the business sector has plummeted. The decline from 2013–14 to 2015–16 in this sector was $2.19 billion, or a massive 18%.

The manufacturing and the mining industries have experienced the brunt of the decline, presumably because of the fall in prices for mineral and petroleum resources and the collapse of car manufacturing. Figure 1 shows where the changes have taken place.

Manufacturing remained the largest contributor with $3.90 billion in 2015–16 followed by Professional, Scientific and Technical Services with ($3.75 billion or 23%), Financial and Insurance Services with $3.22 billion and Mining $1.88 billion. Together, these four industries accounted for more than three quarters (77%) of the total Business Expenditure on R&D in 2015–16.

Jobs in manufacturing plummet

The ABS 2016 census data released on 23 October 2017 also reveal the plight of Australian manufacturing. According to the ABS, the number of jobs in that sector fell from 902 829 workers in 2011 to 683 688 in 2016. No wonder the

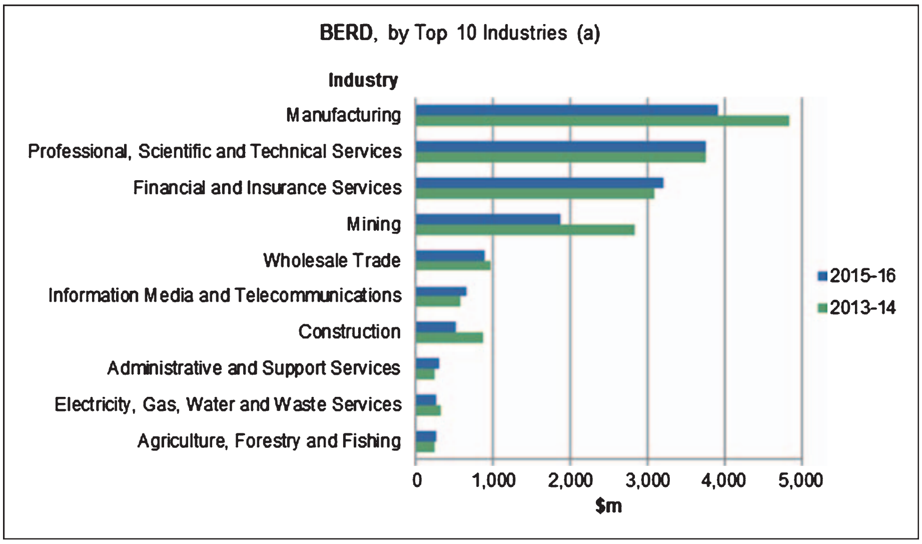

Figure 1. *Business Expenditure on R&D 2013–14 and 2015–16 (courtesy Australian Bureau of Statistics).*

Table 2. Top 25 countries ranked by GERD/GDP

Country	Year 2015	Country	Year 2008
Israel	4.25	Israel	4.35
Korea	4.23	Finland	3.55
Switzerland	3.42	Sweden	3.50
Japan	3.29	Japan	3.34
Sweden	3.28	Korea	3.12
Austria	3.12	United States	2.77
Chinese Taipei	3.05	Denmark	2.77
Denmark	2.96	Switzerland	2.73
Germany	2.93	Chinese Taipei	2.68
Finland	2.90	Singapore	2.62
United States	2.79	Germany	2.60
Belgium	2.46	Austria	2.59
France	2.22	Iceland	2.52
Slovenia	2.21	**Australia**	**2.25**
Iceland	2.19	France	2.06
Singapore	2.18	Belgium	1.92
China	2.07	Canada	1.86
Netherlands	1.99	United Kingdom	1.64
Czech Republic	1.95	Luxembourg	1.64
Norway	1.93	Netherlands	1.63
Australia	**1.88**	Slovenia	1.62
Canada	1.71	Norway	1.56
United Kingdom	1.70	Portugal	1.45
Estonia	1.50	China	1.44
Hungary	1.38	Ireland	1.39

Data from: http://www.oecd-ilibrary.org/science-and-technology/data/oecd-science-technology-and-r-d-statistics/main-science-and-technology-indicators_data-00182-en.

R&D investment in this sector dropped so significantly. Meanwhile, jobs in healthcare and social assistance (spanning sectors such as hospitals, GPs and aged and childcare) has boomed by 16%. It has solidified its position as the largest industry by employment, ahead of the retail industry, accounting for 12.6% of Australia's working population. I will leave the reader to judge whether the changing profiles are beneficial from a national perspective.

The mining industry is almost a minor player and ranks 16th in the ABS table that ranks the 18 largest employers. Its employment numbers have remained unchanged at about 180 000 over the five-year period since the 2011 census:

https://www.theguardian.com/australia-news/2017/oct/23/census-2016-manufacturing-jobs-in-australia-drop-24-in-six-years

How does our research effort compare with other countries?

Well not very well. The table on the left shows the GERD/GDP ratios for the top 25 countries listed by OECD for 2015, the most current year available, and 2008, when Australia reached its highest ranking. Notice how China and Korea have risen through the ranks, and although the United States has slipped from 6th to 11th, and the UK from 18th to 23rd, their GERD/GDP ratios have increased. Both Canada and Australia 'could do better' as a teacher's assessment might say for a lazy student. They have slipped both in the ratio and the ranking.

Because the methodologies in each country may be different for calculating both GERD and GDP, one must be careful when making comparisons, but overall the countries with the highest GERD/GDP appear to be the most successful.

It seems to me that if we are looking seriously to the future we must have an active and significant R&D sector. Even if it is just to evaluate and use technologies that have been developed overseas. If we cannot do that, we really will go down the tube. We can do better and somehow, we need to find a way to improve our performance.

Demand for gold declines but price remains solid

The third quarter of 2017 saw a 9% year-on-year drop in gold demand to 915 tonnes according to the World Gold Council (https://www.gold.org/research/gold-demand-trends). This is the lowest value since the third quarter of 2009, when the demand was less than 900 tonnes. It is a significant drop since the 1257 tonnes value of the 4th quarter of 2012.

The main reason for the decline was a fall in demand for jewellery, with Indian weakness largely being responsible.

On an annual basis, demand for gold in the last eight years has been between a low of 4227 tonnes in 2010 to a high of 4734 in 2011 with an average annual demand of 4432 tonnes.

Meanwhile, the price of gold in Australian dollars has risen steadily since 2009 from about $1200/oz to $1650/oz – an increase of 35%. A very sound return, as can be seen in the Figure 1.

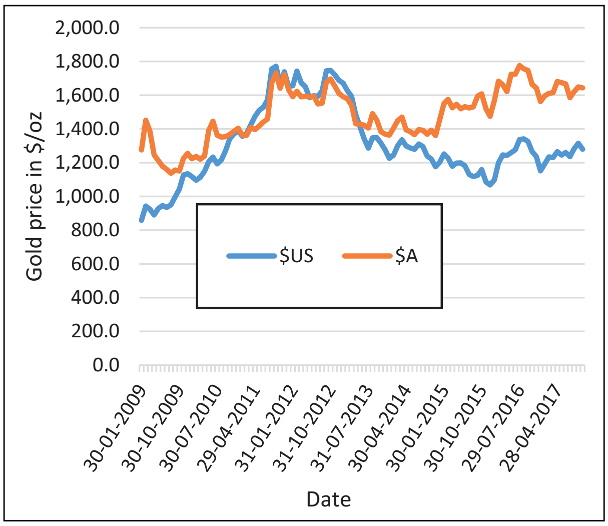

Figure 1. *Price of gold per quarter (not adjusted for inflation) from 2009–2017.*

Education matters

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The future of our profession as seen via student theses

Our annual summary of higher-degree and Honours theses demonstrates the breadth of geophysical activity in Australia today. Three theses apply seismic interpretation to basin structural analysis for hydrocarbon applications, and six apply potential field and electrical methods to mineral geophysics, especially the understandings necessary for mineral provinces. Seven theses deal with development of geophysical technology such as the use of unmanned aerial vehicles, palaeomagnetism, thermal conductivity, controlled-source EM and passive seismic methods. Four apply electrical and airborne EM methods to hydrology, CO_2 sequestration and soil erosion studies, and two take a cold hard look at the use of a suite of geophysical methods to study characteristics of the Sørsdal Glacier and ice sheets, East Antarctica. And congratulations to Ben Witten of UWA on completion of his PhD thesis on the use of passive-seismic methods for micro-seismic monitoring of fluid movement. Ben's project was supported by an ASEG Research Foundation award, so it is a hearty three cheers to Ben for a magnum opus completed, and to the ASEG RF for underwriting another successful student project!

Editor's note: Ben Witten will be reporting on the results of the research that was part-funded by the ASEG RF in greater detail in a future issue of Preview.

2017 Student theses

BSc Honours Theses

Elizabeth Grange, The University of Melbourne: *Geophysical and geochronological constraints on the emplacement and geometry of the Pilot Range Suite north-eastern Victoria.*

The Lachlan Fold Belt in south-eastern Australia records widespread magmatism during the Devonian. In the north-eastern Tabberabbera Zone (north-eastern Victoria) this magmatism and the spatially related molybdenite mineralisation is poorly understood. This study retrieved new petrophysical, high-resolution gravity, and geochronological data from the Murmungee region north-eastern Victoria to better constrain the geometry and emplacement ages of all major Pilot Range granites. Nine rock types were analysed for their density and magnetic susceptibility to provide constraints for the forward modelling of the gravity and magnetic data. U-Pb zircon LA-ICP-MS analysis was completed on six intrusive bodies to provide accurate ages of emplacement. Geophysical interpretation suggests these intrusives are much more extensive at depth than the surface outcrop distribution implies. The highly-magnetic Murmungee Granodiorite was interpreted over an area of ~150 km^2 compared with a surface outcropping of ~1 km^2. Geophysical forward modelling identified a close spatial relationship at depth between the highly magnetic Murmungee Granodiorite and the non-magnetic Beechworth Granite to the north. Previous geochronological data from the intrusives ranges over ~15 myr between the different units with very large errors. The new geochronological analysis identified a temporal relationship, whereby the intrusive emplacement ages calculated were all statistically similar occurring between ~380–390 Ma. These new geophysical and geochronological data identify a temporal and spatial relationship, between the Murmungee Granodiorite and Beechworth Granite. Combined with similar geochemical relationships to other Lachlan Fold Belt granite suites, this relationship implies the granites were all sourced from the same melt and separated due to fractionation. The molybdenite mineralisation formed at 379.6±1.9 Ma (Huston pers. comm., 2016) and the mineralisation is most likely genetically linked to the Everton Granodiorite.

Hamish Stein, University of Melbourne: *Geological and rock-physical considerations for building facies dependent elastic property models in shallow carbonates: interrogating sonic velocity, porosity, density and pressure relationships from the North West Shelf of Australia.*

Modern imaging projects can lack geological context and rock physical constraints when building complex, high resolution velocity models of the shallow overburden. This is especially prevalent in the case of shallow strata often overlooked by drilling regimes, or in carbonate lithologies that may express significant lateral variation of elastic properties. International Ocean Discovery Program Expedition 356 retrieved abundant high-resolution geological and physical property data from Neogene strata at four sites in the Northern Carnarvon Basin on Australia's North West Shelf. The unique data set comprises of core, well-logs, density and porosity data from the upper 1000 m below mudline. Geochemical and petrographical analyses were conducted on 140 core samples and 49 thin sections to characterise the carbonate facies. Porosity-depth analysis identified a point of geological significance at ~450 m below seafloor where widespread cementation occurred. Prior to cementation porosity loss was controlled dominantly by compaction. Current industry standard rock physics models, when tested for velocity predictive capability in the region, were unable to accurately estimate the porosity-velocity response of sediments in both compaction and cementation domains. Subsequently a hybrid-model is proposed whereby the contact-cement model is preferred until widespread cementation, at which point the Sun model best captured the trend. Velocity response was found to be facies dependent throughout the compaction dominated domain, whereas following cementation the porosity-velocity response was similar for all facies. The predictive velocity model generated from this work may be suitable for improved characterisation of the elastic properties of carbonates throughout the North West Shelf.

Martin M. Nguyen, Monash University: *Structural and lithogeochemical characterization of the Depot Domain, Eastern Yilgarn – a study in gold prospectivity.*

The Depot domain located in the highly gold-endowed Kalgoorlie terrane of the Eastern Goldfields has experienced little scientific attention in recent times despite the presence of major gold-hosting structures such as the Zuleika and Kunanalling Shear Zone. Geophysical mapping, field mapping and lithogeochemistry have been used to characterize the structural evolution, stratigraphy and prospectivity of the Depot domain. A regional geophysical interpretation constrained by field observations revealed six deformation phases which correlated well with existing literature. Lithogeochemistry and petrographic quartz-feldspar-lithics anlaysis (QFL) point towards deposition of the volcanics and volcaniclastics in a back-arc basin proximal to a continental volcanic arc environment. The dacites and andesites of the Depot domain show striking similarity to modern day arc-related volcanics, which may reflect a deep, fertile mantle source based on trace element geochemistry. Field mapping found the Depot domain to have deformed rigidly with respect to the neighbouring domains. Strong strain partitioning during post-D_3 deformation along the Zuleika and Kunanalling Shear Zone and the lack of rheological and geochemical contrast has had negative effects on the prospectivity of the Powder Sill Syncline although syn- to post-D_3 structures which have crosscut major D_3 shear zones may be attractive targets for gold exploration. This may be due to the imposition of heterogeneous strain fields which would produce dilational sites, promote fluid flux and increase the generation of dynamic porosity and permeability within 2nd and 3rd order structures off D_3 shear zones. The Depot domain also shows petrological, geochronological and structural similarities with the Yamarna and so exploration strategies used for gold exploration at the Depot domain may have corollaries for gold exploration within the Yamarna terrane.

Karlo Vickov, Monash University: *Developing an exploration model for the Glenlyle base metal prospect using geophysical methods.*

An exploration model based on geophysical data was developed for the Glenlyle base metal prospect in Willaura North, Western Victoria. The prospect was initially targeted due to a circular (5 km diameter) magnetic anomaly overprinting the linear north trending Mount Dryden Belt of the Mount Stavely Volcanic Complex. Newly acquired high-resolution gravity data was used to model a plug like porphyry that terminates as a sub-horizontal dyke at shallow levels. The porphyry is coincident with a high magnetic, low gravity anomaly in the centre of the prospect. Cross-cutting relationships of the 2D modelled geometries suggest that the porphyry was intruded post-tilting of the Mount Stavely Volcanic Complex, possibly contemporaneous with the Bushy Creek Granodiorite (502–498 Ma). A strong correlation between gold and copper concentrations is encountered within the quartz feldspar porphyry. The top of the upright porphyry system encounters propylitic alteration suggesting that at deeper levels a potassic, highly magnetised central zone containing significant mineralisation may be encountered.

Luke Smith, Macquarie University: *Precision positioning in unmanned aerial geophysics.*

This research investigates the implementation of precision GPS to Unmanned Aerial Vehicles for use in geophysical exploration. The prompt for this research was the Desert Fireball Network's meteorite recovery program, where an advanced impact site prediction system is followed by manual search and recovery. A small, automated, search vehicle is needed to explore the likely impact zones, which would require precise and accurate positioning in conjunction to its sensor capabilities. This thesis presents a Kalman filter implementation to improve and interpolate positioning during post-processing. This thesis also presents a sub-2 kg UAV magnetometer system utilising an RTK GPS to achieve centimetric positioning. A RTK GNSS module was integrated with an Arduino microcontroller for acquisition of in-house magnetometer gradiometer data. Results are presented for two field trials, testing both positioning and magnetometer performance. Magnetic performance was limited, particularly due to flight effects and sensitivity, however under ideal conditions the system was capable of locating a meteorite sample.

Dropout of DGPS during flight was found during surveys, which the Kalman filter was successful in ameliorating.

Kathryn Job, University of Tasmania: *Palaeomagnetic analysis of the Palaeozoic orocline model for Tasmania.*

Palaeozoic units of the Dundas Trough in western and northern Tasmania form an arcuate trend, noticeable in outcrop and aeromagnetic images, which appears to wrap around the Pre-Cambrian Tyennan region. Kinematic and structural analysis of this arcuate feature are important in reconstructing the tectonic history of Tasmania. Previous modelling suggests the region is a primary arc and attributes the arcuate shape to sedimentation in rift and graben systems. Recent modelling suggests the arcuate trend is a result of oroclinal rotation of a former linear orogen. Examination of palaeomagnetic data from around the Dundas Trough indicates far north-eastern sections of the arc have undergone ~90° clockwise rotation while western regions have undergone no rotation.

Palaeomagnetic samples were collected from selected early Palaeozoic sedimentary sequences at 22 localities around the Dundas Trough and correlates in the Adamsfield-Jubilee region. Low-temperature and thermal demagnetisation was conducted on most samples with selected units also demagnetised with the alternating field technique. From the 22 localities sampled 11 produced clear demagnetising results. Principal component analysis was used to determine characteristic remanent magnetisation directions with site mean directions and palaeomagnetic poles calculated from available data. Using mean palaeomagnetic data an orocline test was conducted and rotations around a vertical axis simulated.

The orocline tests, with gradients between 0.67 and 0.82, indicate palaeomagnetic declinations vary with regional strike. Average declinations in the north-east section of the study area (Dm 97.2°, Im 36.2°) suggest a clockwise rotation ~90°. Results from the northsouth trending western region (Dm 021.1°, Im 14.8°) indicate this proposed limb has remain fixed. Average directions from the central region (Dm 003.7°, Im 8.5°) show less confidence in the orocline model. Further study of the east-west trending section of the region is required to constrain rotation and determine if observed palaeomagnetic directions are due to oroclinal rotation of the whole region or localised rotation of thrust sheets.

Thomas Schaap, University of Tasmania: *Geophysical investigation into Sørsdal Glacier, East Antarctica.*

Numerical models of outlet glacier dynamics provide indicators for the state of the ice sheets from which they originate. Basement characteristics and englacial meltwater behaviour are important considerations in these models. Seismic, airborne radio-echo sounding, ground-penetrating radar, and gamma-ray spectrometry surveys have been analysed for information which may improve dynamics modelling of Sørsdal Glacier, East Antarctica.

Seismic reflection data indicate that Sørsdal Glacier sits on a retrograde bed, with measured ice thickness above water ranging from 611 ± 28 m towards the calving front to 1045 ± 48 near the grounding line. The maximum measured grounded ice thickness was 1647 ± 77 m. The maximum measured water column thickness was 500 ± 13 m. The grounding line position was constrained to within 4 km between seismic soundings. Refraction and surface wave analyses indicate that there is no near-surface low-velocity firn layer in the lower portion of Sørsdal Glacier.

Two airborne radio-echo sounding profiles have revealed internal stratigraphy and basement topography in the ice sheet adjacent to Sørsdal Glacier, but do not show the base of the glacier likely due to the effects of scattering of radio waves in highly deformed ice.

Ground-penetrating radar surveys in the Channel Lake area delineate subsurface reflective features at depths between 5 and 10 m. There features are interpreted as former englacial drainage conduits beneath the basin and may indicate the presence of an interconnected network of channels.

Heat production values between 1.1 ± 0.4 $\mu W/m^3$ and 1.6 ± 0.5 $\mu W/m^3$ were estimated using gamma-ray spectrometry for lithologies in the Vestfold Hills adjacent to Sørsdal Glacier. These values are low compared to estimates from other East Antarctic rocks, and global averages.

Sam Jennings, University of Adelaide: *A new compositionally-based thermal conductivity model.*

I report on 340 new thermal conductivity measurements of (mostly) plutonic rocks using an optical scanning device, coupled with major element geochemistry and modal mineralogy to produce broadly applicable empirical relationships between composition and thermal conductivity. Predictive models for thermal conductivity are developed using (in order of decreasing accuracy) major oxide composition, CIPW norms and estimated modal mineralogy. I find that SiO_2 content is the dominant elementary control on thermal conductivity due not only to its relationship with quartz but also its relatively large abundance over the entire compositional range. The feldspars are the major control on thermal conductivity for both mineralogy based models, with particular emphasis on the transition from Na-rich albite to Ca-rich anorthite. Four common mixing models (arithmetic, geometric, square-root and harmonic) are tested and, while the results are similar, the geometric model produces the best fit. The preferred model uses five commonly reported oxides (SiO_2, Al_2O_3, FeO, Na_2O and K_2O) plus loss on ignition to predict thermal conductivity across the entire compositional spectrum of plutonic rocks to within 0.27 W m^{-1} K^{-1}. A comparison of thermal conductivity and oxide-based estimates of P-wave velocity and density reveal systematic trends across the compositional range.

Ben Vincent Kay, The University of Adelaide: *Testing the UNCOVER paradigm: crustal fluid pathways in the Curnamona Province.*

In July 2017, scale-reduction was undertaken to improve the bandwidth and resolution of the AusLAMP defined Curnamona Conductor (Robertson et al., 2016) by way of a broadband magnetotelluric profile with site spacing of 2 km, extending from the Erudina Domain across the Mudguard and Quinyambie Domains in the Curnamona Province. A fossil fluid pathway has been identified from the lower mid crustal conductor to the near surface situated near a topographic basement high. The upper crustal conductor has been further delineated beneath the Quinyambie Domain to within 5 km of the surface situated alongside a major crustal feature.

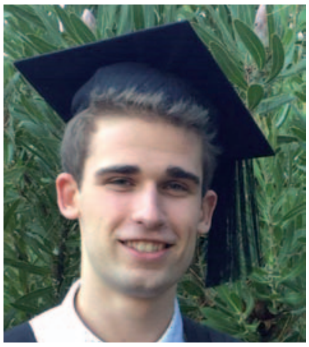
Musab Al Hasani, Curtin University: *Optimising geophone placement for land seismic measurements.*

Geophone placement is an essential aspect of land seismic measurements, and optimising this placement is a need for better data quality. This study focuses on geophone coupling, which can be described by a resonance frequency observed in the amplitude response. The approaches used to study the coupling phenomenon are laboratory and field experiments. The laboratory experiments were conducted a shaker-table and they described the effect of coupling conditions on the data as distortions in the signal, where poorly coupled geophones showed noticeably lower distortions compared to well-coupled geophones. The field experiments included different scenarios of geophones spikes and baseplates as well as several different soil types. I observed that horizontal components are more sensitive to coupling as a shift to lower resonance frequency for poorly-coupled geophones compared to well-coupled geophone. Also, longer spike and larger baseplates better coupling (i.e. higher resonance frequency). Also, the effect of stiff soil is shown as resonances observed at higher frequencies.

Chanel De Pledge, Curtin University: *Basement structure and evolution in the Ceduna SubBasin.*

The basement in the Ceduna Sub-Basin has been poorly understood due to its increasing depth and limited availability of deep crustal geophysical datasets. With the availability of the BightSPAN dataset provided by ION Geophysical, a new model of the basement has been produced with the use of PSDM, 2D seismic data, depth migrated to 40 km, and potential field data acquired along the same lines. Seismic interpretation constrained in deep areas of uncertainty by gravity forward modelling and combined interpretation of magnetic grids has aided in further defining basement depth and structure. A revised depth of 25 km to basement is proposed in this model, unlike previous depths of ~15 km. A new depocentre is defined in the NW of the study area trending in an E–W direction. Both depocentres structure and orientation support the prior evidence of oblique NW–SE rifting that occurred during the final break up of Gondwana, following old E–W oriented rifting. Basement thickness and structure indicates extensional faulting, with the increase of shallow basement in the south indicative of flexural uplift likely due to mechanical unloading of the lithosphere. The thickness, change in density, and introduction of serpentinised mantle also point towards evidence of the continental-oceanic transition zone.

Tom Dronfield, Curtin University: *Delineation and modelling of clay features within a saline water interface, Cockburn Sound, Perth WA.*



Clay lensing can significantly impact hydraulic flow, and is prominent throughout shallow aquifer systems in Perth, Western Australia. The impact of such lenses on the geoelectrical response and the extent of seawater intrusion must be considered. Electrical resistivity imaging (ERI), through numerical modelling techniques, was used to simulate clay lensing scenarios in shallow coastal aquifers. A clear dependence between electrode configuration and electrode spacing was identified. Hydraulic flow and solute transport modelling was able to additionally highlight the impact of these lenses on the extent of saline water intrusion, with clay layers at various depths within the mixing zone impeding the salient water plume. Field testing at a location south of Perth indicates the possibility of clay lensing from geoelectrical inversion. Crossline ERI surveys were deployed and detected additional lithological information that pertained to the calibration of the study area. A hydraulic flow model, based on geophysical and geological data, was created, to aid interpretation for the position of the saline water interface.

Olumide Adepoju, Curtin University: *Characterization of the shallow soil layer at the OTWAY CO_2CRC site using electrical geophysics.*

An ERI survey was completed at the CO_2CRC Otway Site in other to assist in characterizing the shallow clay layer prior to a planned controlled release and monitoring experiment which would involve injecting CO_2 into a fault zone. The major objective of the ERI survey was to map the thin surficial clay layer that exists within 5 m of the surface.

An interpreted surface of surficial clay is produced based on four 10 m spaced E–W transects in proximity to the proposed injection site. Two inversion algorithms Res2dinv and Boundless Electrical Resistivity Tomography were employed for inverting these lines.

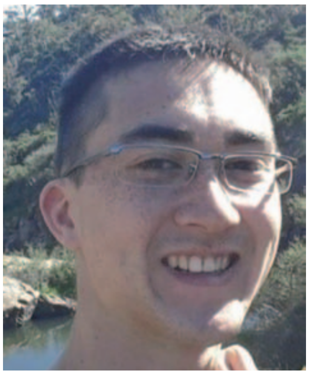
The results from the Res2dinv algorithm revealed a shallow conductive layer with conductivity values ranging from ~250 mS/m to ~150 mS/m while the BERT results provided conductivity values ranging from ~194 mS/m to ~127 mS/m. These values reflect a high fraction of clay and a region of low permeability.

The two algorithms show good similarities in the continuity of the clay distribution and also showed regions in the shallow clay layer which exhibited lower conductivity values and may warrant consideration in future planning.

Dane Peter Padley, Curtin University of Technology: *Controlled source electromagnetics using a long electrical bipole Antenna.*

Controlled source EM using a high-powered bipole transmitter together with electric field sensors provides high-quality electrical resistivity data from the near surface to depths of several kilometres. Aquifers in the Gnangara groundwater system located in the Central Perth basin provides a majority of Perth water resources. The aquifers are cut by the North-South trending Badaminna fault. The electrical resistivity data from CSEM could be used to differentiate clay and shales (aquicludes) from sands units (aquifers) and resistivity changes produced from salinity change could have the benefit of indicating transmissivity across the fault. The project analyses the electric response from different geoelectrical models (based on existing geological/geophysical models) and different transmitter and receiver configurations, providing additional information for planning a CSEM survey over the Gnangara groundwater system.

Brendan Ray, Curtin University: *The coastal hydrogeology of the north and central Perth Basin using airborne electromagnetics.*



A study of the coastal hydrogeology of the north and central Perth Basin, with emphasis on the saline water interface (SWI) was performed using airborne electromagnetic (AEM) data. A strong correlation was found between the inland extents and gradient of the SWI with relation to the depth of the underlying Kardinya Shale. Deeper Kardinya Shales led to shorter SWI inland extents and steeper gradients and vice versa. This trend was found along the length of the entire survey area (40 km) with the southern-most edge of the survey located 34 km north of Perth. The geometric extents of the SWI along with the Kardinya Shale were mapped and 3D surfaces were created, allowing the visualization of the change in vertical extents and relationship between the two features. Furthermore, a 3D conductive volume was created for the SWI which reveals the decrease in electrical conductivity with inland extent. Validation of the AEM data was also performed using two coastal electrical resistivity imaging (ERI) surveys and three well logs all of which were situated within 1.5 km of the ERI surveys. Guidelines were also developed for further studies of coastal AEM data to increase the accuracy of interpretations of the SWI along the coastline.

Aidan Shem, Curtin University: *Optimisation of the Horizontal to Vertical Spectral Ratio (HVSR) passive seismic method in the Hamersley Province of Western Australia.*

The Horizontal to Vertical Spectral Ratio (HVSR) passive seismic method is becoming an increasingly popular technique to cost effectively determine the depth of cover layers for mineral exploration. As the method has only recently been adapted as a tool for low cost mineral exploration, the optimum acquisition parameters are still insufficiently investigated. This project evaluates the potential of the HVSR method for mineral exploration through modelling and specialised experiments.

Subsurface conditions typical of the Hamersley Province were examined through theoretical modelling and I identified the shear wave velocity, depth to interface and acoustic impedance contrast as having the most profound effect on the amplitude and peak frequency of the H/V results. Controlled experiments varying key acquisition parameters were conducted to investigate their effect on the application of the HVSR technique for mineral exploration. As a result, I identified a 4 minute recording time, 50 m station spacing and coupling with long tapered spikes, as optimal acquisition parameters for the HVSR technique in the Hamersley Province, verifying the method as an accurate and repeatable mineral exploration tool.

Louis Paterniti, University of Western Australia: *Basement structure of the Caswell Sub-basin and its impact on Permo-Triassic inversion tectonics.*

The Browse Basin hosts some of Australia's most valuable hydrocarbon reservoirs that are related to Permo-Triassic inversion. Despite this, little is known about the nature and origin of these compressional episodes. Deep seismic profiles are used to develop a structural and tectonostratigraphic framework for the Caswell Sub-basin, and are integrated with 2D cross- section restorations to understand the mechanical controls on inversion. The Browse Basin initiated sometime in the early Palaeozoic in response to northeast-oriented extension. Extension rotated to north-northwest in the Late Carboniferous, coinciding with the regional Meda Transpression. The collapse of a Proterozoic mobile belt guided extension during this time and developed a low-angle crustal detachment along the western margin of the basin. Intermediate heat flows and crustal thicknesses resulted in the formation of a wide rift basin and the separation of the Sibumasu Block from Australia. A phase of thermal sag succeeding extension was punctuated by episodes of regional compression in the Late Permian and at five stages throughout the Early–Late Triassic. Faults on the basin margins accommodated the majority of the contractional strain while minor inversion occurred in the central Caswell Sub- basin along Palaeozoic rift faults. Simultaneous transtensional faulting resulted in the development of significant accommodation on the western margin of the basin in the Mid-Late Triassic. Thermal relaxation and cooling of the lower crust/upper mantle throughout the sag phase triggered the formation of Mesozoic narrow rift basins along localised necking zones in the outboard Seringapatam Sub-basin. Extension culminated with the separation of the Argo Block from Australia in the Callovian/Oxfordian and represents the final phase of rifting in the Browse Basin.

MSc Theses

Andrew Pearson, The University of Melbourne: *Redefined structure and evolution of the Wentworth Trough.*

The Wentworth Trough is a 300 km northeast trending trough, which underlies the Cenozoic Murray Basin in southeast Australia. The extent of the Wentworth Trough is characterised by a gravity low (O'Brien, 1981) and has been modelled to be approximately 5–20 km wide and 1.6–5 km deep (Knight et al., 1995). Little is known about the contents of the trough as no boreholes penetrate it in Victoria and it does not outcrop. 724 new gravity stations were collected to provide higher resolution gravity data over the trough. Qualitative interpretation of the gravity data refined the shape and distribution of the Wentworth Trough and suggests it is bounded by linear normal faults. Forward modelling of the gravity data constrained by interpretation of the reprocessed MEMV96 seismic survey and drilling formation intercepts has resolved the geometry and depth of the trough. The Wentworth Trough was modelled to be 400 m wide and 800 m deep compared to previous interpretations of 1.5–5 km deep. Moreover, this study shows that interpreted faulting within the fill of the Wentworth Trough precludes previous suggestions that the trough is filled with Permian or Cretaceous rocks. Instead, the trough is believed to contain Silurian Grampians Group sediments that outcrop further to the south and are known to be poly-deformed. The new interpretation of the fill of the Wentworth Trough redefines the timing of the trough from Permian to the Silurian, constraining the evolution of the trough to the extensional phase of the Benambran Orogeny. This interpretation is supported by the new tectonic model of the Lachlan Orocline proposed by Cayley et al. (2012), which suggests that southeast oriented extension proximal to the Wentworth Trough occurred in response to southeast directed slab rollback in the Late Silurian. The redefinition of the timing of the trough may mean that the Wentworth Trough played a more active role in the Lachlan Orocline than previously thought.

Anthony Finn, Macquarie University: *Tracing shallow lateral preferential pathways of fluid movement using electrical geophysics.*

Assessment of gullies is essential in understanding the effects soil erosion has on resource management, urban planning, agricultural productivity and local environmental conditions. Commonly prediction of gully head cut retreat has been disregarded due to the inherent complexities; this study proposes a method of analysing data to interpret potential pathways of gully retreat. Through the implementation of electrical geophysical (Electrical Resistivity Imaging & Frequency Domain Electromagnetics) surveys positioned uphill of existing gullies shallow conductor's representative of Lateral Preferential Pathways (LPP) will be detected. ERI results detected conductors uphill of the head cut at varying distances showing resistivity values of 1–40 Ωm; these identified anomalous zones were confidently linked to form an LPP. Integrated geophysical datasets were generated allowing for interpreted traces of LPP to be drawn that are representative of the future pathway of head cut retreat. Comparison of currently existing gully assessment techniques suggests that a combination of geophysical prediction of LPP and LiDAR data is necessary for a complete understanding of existing gullies. Based on the results of this integration, informed and targeted management decisions can be developed to remediate current landforms and mitigate future gullying.

Harrison Jones, Macquarie University: *Geophysical signatures of small-scale base metal occurrences in southeastern NSW.*

The aim of this thesis is to ascertain the usefulness of specific high-resolution, ground-based geophysical methods in identifying and evaluating two small-scale polymetallic massive sulphide deposits, located in southeastern NSW. Standard exploratory methods are typically applied at a prospecting or regional scale and may disregard smaller deposits, thus a greater understanding of the resolution required is needed for the range of geophysical methods. Recently obtained time-domain electromagnetic, magnetic and gravity data were analysed using a forward modelling approach. Results showed that a coincident loop time-domain electromagnetic survey effectively delineates the sulphide mineralisation and is useful in mapping deposit parameters such as the azimuth, dip and strike length. Based on the two areas studied, it was determined that high-resolution magnetic and gravity surveys were not effective ways for directly targeting the deposits due to the nature of the mineralisation and its host rocks. However, these methods were effective in delineating the surrounding geology, such as intrusive volcanic plugs and basement geologies and structures.

Lara Urosevic, The University of Western Australia: *Wilkes Land, East Antarctica: using subglacial geology as a key test for ice sheet stability.*

Ice sheets have been of global interest because of their influence on sea level rise in the currently warming world. Ice sheet stability is difficult to model, especially in relation to destabilisation events that occurred in the past. Studying ice-rafted detritus allows for ice sheets processes to be better understood, but are limited by provenance determination. The aim was to simulate the provenance of detrital signatures from Wilkes Land by mapping geophysical data and spatially analysing the erosive potential within these maps *via* ice sheet modelling. The ice sheets models used were 'retreat models' and analysed the retreat mechanisms of an ice sheet under different air and ocean temperature forcing states. Results showed that using this approach could determine unique detrital signatures for different modelled ice sheet states, allowing for a better understanding of ice sheet processes and dynamics near Wilkes Land. This understanding can be improved upon with additional data, therefore this process can be used as a preliminary step in determining ice sheet dynamics of a system with limited outcrop data. The ice sheet models used were not time constrained meaning that the detrital signatures could be predicted for different forcings but not for a past climate. They also did not account for processes after erosion, such as entrainment, transport and deposition, which combine to form the IRD 'signature' observed today. Despite the limitations, this study shows that a complex system can be better understood through a multidisciplinary approach.

PhD Thesis

Ben Witten, The University of Western Australia: *Elastic velocity estimation using image-domain adjoint-state inversion of passive seismic data.*

Detection and location of small (microseismic) earthquakes is critical due to increasing subsurface fluid injection activities. Accurately locating recorded earthquakes is paramount for improving productivity and reducing potential hazards. A fundamental parameter for location accuracy is the 30 velocity mode. Current seismological velocity building techniques based on large earthquakes rely on high signal-to-noise data. I present a new method to jointly invert for the velocity structure and accurately locate small magnitude earthquakes that is suitable for micro-seismic monitoring. Thus, it is useful for varied applications from induced seismicity to tele-seismic monitoring.

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Environmental geophysics

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Low induction number approximation

Welcome readers to this issue's column on geophysics applied to the environment. As many of you who have worked with me in the field will know, I love to hate data collected using a Geonics EM31, or any of the various similar but different incarnations of terrain conductivity meters (TCM) that have been developed over the years (think DualEM and GF Instruments and probably others). It's not the instruments that drive me crazy, it's the low induction number (LIN) approximation that is used to calculate the apparent conductivity that these instruments record.

Over time I have come to realise that the LIN approximation is (was) a very clever idea – one that I have always credited to Duncan McNeill in his Technical Note 6 (TN-6) (McNeill, 1980), but may actually be based on a much earlier paper by Jim Wait (will have to look into that). Anyway to me it is a clever way to make use of the limited portable computing power that was available in the 70s and 80s to provide a pretty good estimate of apparent ground conductivity. The LIN approximation takes a non-linear, complex and complicated expression that equates the ratio of the secondary (received) magnetic field and the primary (transmitted) magnetic field (H_s/H_p) to many other parameters, including a number of deeply buried conductivity terms; in this equation it is impossible to explicitly solve for conductivity. The complete solution for conductivity is done numerically, with Hankel transforms, etc. Back then there was (overall) limited computing power (what will they say about the computing power that we have now in 35 years?), and even less computing power that a person could carry in a long straight tube with a transmitter coil at one end and a receiver coil at the other. So the LIN approximation allows this difficult equation to be solved analytically for conductivity, once the transmitter-to-receiver separation was set to be much less than the skin depth, by judiciously setting the length of the instrument and the operating frequency. The standard shorthand for the skin depth equation is given by:

$$\delta = 505 * \sqrt{\frac{\rho}{f}}$$

where δ is skin depth (in meters), ρ is resistivity (in ohm-m), and f is frequency in hertz. And it might be worth reminding readers that resistivity (ρ) and conductivity (σ) are reciprocals of each other, and that conductivity is given in units of S/m (and I have used mS/m in my figures). Skin depth is often used as the approximate depth of investigation (DOI) for instruments that operate in the frequency domain.

From the EM skin depth equation one can see that the skin depth (approximate DOI) is large when the ground is resistive, i.e. ρ is large (or σ is small), so the LIN approximation works, and that the skin depth is smaller when the ground is conductive, so the LIN approximation eventually fails. McNeill understood this and showed it graphically in TN-6, reproduced here (including its original caption), as Figure 1. As noted in TN-6, the indicated conductivity is about 20% too low (and getting worse with increased conductivity) once the conductivity of the ground is >100 mS/m (shown as 100 mmho/m – the conductivity unit of the day) or <10 ohm-m. This means that when the instrument is used to collect data in many normal Australian settings, e.g. to measure extent of shallow saline groundwater incursion in a wetland (a conductive setting), the output conductivities are incorrect. I do have to admit that as a relatively simple mapping tool the map of conductivity distribution that is produced using LIN approximated conductivities can still be useful (even when used to map saline ground water incursion).

In 2001 Reid and Howlett published a nice article in *Exploration Geophysics* that directly discussed these limitations (the only article that I have ever seen on the subject besides McNeill's 1980 statement of the limitations – there must be others) and how the response of the EM31 changes over ground where the LIN assumptions are not valid. In the process they wrote up some code that allows the input of a set of LIN-approximated data that outputs true conductivity values based on the more difficult numerical solution. It is worth noting that the program may be used on any TCM data, so long as the transmitting frequency, instrument height and the dipole spacing are known. I have used James' program to produce Figure 2, which compares the difference between the correct response (labelled as True Conductivity on the y-axis) and the LIN response (labelled as Indicated Conductivity on the x-axis) for a number of TCM instruments. The EM31 comparison is shown - looking a great deal like McNeill's 1980 results (Figure 1). Three other instruments, with three different dipole lengths, labelled here short, medium and long, are shown as well, to show how the response varies with dipole length. The executable is available from me if anyone wants to use it. Note that James does not guarantee the results, nor does he support it anymore, but does not mind seeing it being used.

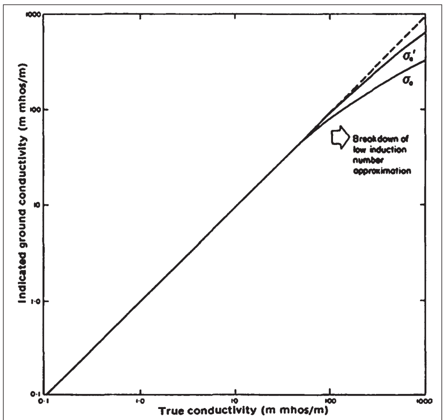

FIGURE AIV. Plot of indicated conductivity for EM31 versus true (homogeneous half-space) conductivity for both vertical (σ_a) and horizontal (σ_a') dipoles.

Figure 1. *Original figure from McNeill's TN6 showing how the indicated conductivity veers away from the true conductivity from conductivities <100 mmhos/meter (100 mS/m or 10 ohm-m).*

One of the conclusions from the Reid and Howlett paper is that the depth sensitivity of the instrument is generally much reduced under non-LIN (conductive) conditions than what is normally assumed; therefore not only are the conductivities inaccurate, but the assumed depth-sensitivity distribution is wrong as well; any inversion of data collected in conductive ground will be incorrect, both for depth and conductivity. I have been experimenting with an inversion routine that uses the raw data and makes no assumptions about LIN conditions – and the results are very interesting. In fact I am actually starting to like what can be done using TCM instruments, especially the newer instruments that collect data using a number of transmitter-receiver spacings, i.e. at a number of depths. The data density is excellent so lateral resolution is very good (limited to about 7 m depth though) and the inverted sections come out very reasonably; but that may be a subject for another column.

Ultimately my point is that it seems wrong to me to use an approximation when we have so much more portable computing grunt available these days than we did when the EM31 was developed back in the 70s. Instrument manufacturers are producing TCMs that provide conductivity information that is needlessly approximate. At the very minimum the instruments should be providing the user with the LIN approximated data, the 'true' apparent conductivity, and the quadrature ratio data in ppt so that the data may be properly inverted without having to back out the raw ratio data.

References

McNeill, J. D., 1980, Technical note TN-6, electromagnetic terrain conductivity measurement at low induction numbers. Geonics Limited: Mississauga, Ontario, Canada.

Reid, J. E., and Howlett, A., 2001, Application of the EM-31 terrain conductivity meter in highly-conductive regimes: *Exploration Geophysics*, **32**, 219–224.

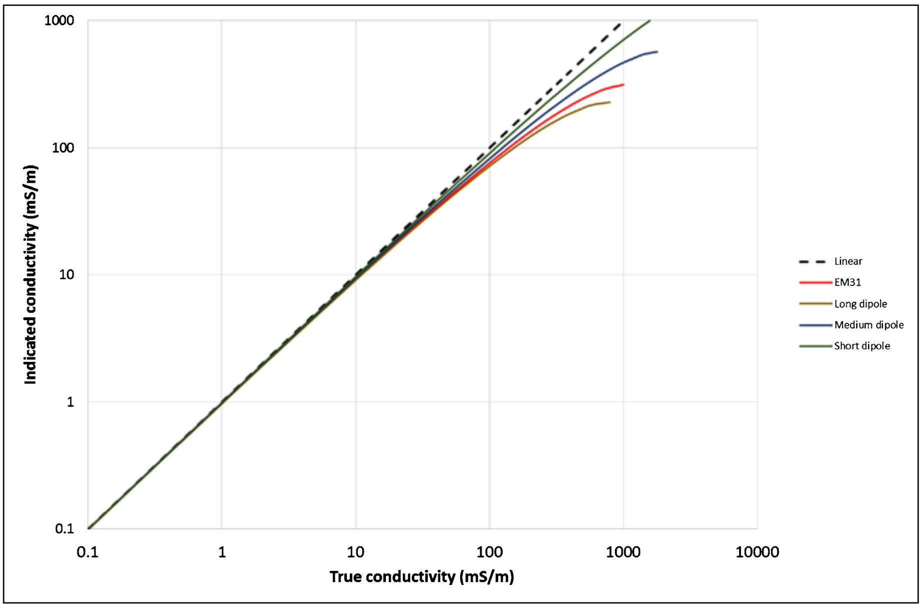

Figure 2. *Results of testing with James Reid's code that recalculates TCM data that is LIN approximated to 'true' apparent conductivity. The dashed line shows where the data would lie if the relationship between the Indicated conductivity and the True conductivity were one-to-one. EM31 results are shown, along with results from other similar devices – one with a long dipole length, etc. as indicated. As expected, long dipoles are more affected by the LIN approximation than short dipoles.*

Minerals geophysics

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If it seems too good to be true…

Once upon a time, in a country far, far away, a magician (geophysicist) appeared at court with an amazing offer.

> *Provide me with a helicopter and a piece of the ore you seek, and I will criss-cross the country and find your mineral deposits.*

The military vetoed the helicopter on security grounds, but our geo-wizard was not to be put off.

> *No problems. I will hold the lump of ore in my hand, pass it over a geological map, and pin-point drill-sites that way.*

The offer was never followed up.

A fairy-tale, right? It could never happen in this day and age, right? Well, wrong. Fantastic schemes are still peddled in our industry, as the following story illustrates. It would be improper to identify the personnel or organisations involved, but I trust the geophysicist who told me the story. This really did happen.

As with many of these schemes it began with a cold call, in this case to someone high up the company hierarchy. Recently declassified foreign power satellite imagery, the cold caller said, had been carefully analysed using sophisticated proprietary techniques, and this analysis had detected a base metal orebody on company ground. A joint venture was proposed, whereby another proprietary technique would be employed to properly locate and map out the orebody. Technical details for this method were sketchy, but it was based on atomic physics. The method would provide very detailed soundings of metal grade (virtual drill-holes), reducing the need for conventional drill-testing.

Management asked geoscientists within the company to assess the technique, and, using the limited information provided, they dismissed it as probable scientific nonsense. None-the-less, senior management was interested in pursuing emerging innovations and called for the contractors to carry out a program of field tests to verify the technique against information from existing drill-holes, along with combined helicopter and ground exploration to properly locate and detail the potential orebody.

This program was duly organised and carried out by the contractors under company supervision. The field verification tests were disappointing. The contractors had been reluctant to undertake some of the work, and the results they provided were often preliminary in nature. When compared with existing drill-hole information some results were clearly wrong; nevertheless there were some possible correlations. The exploration component, however, was a resounding success! The contractors' base metal orebody was located by the helicopter work and mapped in detail on the ground. Copper content was assessed at 2%–4% over a vertical extent of 600 m from 150 m sub-surface. Based on their survey results and interpretation, the contractors sited two vertical drill-holes to confirm their findings.

Drilling found nothing, unless one speck of malachite in the weathered zone could be taken as significant; in particular, the geological environment was spectacularly un-promising. The contractors were not dismayed; they knew the orebody was down there somewhere. They produced a new interpretation showing the mineralisation, now sub-vertical, fitting neatly between the two close-spaced drill-holes; these, they now insisted, should have been drilled on the incline. However, management had had enough. The technique was considered discredited, and the project terminated.

The thought processes associated with this tale are interesting. Initially, the scientific groundings of the method were stressed, but without going into too much detail on exactly how these were applied. When this was challenged, the possibility that the technique might work because the science couldn't entirely be dismissed was played upon. Once the verification field test results were available, the possible correlations were emphasised, rather than the obvious discrepancies – a true believer will naturally look for supporting evidence. Finally, when the definitive drill-test was done and the results were negative, there was an alternate interpretation to explain the lack of success, and reasons given why more testing should be done.

Are there any positives to be taken out of this? Well, yes, I believe there are. Credit is due to management who backed their idea to have the method tested, and much credit is due to the exploration team, who, despite their communicated misgivings, designed and supervised the test program. And, of course, their initial doubts regarding the scientific validity of the method were vindicated.

Now, if I've still got your attention, I've got my own science-based scheme in mind. It involves passing small electric currents (solar powered, with battery back-up, naturally) through public swimming pools and collecting the precious metals leached from swimmers' jewellery; as a bonus, gemstones dropping from corroded and weakened jewellery settings could also be harvested from the bottom of the pool at regular intervals. All expressions of interest and any offers of seed money are welcome!

Seismic window

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An introduction to spectral decomposition

Subtle traps and depositional features are often not obvious on normal seismic displays but can be enhanced by spectral decomposition, which always seems to produce great looking pictures. The technique has been in the interpreter's tool kit for some time now, and is used to transform normal seismic data into the frequency domain so that instead of one volume of data (amplitude) there is an unwieldy set of several to be analysed – one for each frequency component. Because of tuning each frequency component responds to a different bed thickness with high and low frequencies highlighting thin and thick beds respectively.

Historically a Fourier transform (FT) was used to calculate the frequency components, but this transform uses a constant window length regardless of frequency. To analyse a low frequency a longer window is used, and this leads to uncertainty in the origin of the high frequency response within the window. This trade off between frequency and temporal position has led to the use of other techniques such as the continuous wavelet transform (CWT). Although the CWT looks much more complex than the Fourier transform (Figure 1) it is essentially the same with the main difference being the CWT replaces the continuous cosine/sine wave with a finite length wavelet and a scaling term (regular readers may be shocked – I actually do know more than one formula!). The wavelet term (boxed in red) is more complicated because the length of the

Fourier Transform

$$\hat{f}(\xi) = \int_{-\infty}^{\infty} f(x)\,\boxed{e^{-2\pi i x\xi}}\,dx,$$

Continuous Wavelet Transform

$$X_w(a,b) = \frac{1}{|a|^{1/2}} \int_{-\infty}^{\infty} x(t)\,\boxed{\overline{\psi}\left(\frac{t-b}{a}\right)}\,dt$$

Figure 1. *The continuous wavelet transform (CWT) and Fourier transform are similar with both containing the input function and a wavelet description (red box). As frequency varies the CWT wavelet maintains its shape but varies in length while the Fourier transform uses continuous cosine/sine functions.*

analysis window changes with frequency while the wavelet's shape is maintained so that when higher frequencies are analysed a shorter wavelet is used.

Notice how the maximum amplitude (dark red) in Figure 2 is between 30 and 60 Hz for most of the time levels. This is because the frequency spectrum has a strong wavelet overprint on the tuning information. In some implementations of spectral decomposition there is an option to normalise the data by setting the average amplitude (or maximum) to a constant value for each frequency. This whitening removes the wavelet overprint that is embedded in the data. The displays in Figure 2 have not been normalised so very low and very high frequencies have diminished amplitudes and the tuning effect may be masked.

Let's have a look at how spectral decomposition can be used to contour a prospect with an example from the Exmouth sub-basin of Western Australia.

The strong amplitude anomaly seen on the map view and seismic line of Figure 3 is possibly a gas accumulation, but other information is contained in the seismic data. By applying spectral decomposition it is possible to estimate the thickness of the gas column and calculate the rock volume of the anomalous structure. Figure 4 shows selected frequency components of the same data with the corresponding estimates of bed thickness as shown

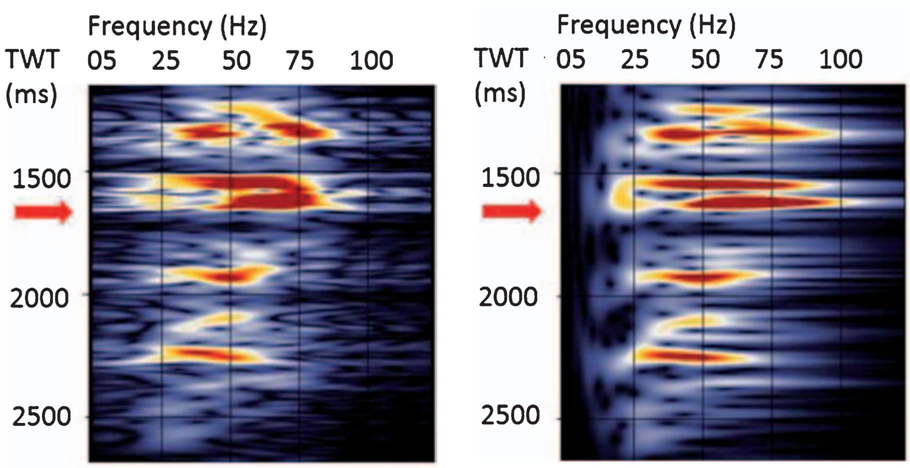


Figure 2. *Comparison of Fourier transform (FT) (left) and continuous wavelet transform (CWT) (right) using plots of frequency vs time for a single trace. These plots are a display of the frequency spectrum at every time sample in the trace. The FT (left) plot has less vertical resolution but more focussed frequencies than the CWT plot (right). The high amplitude reflector used in Figure 3 is indicated with the red arrow.*

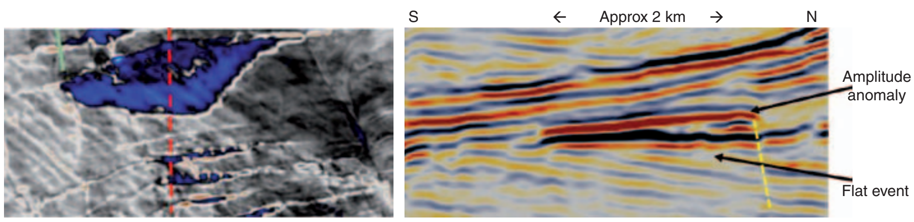


Figure 3. *Map of seismic amplitude anomaly (left) and a south to north seismic line (right) with high amplitude anomaly over a possible flat event. The amplitude anomaly is 6 km long and 2 km across.*

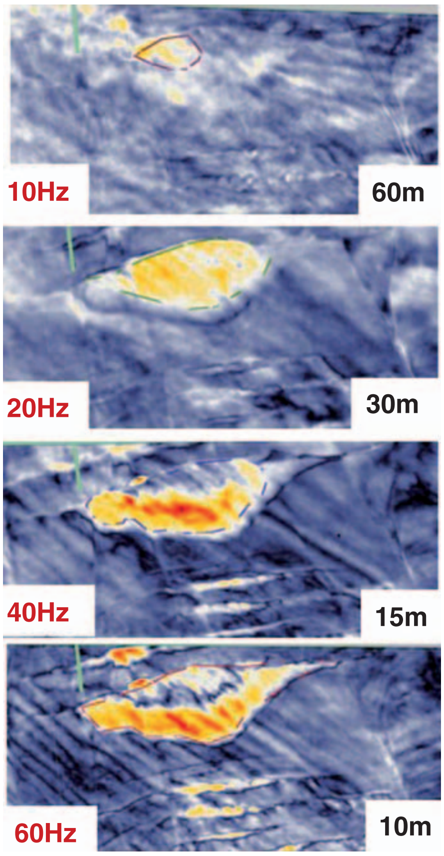
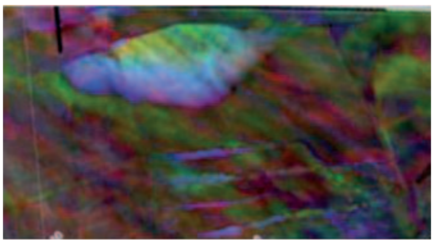


Figure 4. *Selected frequency slices of the amplitude anomaly of Figure 3. The anomaly expands outwards as frequency increases and thickness of the interpreted gas column decreases. These displays have not been normalised so the relative amplitude of the anomalies reflects the frequency spectrum of the wavelet in the data peak frequency is 30–40 Hz.*



Red 10Hz Green 20Hz Blue 40Hz

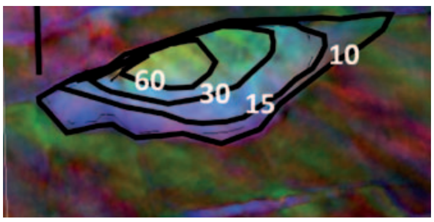


Figure 5. *Blended RGB display with and without contours based on spectral decomposition amplitude anomalies.*

in Table 1. The peak amplitudes are a tuning effect so, given the frequency and velocity, a thickness can be estimated for each component with high frequencies responding to thin beds and low frequencies responding to thick beds. By tracing the outline of an anomaly on a judicious selection of frequency slices a contour map of the anomaly can be built up (Figure 5) and a gross rock volume calculated.

Table 1. Estimates of thickness

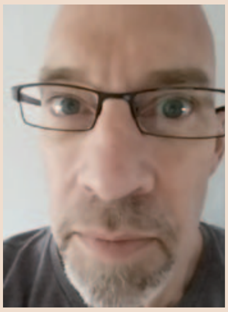
Thickness estimate (assuming a velocity of 2400m/s)				
Frequency (Hz)	10	20	40	60
Tuning thickness (m)	60	30	15	10

The number of data volumes produced makes analysis difficult, so the use of RGB colour blending can assist by allowing multiple (three) frequency components on the same display. To maximise the information contained in a colour blended display I have found it useful to select input frequencies an octave apart (e.g. 10, 20, 40 Hz or 15, 30, 60 Hz). Notice how the colour changes are somewhat conformable with the contours in Figure 5.

I encourage you to give Spectral Decomposition a go and if you have some good examples why not send them in.

Wishing you all a Merry Christmas!

Webwaves



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Data breaches

Recently Thomas et al. (2017) presented the results of a year-long longitudinal study of the effects on users of different types of credential theft *viz*: data breaches, phishing and keyloggers. Keyloggers are legal tools designed to covertly capture keystrokes and, while they are sometimes integral components of an operating system, are often installed without users' knowledge in order to steal password or credit card information. Phishing was briefly discussed in PV189, and is the attempt to obtain sensitive information by using a disguise. Data breaches were the third type of credential theft studied, and this type is the main topic of this month's Webwaves.

Data breaches are the intentional or unintentional release of secure or private or confidential information to an untrusted environment. One source (breachlevelindex.com) suggests that, worldwide, some 1 901 866 611 data records were compromised during 918 incidents in the first six months of 2017. This works out to slightly over 10.5 million records per day from organisations such as a motor vehicle registry in Kerala, India, an email marketing organisation in the USA, a data analytics firm working for a USA political party, a restaurant app and the UK's NHS. Only 18% of those breaches were accidental. Most data breaches were malicious, and most (74%) were from outside the organisation. As to the remainder of incidents, only 8% were the result of a malicious insider, and there was one state-sponsored incident.

So what was the nature of these breaches? What data were released without authorisation? Only 13% were directly related to finances. Some 6% were related to account and to data access. Most (74%) data released were directly related to identity theft. Identity theft affected over 770 000 Australians in 2015 (http://www.abc.net.au/am/content/2015/s4215824.htm) and can have far-reaching impacts on its victims.

As any geophysicist is aware, not all data are equal. Of all compromised records it is estimated that some 4.6% were useless because they were encrypted. For this reason, experts currently consider that, whilst some emphasis should remain on network security, it would be better to shift the focus of data protection towards rendering data useless if (when ...) it is released.

With this in mind, the EU has introduced the General Data Protection Regulation (GDPR) to be implemented on 25 May 2018. One requirement of the GDPR is that companies storing data must lodge notification of breaches within 72 hours. Others include the right to be forgotten, the right of individuals to transfer data from one processing system to another, and the necessity for a lawful basis for data processing. Data are required to be protected by default, and therefore data are pseudonymised so that stored data cannot be attributed to individuals without additional information. Decryption keys must be stored separately to pseudonymised data. In this way, if (when ...) data breaches occur, their impact on individuals is minimised.

So why is this matter being discussed in the ASEG's Webwaves column? The ASEG is affected by this Regulation because of our European membership. Therefore, early in 2018, the database that stores Members' details will be moved to two-factor authentication. Member's data will be more secure because two sources of information will be required to access their data – not just one source, which is the current requirement.

So what were the results of the longitudinal study into types of credential theft? Thomas et al. (2017) showed that blocking unusual location-based login attempts that were typically the result of keylogging or successful phishing trips (...) could mitigate the risk of data breaches. Because attempts at identity theft are increasing, recommendations for care when following URLs are likely to remain for the foreseeable future.

In more prosaic web-related news, readers are altered to updates of the manuals section of the website (aseg.org.au/equipment-manuals-brochures). Recently, Peter McMullen (GeoResults Pty Ltd) was able to supply updated manuals for some magnetometers and susceptibility meters. A video recording of the WA Branch's October Technical night featuring Bill Peters (Southern Geoscience Consultants) talking about 'Geophysics for magmatic Ni-CU (PGE) Exploration' has also been added (aseg.org.au/wa-branch-technight-night-bill-peters). The efforts of Kim Frankcombe and Chris Bishop in resolving technical issues before this talk could be advertised on the website are much appreciated.

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Haematite: the bloodstone

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Introduction

Any appreciation of significant members of the mineral kingdom should include the humble and ubiquitous sesquioxide of iron, Fe_2O_3 or haematite, also known as the bloodstone. Humble it may be, but its roles in human culture, science, and commerce compare well with any other mineral.

Polycrystalline dark metallic haematite has a distinctive red streak when scratched; when cut it seems to bleed with the saw coolant turning red. In thin plates it is translucent and red. Amorphous earthy haematite can range in colour, on the Munsel scale, from light to dark red.

The ancient Greek for blood is αἷμα, genitive case αἵματος, and it is from this ("of blood") that the name haematite derives; *haematites* in later Latin. Theophrastus (c370-c287BC), Aristotle's pupil and colleague, noted in an abbreviated treatise on stones: "and the haimatitis is a compact material with a rough appearance; and as its name suggests, seems to be made of dried coagulated blood" (πυκνὴ δὲ καὶ αἱματῖτις· αὕτη δ' αὐχμώδης καὶ κατὰ τοὔνομα ὡς αἵματος ξηροῦ πεπηγότος). Caley & Richards (1956), and others, have proposed that Theophrastus was referring to jasper, which is a red chert associated with sedimentary iron beds and comprising mainly cryptocrystalline quartz coloured by iron oxides. Possibly so, but in jaspilites (or banded iron formations) some jaspers can be highly haematitic, (Joplin, 1968), and quite red in colour. A typical haematitic banded iron formation (BIF) is shown in Figure 1.

Three types of haematite can be distinguished visually by colour. Each also has a lustre, which is a qualitative description of the nature and degree of light reflectance from a material's surface dependent on surface smoothness, refractive index, and absorption coefficient (Bloss, 1971). Earthy red haematite has no lustre and appears dull because its myriad sub-microscopic component particles present an optically rough surface to the viewer. Specular grey-black haematite has a metallic to metallic-splendent lustre (*specularis* is Latin for mirror). Steely black haematite with its polygonal structure has a submetallic to metallic lustre. These three categories, in the writer's experience, also usefully serve as resistivity indicators for solid materials in the dry state.

A succinct summary of haematite as a formal mineral can be found in Deer et al. (1992). Details of Australia's commercial haematites can be found in Harmsworth et al. (1990), Yeates (1990), and in many other publications on iron enrichment in the banded iron formations of Precambrian basins. Selected physical features of haematite are given in Table 1.

This article, following the writer's whim, and making no claims to be comprehensive, cherry-picks its way, with a couple of digressions, through haematite's history, lore, and properties.

Red

In the visible spectrum, humankind could, perhaps, manage without indigo, but not without red. For centuries it has ranked high as a colour, which has many shades; it can be dynamic, evocative, stimulating, and emotive. Around the 8th c. BC, in *The Iliad and the Odyssey*, Homer mentions red ochre (μίλτος) as a distinguished colour painted on ships, but elsewhere in his epics Homer did not much refer to colour. In life we respect the Red Cross and its humanitarian works; we delight in the tinted clouds of a sunrise and a sunset; we never tire of gazing at the rainbow with its outer convexity so diffusely red; we gaze in wonder at Jupiter's huge red spot, origin unknown; a red flag alerts us to danger; and red is a common colour in the sunburnt vastness of the Australian outback where the Sturt's desert pea surprisingly thrives, spectacularly red-petaled, on arid sands; and red cliffs overhang the Kimberley's free running water holes.

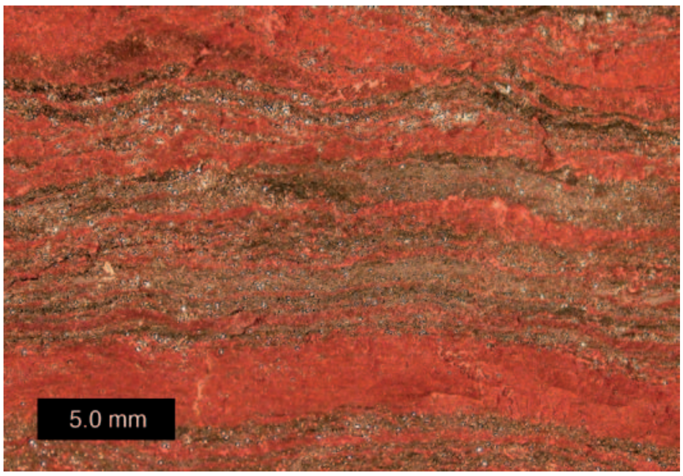

Figure 1. *Haematite in Precambrian iron formation from Upper Michigan, Lake Superior region USA. Photograph taken by Mark A. Wilson, https://commons.wikimedia.org/wiki/File:MichiganBIF.jpg.*

Table 1. Haematite Fe_2O_3

Chemistry	Iron sesquioxide Fe 70%, O 30%	Common iron oxide, which can contain some Ti, an abundant iron ore
Crystallography	Trigonal (hexagonal-scalenohedral)	Crystals thin to thick tabular, but not all that common
Features		
Colour	Red to black	Red ochre (reddle) is an earthy haematite
Hardness (Moh scale)	6 ±	Conchoidal fracture, brittle yet tough
Streak	Distinctive Indian-red	Ti varieties: black streak
Physical forms	Granular Platy Micaceous Reinform/botryoidal Specular Earthy and/or pisolitic	Massive Micro, meso Foliated Fibrous kidney ore Aggregation of thin platy crystals Ochreous
Galvanic elec. Petrophysics categories	Grey-black, specular *Metallic-splendent lustre*	Euhedral, well crystallised, platy aggregates, lustrous shiny, grain sizes fine to coarse
	Steely-black *(Sub) metallic lustre*	Anhedral, to subhedral, fairly well crystallised, interlocking equant grains, polycrystalline mosaic, fine to medium grain size
	Earthy-red *Dull (no lustre)*	Crypto-crystalline to amorphous, extremely fine grain sizes, microporous, diffuse particle boundaries
Density	5.26 g/cc	For crystals, zero porosity solid haematite
Mag. susceptibility, k	100–1000 × 10^{-5} SI common range, but can be higher, see Hrouda (2002)	Weakly to moderately susceptible, but if Ti present (ilmeno haematite) or trace amounts of magnetite or maghaemite → higher mag k
Remanence, Qn	300 ±	Qn = modulus of J_{NRM}/J_{IND}, J: vector, intensity of mag. J_{NRM}: remanence, can be strong J_{IND}: k F (F, earths field) induced mag.
Conductivity/resistivity	Varies with crystallinity	To be discussed herein

Notes:
- Haematite here is α Fe_2O_3, it is one of the iron oxide “ferromagnetics” (actually canted antiferromagnetic). Maghaemite, γ Fe_2O_3, has haematite’s chemistry and magnetite’s spinel structure, it is a dense (~4.8 g/cc), red-brown mineral that is very magnetic (not dealt with in this article). See Clark (1997) for a comprehensive discussion of the magnetic properties of iron oxide minerals.
- Goethite, α FeO(OH), a very common mineral, dehydrates to haematite α Fe_2O_3. Lepidicrocite, γ FeO(OH), dehydrates to maghaemite, γ Fe_2O_3. Magnetite, Fe_3O_4, oxidises to haematite (martite) or to kenomagnetite, an intermediate phase between magnetite and maghaemite. Sometimes the low mag k of a haematite host is increased by trace amounts of magnetite and/or maghaemite. See the iron ore literature for details.
- The convenient galvanic petrophysical categories are subjective and based on the writer’s experience. Others may prefer a different categorisation.

In matters culinary: raw red steak is the principal meat on any barbeque; red chilli spices our food; at football matches and fairgrounds the hot dog’s red frankfurter sustains the enthusiasm of attendees; the glistening dollop of a rich tomato sauce so savours that iconic edible – the Australian meat pie; and the inedible red herring diverts us from our proper purpose. For literature, red is such a handy hue. On the sacred side: the strawberry, red and fragrant, was the symbol of perfect righteousness in medieval art (Post, 1974). Rubrics are the ceremonial directions, written in red, in books of Christian religious rituals, a practice deriving from the ancient Roman lex *rubr(ic)a* – the first words (or more) of a law were written in red, probably with a red ochre paint as *rubricia* is the Latin for red ochre. In medieval manuscripts such as psalters, some of the pigments in illustrations are derived from haematite. The American poet Edwin Markham in 1901 wrote of President Lincoln: “… the colour of the ground was in him, the red earth/ the smack and tang of elemental things …” On the profane side: in Dante’s *Inferno*, written around 1314 (see Durling, 1996), the three-throated hell-hound Cerberus has red eyes (canto 6) and one of the three faces on Satan’s head is red (representing hatred, canto 24). In *Lolita*, Vladimir Nabokov’s 1959 novel, the eponymous, lip-sticked, pink clad nymphet, by playing with an Eden-red apple, induces cardiac quickening in the depraved Humbert Humbert. The vision of the deplorable Roger Micheldene, the lead character in Kingsley Amis’ 1963 story, *One Fat Englishman*, is frequently impeded by the red mist of rage rising before his eyes as he waddles, vexatious, from bed to bottle to brawl. Red, as can be seen, is a powerful signifier in human affairs.

In the mineral world, vibrant scarlets are derived from poisonous red lead (Pb_3O_4) and unstable cinnabar (HgS). But for the writer, the rubescence that excels lies in the earthy form of the mineral that sells so well on international markets – robust, brick-red haematite. Published statistics (Resources and Energy Quarterly, March 2017) indicate an Australian production of about 850 000 000 tonnes of iron ore (haematite mainly, and other iron oxides) valued at $72 000 000 000. It is by far our most important individual exported resource, contributing significantly to Australia’s prosperity. Haematite has a solid, subdued red, it is not flashy; it is a natural colour of substance. This pleasing and stable shade has been attractive to generations of humankind; it is also a very interesting mineral in other respects.

Red ochre

Ochre is simply a metallic (usually Fe) oxide, in varying amounts, in a base of powdery clay; sometimes the base is chalk. It is an earthy pulverulent, i.e. easily powdered. Haematite (Fe_2O_3) is the oxide in red ochre (reddle, ruddle); goethite FeO(OH) is in yellow/brown ochre. Haematite is the end point of iron oxidation mineralogy in highly weathered environments. Goethite dehydrates to haematite, either naturally in a weathered profile, or by heating in a mill; $2FeO(OH) \rightarrow Fe_2O_3 + H_2O$. The purest red ochre is mainly just haematite, but this is rare. Red ochre, with up to about 75% haematite, tends to occur in discrete pockets or seams, mined locally, since pre-history, to be used as a pigment, an adornment (of objects or bodies), and in rituals.

Tradition has it that European iron was first discovered in the ashes of a large fire built close to a red ochre deposit: $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$. When the paint-rock and the fire were realised to be the cause, and metal the effect, crude rock furnaces were designed to produce a material whose utility is valued to this day.

The extraordinary cultural role of red ochre in rituals and funerary practices from pre-historic times is documented by Clifford (2012) who argues for its worldwide symbolic use in the Palaeolithic (Old Stone Age), and later. From 100 000 years BP onwards there is evidence of widespread funerary use where red ochre (and, sometimes, pure haematite) was sprinkled on and/or under the deceased. Clifford maintains that the ochre represented the life-giving energy of real blood and so facilitated rebirth in the after-life, a posited belief of early religion (but this is by no means the only interpretation advanced by archaeologists). Apparently, in some regions, the practice continues to the present.

A local example of the red ochre funerary traditions is at Lake Mungo in western NSW. Here the remains of a male who died ~40 000 years BP were found coated with red ochre applied at the time of burial.

In Australia red ochre was and is an important mineral for Aboriginal people. Paterson and Lampert (1985) note its wide use and provide details of a small mine still used by Warlpiri men. The mine is a hillside excavation in the Campbell Ranges, northwest of Alice Springs, NT. The Warlpiri gouge small parcels of the lumpy powdery ore, which is taken outside in buckets and then ground into a fine powder by hammering and abrasion. The seam of ochre contains a soft, mica-speckled haematite and lies at the base of a sequence of quartzite, haematitic sandstone, and pebbly conglomerate. Red ochre has dreaming stories associated with it (Finlay, 2004). Many stories involve the spilling of blood from the slaughter of an animal such an emu or a dog, or from a man. The ochre is the congealed blood.

Pictographs are a type of ancient rock art where pigments have been applied to stone surfaces (Voynick, 2017). Over millennia, different cultures in all the settled continents have left countless sites adorned with symbols and artwork of great interest to archaeologists. To make paint haematite ochre was dispersed as a slurry in a base of water, or suspended in animal fat, or liquid raw material such as seal oil, linseed oil, gum or egg. Variations in local recipes, ochres, and bases gave rise to a range of red colours that survive to this day. Figure 2 shows two haematite pictographs from the Northern Territory in Australia, and one from Spain.

Figure 2. *Pictographs: (a) painting of Dreamtime shapes in rock art at Nurlangie NT, red ochreous haematite pigment (source: Shutterstock.com), (b) red ochre fish. (source: https://commons.wikimedia.org/wiki/File:Red_ochre_fish_-_Google_Art_Project.jpg), (c) painting of a bison in haematite ~16 000 BC, cave of Altamira, Spain, red ochreous haematite pigment (source: https://en.wikipedia.org/wiki/File:Lascaux2.jpg).*

The ancient Mediterranean world

Haematite was a significant mineral in antiquity. Iron ores in ancient Europe seem to have been plentiful in the form of siderite ($FeCO_3$) and limonite/goethite ($FeO(OH)$). Rich deposits of haematite (including the specular variety), mined for centuries, occur on the Isle of Elba just off the west coast of Italy. Secondary haematite would also have been common in the form of cappings, crusts, pockets, and veins formed in the weathering and alteration of iron and other metallic ores (Bateman, 1959).

Celsus (fl AD14–37), in his encyclopaedic compilation on ancient medicine, notes haematite's use as an exedent (to eat away morbid flesh) and as purgative or cleansing agent (Spencer, 1938).

Pliny the Elder (AD23–79) describes haematite in several passages of Books 33, 36, 37 of his *Natural History*, an extensive compilation of facts and factoids (Rackham, l984; Eicholz, 1971). Pliny's commentary suggests that haematite would have been an ore of iron, and notes its use as a pigment, but it was its application in quite bizarre medications attracted the attention of literary types. Pliny mentions several claims as to haematite's efficacy in treating eye, bladder, blood, and liver problems, burns also; and its use as an ointment beneficial in battle.

The medieval world

The medieval world, like antiquity, was well aware of and interested in mineralogy and stones; much was written about them. Marbod (1035–1123), Bishop of Rennes in Brittany, in his famous book on 62 stones and gems, *Liber Lapidum,* devotes 20 lines of hexameter verse to haematite. Beckmann (1799) compiled and edited Marbod's mineral poems and supplied useful footnotes. The 32nd poem (lines 476–495) is *De haematite*:

Sumsit haematites graecum de sanguine nomen,
Naturae lapis humanae servire creatus,
Styptica cui virtus per multa probatur inesse;
Nam palpebrarum superillitus asperitatem,
Et visus hebetes, pulsa caligine, sanat,
Eius rasurae si glarea mixta sit ovi.
Succo dilutus, quem punica mala remittunt,
In medicinali valet ad collyria cote,
Vel resolutus aqua, iuvat hos, qui sanguinis ore
Spumas emittunt, et quae sunt ulcera curat.
Potatus stringit patitur quem femina fluxum,
Carnes crescentes in vulnere, pulveris huius
Vis premit, et ventrem retinet sine mora fluentem,
Vino dilutus veteri bibitusque frequenter.
Serpentis morsum, vel quod fit ab aspide vulnus,
Egregie curat, resolutus aquis et inunctus.
Mixtus melle potest oculos sanare dolentes.
Vesicae lapidem bibitus dissolvere fertur.
Hic ferrugineo rufove colore notatur.
Africa mittit eum, sed et Aethiopes, Arabesque.

Haematite derived its name from the Greek noun for blood;
a stone created to help humankind;
astringent power is much attested as residing within it,
for if abraded (haematite) is mixed with egg white,
and smeared on swollen eyelids, it heals them,
and dim vision too, by banishing the blurriness;
mixed with pomegranate juice,
it is very effective in ointment preparation on a medical stone,
or dissolved in water it helps those frothing blood in the mouth,
and it cures any ulcers that are there;
drunk by women it tempers excessive menstruation;
powdered, it can suppress swelling in a flesh wound,
and quickly curb diarrhoea,
by frequently drinking it, diluted in old wine;
dissolved in water, it is an outstanding treatment,
rubbed in, for adder and serpent bites;
mixed with honey it can heal sore eyes,
when drunk it is said to dissolve stones in the bladder;
this (stone) is distinguished by a red or rusty colour;
it is supplied from Africa, also from Ethiopia and Arabia

The first encyclopaedia of natural history, *Hortus Sanitatis*, The Garden of Health, of uncertain authorship, was published in the late 15th century and by popular acclaim became a standard reference of the time. Haematite is discussed in the volume devoted to rocks and minerals (Anon., 1491). Much of this is a repeat of Marbod, but, in addition, the compilation states that haematite: mixed with boiling water renders it tepid; scintillates in the sun (true, some haematite is iridescent); and keeps fruit safe from locusts and hailstones. A woodcut (Figure 3) shows haematite being applied to staunch a nosebleed.

A post-medieval compilation of ancient and medieval haematite writings can be found in the comprehensive work of Bauschio (1665) where haematite types, powers, preparations, and substitutes are listed in great detail, far too extensive to summarise here.

Haematite, except as a placebo, achieves none of the effects claimed by authors from antiquity and medieval times. But belief in the bloodstone was widespread. Experiments and observations that refuted the claims could/would have been carried out but, if so, the results were not accepted. The writer can find no direct evidence of such debunking investigations on haematite, but believes there must have been some cynicism. However, it is instructive to consider the published debates on another iron oxide assemblage, the lodestone (Emerson, 2014).

Figure 3. *Medieval medication – an apothecary applying haematite to stop a nose bleed, from Anon. (1491). Modified from University of Cambridge/CC-BY-NC 3.0/, http://cudl.lib.cam.ac.uk/view/PR-INC-00003-A-00001-00008-00037/764/.*

Garlic was believed to disempower the magnet/lodestone. The renowned antiquarian Sir Thomas Browne (Sayle, 1904), following some measurements, dismissed the garlic/magnet antipathy as false in 1646. But the old views persisted into the era of the great Sir Isaac Newton, as evidenced by Ross' (1652) reply to Browne, a model of expediency and casuistry:

> *yet I cannot believe that so many famous Writers who have affirmed this property of the garlick, could be deceived; therefore I think that they had some other kinde of Load-stone, then that which we have now. For Pliny and others make divers sorts of them, the best whereof is the Ethiopian. Though then in some Load-stones the attraction is not hindred by garlick, it follows not that it is hindred in none; and perhaps our garlick is not so vigorous, as that of the Ancients in hotter Countries.*

Wootton (2015) in an insightful and lucid discussion of the controversy comments: "Ross knew perfectly well that he would not be able to confirm the story by testing it, yet he continued to believe it nevertheless". For many centuries reason was no match for the authority of scripture, ancient Greek writings, folklore, traditions, rumour, and the pronouncements of various grandees.

The modern world

Haematite is popular with mineral collectors (Jones, 2015). It has a range of colours (grey, black, red), occasionally it can show iridescence, where surficial mini-platelets diffract incident light. It displays a wide variety of physical forms: crystals, plates, foliae, rosettes, fibres, spheroidal surfaces, columns, grains, oolites. Martite clusters, octahedral after magnetite, make attractive haematite specimens. Haematite is a hard durable mineral that can take a very high polish. The Maya used mosaics of specularite to fashion quite effective mirrors of great spiritual significance to their nation (Voynick, 2016).

Haematite has achieved importance in planetary exploration. It has been discovered in several locations on the red planet, Mars, not in its red form, rather as a grey specularite (Bandfield, 2002). Its occurrence is thought to indicate volcanic activity or the past presence of water as grey haematite is a common precipitate in standing bodies of waters and mineral hot springs.

Currently, haematite is of interest to workers in environmental science, where its mitigating effects on groundwater pollution have been recognised. The haematite mineral surface can act as a platform for contaminant sorption or contaminant transformation. In hydrogen fuel research haematite has been shown to function well as a semiconductor electrode material for solar water splitting. Sulphated haematite has applications in the chemical and petroleum industries where it is catalytically active in a range of organic chemistry reactions (Morel, 2013).

Haemotherapy continues to the present day. In the natural healing literature (leaflets, pamphlets, posts etc.) haematite is believed to assist in promoting blood circulation, energy, and vitality, among other claimed health benefits.

Haematite is also admired as an ornamental, low cost gem. Pretty pieces, polished fondling stones, and rings (Figure 4) are readily available for purchase, as are haematite beads for bangles and necklaces. Beyond adornment any therapeutic effects flowing to the wearer would, naturally, be a welcome bonus. Haematite can contribute to gemminess in other minerals. Sunstone is a reddish plagioclase feldspar displaying adventurescence, i.e. fiery colour flashes from the reflections of incident light by included disseminated haematite flakes.

Haematite in geoscience

Haematite is ubiquitous in the earth's crust. It occurs in: a wide variety of sediments, some igneous rocks, hydrothermal deposits, ore alteration zones, volcanic fumaroles, hot springs, and low, medium and high grade metamorphics (Clark, 1982). Vast amounts are dispersed in soils, red beds, and red earths – the highly leached, clayey, porous, weathered profiles of the humid tropics that are low in silica and high in sesquioxides (Blanchard, 1968; Clark, 1982; Deer et al., 1992; Peters, 1978). In ancient banded iron formations, where enrichment has occurred as a result of alteration and concentration, haematitic iron ores are extracted in huge mines in Australia, North America, and elsewhere (Bateman, 1959). Haematite is the dominant iron oxide in one very important IOCG (iron oxide copper-gold) style of deposit (another style has magnetite). Haematite is the relevant Fe oxide in the major Olympic Dam copper-uranium-gold-silver deposit (Belperio, 2004; Reeve et al., 1990).

Clearly, haematite is one of the very basic minerals in the geosciences, pure and applied. In geophysics, its ability to hold a remanent magnetisation, despite its low magnetic susceptibility, has established it as a key mineral in palaeomagnetic studies, and as a mineral whose effect may need to be considered when interpreting many magnetic anomalies (Clark, 1997). So, haematite, besides being dense, has well documented magnetic properties that are useful in applied geophysics. Multidomain haematite has an unusually high thermoremanent magnetisation because of its weak internal demagnetising field (Özdemir and Dunlop, 2005). This means that in some high metamorphic zones strong magnetic anomalies may arise from remagnetised haematite. Although beyond the scope of this article, haematite

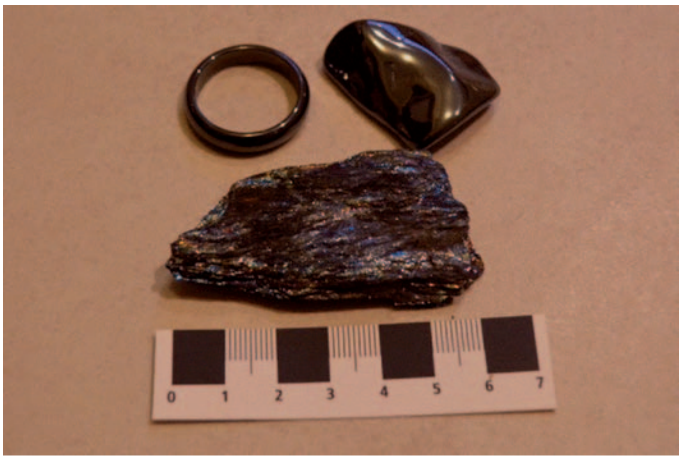

Figure 4. *Haematite in ornaments – a ring, a polished fondling stone, and an iridescent piece of haematite schist on which tiny scaly crystals of haematite have created a thin film causing colour flashes by reflection and diffraction of incident light. These three ornamental haematites are quite resistive; neither polish nor iridescence impart conductivity. The iridescent haematite comes from Nova Lima, Minas Gerais – southeast Brazil (cm/mm scale shown).*

also displays unusual anisotropy of magnetic susceptibility (Guerrero-Suarez and Martın-Hernandez, 2012).

However, the low frequency electrical properties of haematite are another matter. From the physics viewpoint haematite is a narrow band energy gap semiconductor of the *n* or *p* type according to impurity content and oxygen deficiency. Titanium is the most common impurity in natural haematite (Shuey, 1975). The writer first became interested in haematite years ago when frequently encountering puzzling low resistivity and moderate induced polarisation responses in samples from hard rock ore environments. Careful observation (aided by that red streak) and galvanic microprobing demonstrated that haematite was responsible. It is, of course, now well appreciated that haematite has electrical characteristics of interest, but although some information is available (Parasnis, 1956; Vella and Emerson, 2012) there is, in the writer's view, a need for more data especially as it seems that other minerals associated with the haematite may have contributed to, or been responsible for, some previously reported low resistivities, e.g. Zablocki's (1966) work on Lake Superior Fe oxides. Accordingly, out of interest, the writer carried out resistivity / conductivity measurements on some haematites.

Physical properties of some haematites

Twenty two samples of haematite were selected for measurement. The sample suite comprises Australian and overseas materials and includes four red ochres. Some of the samples are shown in Figures 5–8. The writer's main interest lies in the low frequency resistivity / conductivity of the actual haematite material, so in considering, say, a porous haematite, the focus is on the resistivity of the solid matrix and not of the water saturated rock (which, knowing the porosity, can be estimated by the Archie equation or its modifications, e.g. see Parkhomenko, 1967). Accordingly, samples were oven dried to 105°C for two days and 1 kHz galvanic resistivities were measured after cooling to room temperature (20°C) in a desiccator. Four electrode DC resistivities were measured for the more conductive samples ($\sigma > 0.5$ S/m). Densities, porosities, and magnetic susceptibilities were also measured. The data are presented in Table 2 as seven categories of haematite (see the table for details). Pursuant to the leaching mechanisms involved in BIF haematite enrichment (Bateman, 1959), considerable void space is evident in some samples e.g. the top grade iron ore #3H with 19% porosity resulting in a moderate dry bulk density (4.13 g/cc) although the grain density (5.10 g/cc) approaches that of pure haematite (5.26 g/cc). Some of the magnetic susceptibilities are high for haematitics, they could be due to the presence of minor amounts of magnetite and/or maghaemite and/or titanohaematite, but these were not observed under binocular inspection. Anyway, if present, it is considered that they would not contribute significantly to the haematite matrix conductivities especially if disseminated (Emerson and Yang, 1994). All the solid samples manifested a Moh's hardness ~6, and the characteristic red haematite streak. Titanohaematite is the most common impurity in natural haematites (Shuey, 1975), but if considerable titanium had been present in any samples the streaks would have been black, they were not.

The resistivity data in Table 2 are best viewed in the seven group perspective of the density crossplot in Figure 9. The red haematites have the highest resistivities (100 000s ohm m); the black haematite resitivities are lower (1000s ohm m). The red haematites are turning into dielectrics at 1 kHz, i.e. the phase lags, of voltage behind current, are of the order of tens of degrees and displacement currents dominate the ohmic component. The specular haematite in groups 7 and 8 have moderate resistivities (few ohm m) at lower densities (i.e. lower concentrations) and moderate conductivities at higher densities, up to 333 S/m (res 0.003 ohm m) for the coarsely crystalline, grey-black, very lustrous Brazilian sample #16. Specularite occurring as a poorly networked subordinate phase in the group 4 black haematites lowers resistivities somewhat (~1000 ohm m). Networked copper sulphides in the group 6 black haematites lower resistivity significantly (0.1–19 ohm m) and mimic the trend of the group 7 specularites. The sole member of group 5; a coarse grained polycrystalline, metallic lustre haematite, has a resistivity (8 ohm m) intermediate between the duller black haematites and the lustrous specularites. This is thought to reflect its crystallinity and multiple grain boundaries.

These data, though limited, are considered to provide some insight into the lower frequency electrical character of solid haematite minerals. Red haematites are very highly resistive and indeed are virtual dielectrics. Black haematites are quite, but not very, resistive even if they have (sub) metallic lustre; and this type of haematite does manifest minor ohmic conduction. Grey-black, well crystallised, lustrous specular haematites can be moderately conductive. Conductive distributions of specularite will diminish, somewhat, the composite resistivity of black haematite, and in the case of included disseminated/veinlet copper sulphides (cpy, bn, cc) that are networked, the composite resistivity of the black haematite will be similar to some specularites.

Resistivity is plotted against magnetic susceptibility in Figure 10. The sulphidic haematites (# 9, 10, 11) contain relict magnetite. The resistivities of the less resistive coarsely crystalline specularites (#12, 13, 15, 16) are seen to decrease as

Figure 5. *A banded iron formation, or jaspilite, developed from an altered schist in the Krivoy Rog, Donetz Basin, Ukraine. The long dimension is 75 mm. The dark bands are martitic haematite (octahedral after magnetite) and the red bands are jasper (a highly haematitic microcrystalline quartz). There is also vertical texture in the form of micro-fractures and anastomosing veinlets. This sample (3K in Table 2) has a 1 kHz dry state resistivity of 10 800 ohm m along the banding and 14 275 ohm m normal to the banding. The dark haematite virtually carries all the current; the red bands are extremely resistive. The sample represents sub-economic ore.*

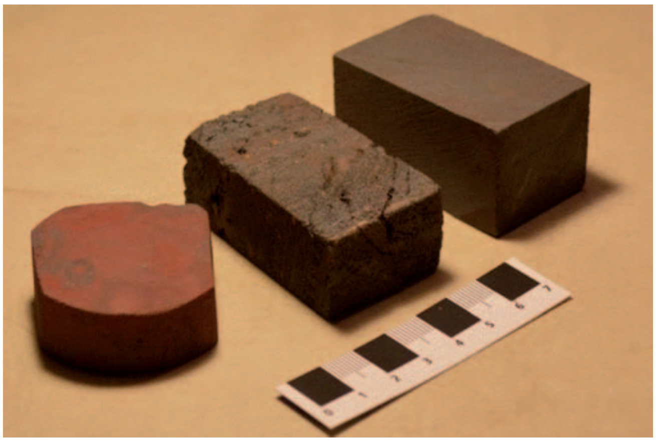

Figure 6. *Finely crystalline Precambrian hard-rock haematites, offcuts from tested samples; left: red and black mixed haematite from Stuart Shelf, South Australia (#1, Table 2); middle: porous martite-microplaty high grade iron from the Hamersley Province, Western Australia (# 3H, Table 2); left: tight, dense martite-microplaty high grade Hamersley iron ore, with reddish undertone. (#2, Table 2) The Hamersley haematites' grain shapes are anhedral to subhedral (cm/mm scale shown).*

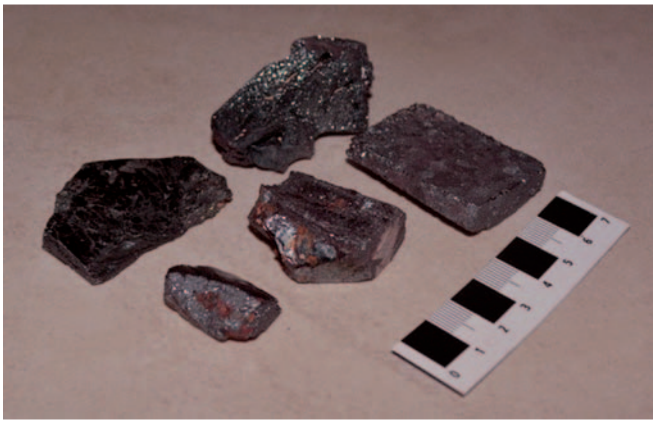

Figure 7. *Relatively conductive specular haematites, tending to euhedral grain shapes, that are offcuts from tested samples: far-left – very coarse grained, very lustrous, platy, crystalline, from Ouro Preto, Minas Garais, Brazil (#16, Table 2); top – coarse grained, martitic (after magnetite), from Payun Volcano, Altiplano de Payun, Mendoza, Argentina (#13); bottom-left coarse grained, platy, from Isle of Elba, Livorno Province, Italy (#15); bottom middle – coarse grained, platy, some felsic material, from Port Sorrell, Tasmania (#12); right – granular, medium grained, from Middlebrack Ranges, South Australia (#8).*

Figure 8. *Ochreous haematites, right – pure haematite powder from commercial source (#5, Table 2); left – South Australian very friable, clayey, ochre from private collection (#E3, Table 2); both samples have extremely fine particle sizes, they are amorphous and non-crystalline. These materials are extremely resistive in the dry state, however, when wet, being very porous, resistivities drop by orders of magnitude (cm/mm scale shown).*

Table 2. Dry state resistivities

Dry state resistivities: haematite (105°C dried – bone dry)	Group	Code	DBD g/cc	P_A %	GDA g/cc	Bulk mag k $SIx10^{-5}$	Resistivity ρ_t (ohm m) [oven dried]
Earthy, red haematite (dull, no lustre)	1						
E1			4.54	0.5	4.56	140	72 000
E2			1.74	36.1	2.72	7	341 538
E3		●	1.71	38.4	2.77	17	440 000
E4			1.93	63.4	5.20	42	1 506 818
E5			1.86	65.0	5.26	548	3 530 800
Red and black haematite mix (dull lustre)	2						
1			4.19	3.0	4.32	115	10 309
2		◆	4.92	1.9	5.02	390	5990
3K			3.37	6.2	3.59	168	10 700
Black haematite iron ore (martite/microplaty, dull to submetallic lustre)	3						
3H		◆	4.13	19.0	5.10	444	5736
Black and red haematite + some networked specularite	4						
4			4.12	12.9	4.73	204	1959
5		×	4.21	15.6	4.98	146	1131
6			4.51	12.0	5.12	142	938
7			4.92	5.8	5.22	1192	297
Intermediate haematite (polycrystalline, metallic lustre)	5						
8		■	5.21	0.2	5.22	1517	8
Black and red haematite + networked dissem./veinlet sulphides: cpy, bn, cc	6						
9			4.54	6.9	4.88	1326	19
10		●	4.98	0.6	5.01	8531	0.4
11			5.35	4.0	5.57	266	0.1
Specular haematite (metallic lustre, platy, grey-black, crystalline)	7						
12			4.62	2.0	4.72	998	7
13			4.32	15.7	5.13	2521	0.9
14		◇	4.72	6.2	5.03	639	1.3
15			5.20	1.3	5.27	3938	0.08
16			5.18	1.6	5.24	9339	0.003

Notes:
- DBD – dry bulk density, 105°C dried; P_A – apparent (water accessible) porosity; GDA – inferred grain density.
- Magnetic susceptibility, mag k, induction coil 460 Hz.
- Galvanic resistivity (ρ_t) measured after oven drying 105°C and cooling to room temperature (20°C) in desiccator $\rightarrow \rho_t$.
- ρ_t impedance bridge measurement frequency 1kHz, except DC four electrode, used for #10, 11, 13–16; min res. cited generally (sub)parallel to any foliation (some samples anisotropic).
- Australian samples from Precambrian locations: #1, 4, 5, 6, 9, 11, 14 Stuart Shelf SA; #2, 3H, 7 Hamersley Basin WA; #8 Flinders Range SA; #12 Port Sorrell Tasmania (has felsic inclusions).
- Overseas samples: earthy #E1 Taouz Morocco, #3K Krivoy Rog Ukraine; #13 Payun Volcano Argentina, #15 Isle of Elba, Italy, #16 Minas Gerais Brazil.
- Ochres: saprolitic #E2 WA, saprolitic #E3 SA, powder #E4 SA, refined haematite powder #E5 from commercial supplier.
- Grain sizes range from coarse (2 mm+) through fine (0.25–0.125 mm) to cryptocrystalline (<0.004 mm). Platy forms quite common with plate thickness 10s to 100s μ. Grain-shapes generally anhedral to subhedral excepting to specular haematites euhedral i.e. well crystallised. The red and the ochreous haematites comprise myriad randomly sub-microscopic forms that are optically rough and so have an earthy dull appearance i.e. no lustre. The red parts of #1, 2, 4, 6, 11 are cryptocrystalline; #1, 3K, 4, 5, 10 are microcrystalline (0.63–0.004 mm); #9, 14 are very finely crystalline (0.125–0.063 mm); #2, 3H, 7 are finely crystalline; platy specular haematites #12, 13, 15, 16 are coarsely crystalline; #8 is a coarse polycrystalline aggregate.

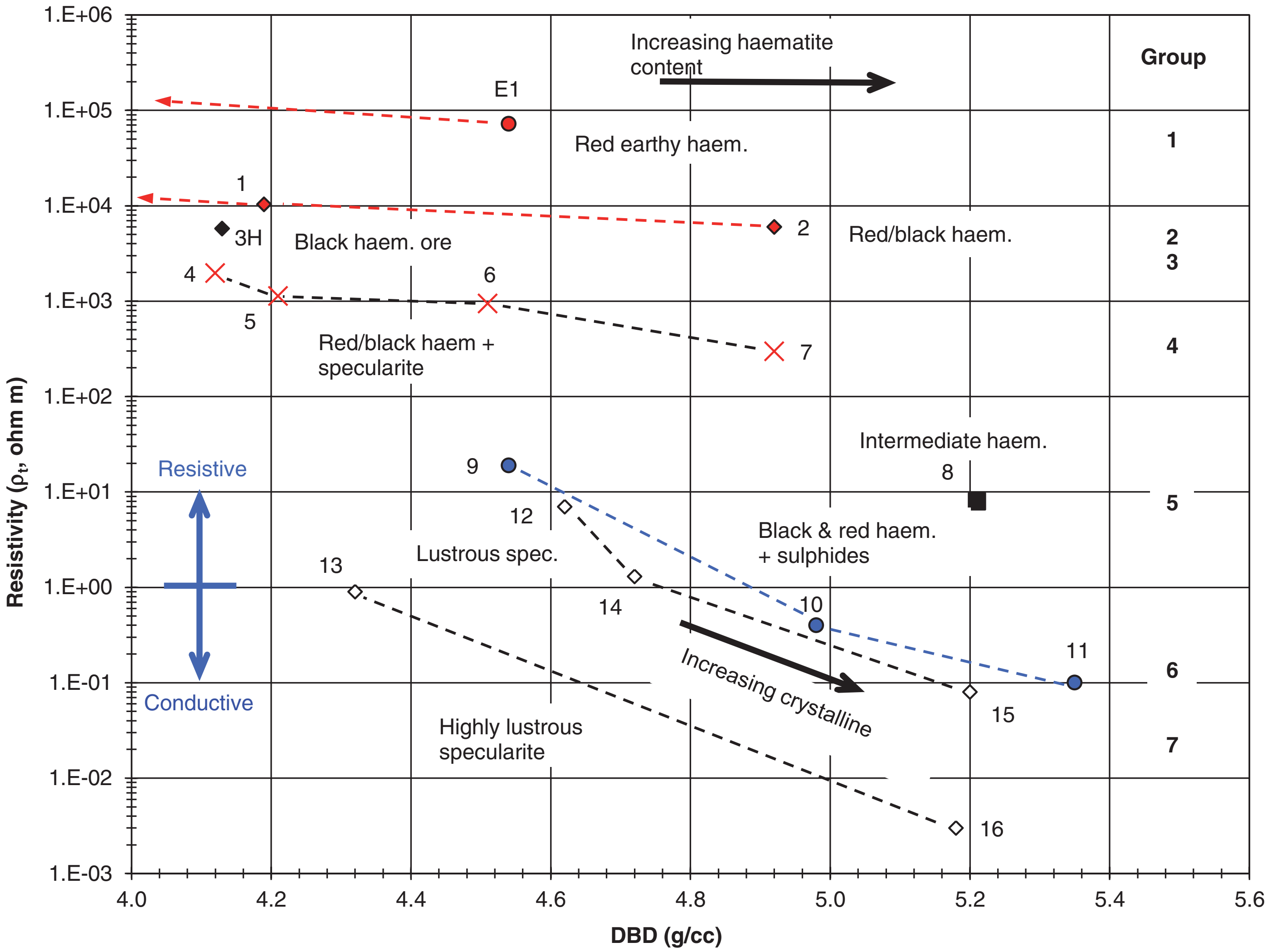

Figure 9. *Crossplot of resistivities 105°C dry against density for haematite samples in Table 2. The "bone dry" resistivities of 17 haematite samples from Table 2 are plotted against dry bulk density (105°C). The very high resistivity, very porous earthy samples E2 to E5 plot a long way off to the upper left and are not represented here, nor is the low density haematitic BIF #3K. Dry resistivities have been used in preference to field or water saturated resistivities as the focus is on the electrical characteristics of the solid haematite rock framework (for samples #1–8, 12–16; E1–E5). Clearly the sulphide-free haematite resistivity depends not only on haematite content (reduced by void space and minor foreign material in many samples) but also on the proportions of highly resistive red earthy haematite, black micromosaic (sub)metallic lustre haematite, and grey-black highly lustrous (even splendent) specular haematite, which is a conductivity booster. It can be seen that minor amounts of networked copper sulphides, in #9–11, substantially lower the resistivity of a black haematite host to give values similar to those of specularite. The specular haematite resistivity seems to diminish most when crystallinity is highest as in # 13, 16. Note that the sample data set is limited, min. res. has been plotted (some samples are anisotropic), and that the trends shown here are speculative.*

magnetic susceptibility increases up to 10 000 × 10^{-5} SI, quite a high value for haematite.

Discussion

In the literature there does not appear to be much information on haematite's resistivity, nor reported detail on the mineralogy/lithology of materials that have been measured. Parkhomenko (1967) cited a value of 2500 ohm m for fine grained haematite from Georgia. In a microelectrode study of Harvard University's collection of mineragraphic polished blocks, Harvey (1928) found only very resistive haematites. Morin (1951) estimated that 1.0 atomic percent Ti, an *n* type impurity, in pure α Fe_2O_3, improved its conductivity by many orders of magnitude (to 20 S/m). Shuey (1975) reported resistivities ~0.5 ohm m, in the basal plane perpendicular to the trigonal axis, for *n* type haematite crystals and resistivities ~0.15 ohm m along the trigonal axis, denoting significant anisotropy. Olhoeft (1981) cited a DC conductivity of 0.01 S/m for haematite. Parasnis (1956) documented a range of haematite resistivities from less than 1 ohm m to over 1000 ohm m; red haematite was very resistive while the black metallic-looking variety was conductive. Fraser et al. (1964) in electrical measurements (0.1–1000 Hz) on samples from the copper-iron mineralisation at Craigmont, British Columbia, found that predominantly specular haematite cores had resistivities of the order of 10 to 100 ohm m, and declared specularite to be a relatively poor conductor, inferring the presence of up to seven percent magnetite in the materials tested. In laboratory measurements, including micro-probing, on banded Ironwood Formation samples from the Gogebric iron range, Wisconsin, Zablocki (1966) noted low resistivities (to <0.1 ohm m) along bands containing networked magnetite and specular haematite, but the conductivity concentration of each was not resolved. All this is useful

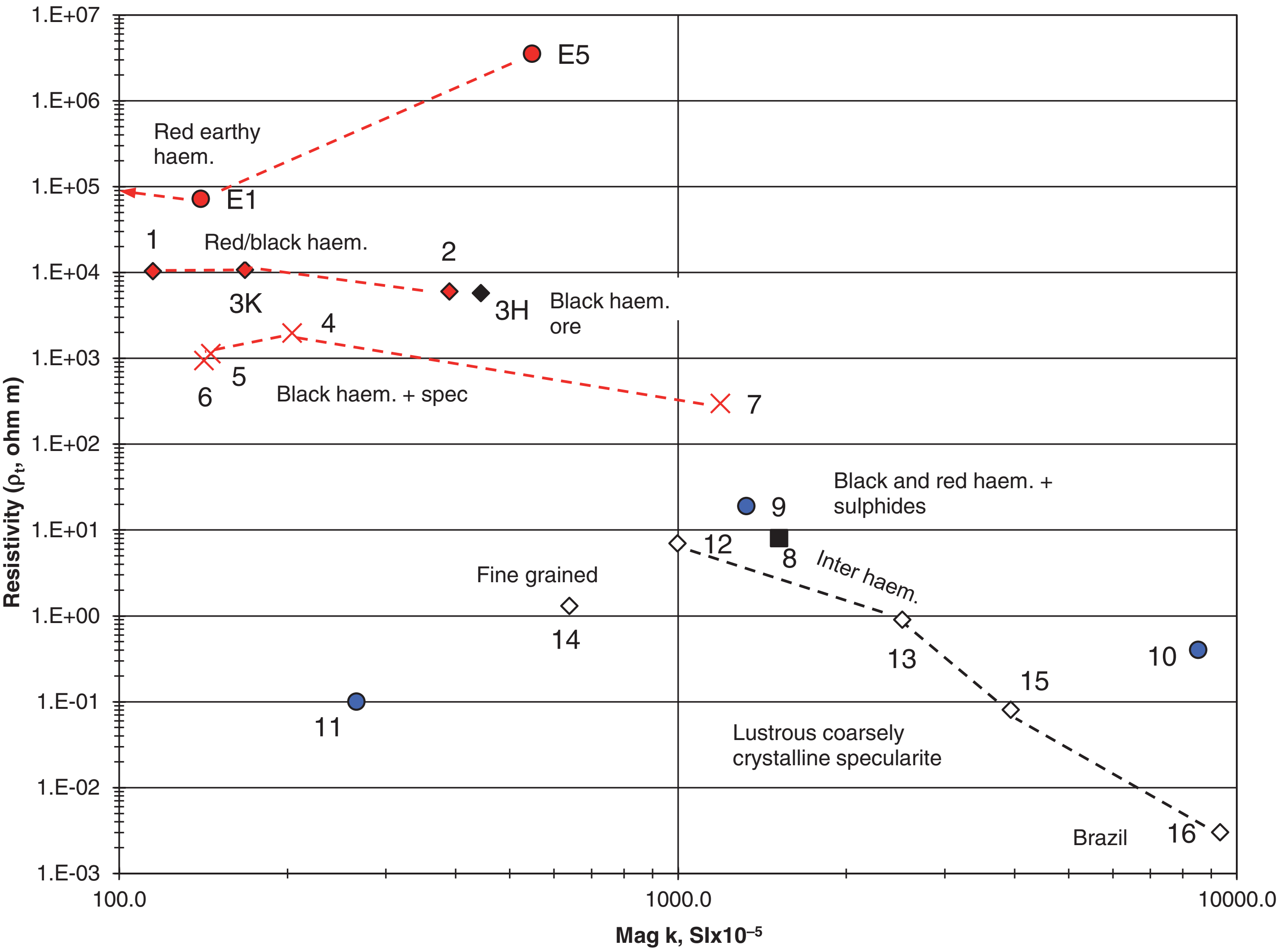

Figure 10. *Crossplot of resistivities 105°C dry against mag k for haematite samples in Table 2. The "bone dry" resistivities of 17 haematite samples from Table 2 are plotted against magnetic susceptibility. Note that specular haematite #14 has a fine grain size and that #8 is polycrystalline; #9, 10, 11 are sulphidic haematites with relict magnetite. There is a considerable spread of magnetic susceptibilities extending from the commonly accepted 100 to 1000 × 10^{-5} SI range up to nearly 10 000 × 10^{-5} SI. There seems to be an inverse relationship between resistivity and mag k for the coarsely crystalline platy lustrous specularites: #12 (with felsic inclusions) Port Sorrell Tasmania, #13 (porous) Payun Volcano Argentina, #15 Isle of Elba Italy, and #16 Minas Gerais Brazil. This correlation may be due to crystallinity. Further study is required.*

information, but it is not possible to link it to definite textural and mineralogical detail.

Apparently the situation is, to some degree, indefinite as regards confidence in predicting reasonable ranges of particular categories of haematite in the absence of actual measurements. Clearly, from Table 2 and the crossplots, haematite does have galvanic electrical character. As a working hypothesis, for the writer's results, three categories are shown in Table 1: red, dull; black, (sub) metallic; grey-black, lustrous. These categories manifest very high, high, and moderate to low resistivities, respectively. A magnetic iron oxide sample that is devoid of silica, silicates, and carbonates, with a colour tending to grey, a very high (almost splendent) lustre, and well-formed platy crystals (the coarser, the better), coupled with a fairly high Moh's hardness (≤6½), and a red streak, is likely to be a moderately conductive specularite, and this is readily checked with an ohmmeter.

It is interesting to compare the resistivities of the two iron oxides most relevant to geophysics. In Table 2 a resistivity of 0.003 ohm m was recorded for the Brazilian specular haematite; #16. In AMIRA Project P416, on magnetite's electrical properties (Emerson and Yang, 1994), the lowest resistivity, 0.002 ohm m, was measured in a coarse grained, well networked, recrystallised magnetite sample from the NW Qld Proterozoic. So, it could be expected that electrical responses in the field would be similar for networked masses of the two iron oxides, and, as these oxides are equally dense, the salient feature presumably would be the magnetisation of the magnetite.

The magnetic volume susceptibility of haematite is a moot point. Generally it is documented as occupying a low range of susceptibility, ~100 to 1000 × 10^{-5} SI, and this seems to cover many haematites. However, Hrouda (2002) measured bulk mag k values of 0.17, 0.29, 0.16 SI for three crystalline haematites from Minas Gerais Brazil, and noted a strong variation of directional k in the basal plane with minimum k parallel to the c axis. These are considerable susceptibilities comparable to those of monoclinic pyrrhotite. Guerrero-Suarez & Martín-Hernández (2012) in investigating fourteen Minas Gerais crystalline haematites for susceptibility anisotropy, measured bulk mean susceptibilities ranging from 0.01 to 1.8 SI, with an average ~ 0.5 SI. A bulk mag k of 0.02 SI (2000×10^{-5} SI) was measured on a single sample from the Isle of Elba. Accordingly some confidence may be placed in the mag k values, exceeding 1000×10^{-5} SI, for the coarsely crystalline specularites (#12, 13, 15, 16) cited in Table 2 and plotted in Figure 2 herein[1].

In contrast to the extensive and rigorous scientific investigations of the magnetic properties of α Fe_2O_3 haematite, there has been comparatively little work done of the electrical properties, at least in the geosciences. It will require a lot more than the limited preliminary results presented here for the electrical properties to be properly documented and understood. Important factors include the chemistry, for the conductivity of semiconductors is sensitive to even minor content of impurities which serve to act as charge carrier sources, e.g. Ti (Morin, 1951); the crystallinity, for this seems relevant to resistivity and magnetic susceptibility; the fabric, for the juxtaposition of grains controls anisotropy, and the development of high resistivity films between grains is known to be important in synthetic sintered haematites (Shuey, 1975); and, of course, mineragraphy and petrology are essential to the measured data in the real world of field geology and geophysical exploration. High frequency (≥1 MHz) dielectric responses of dry haematites, saturated state resistivities, and induced polarisation effects, are also interesting and fruitful fields of study, but well beyond the scope and intent of this article.

Concluding remarks

For centuries haematite has contributed to human culture and, as an iron ore, to human industry. It is an important economic resource, and also a significant mineral in various geological environments. Its low frequency galvanic electrical properties merit further study to further develop or refine the indications presented in this article: there seem to be three physical phases, i.e. red and amporphous, dark black and (sub)metallic, and grey-black and highly lustrous, having very high, high, and moderate to low resistivities, respectively. Crystallinity (or the lack of it), and, probably, impurity chemistry are likely to be important variables.

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The writer thanks Susan Franks for compiling the manuscript, Emilija Kalnins for photography, David Kalnins for providing considerable assistance with the manuscript and designing the figures and also suggesting pertinent references in the literature, and Paul Munro for advice on red ochre literature and history. Lisa Worrall and Bob Musgrave provided encouragement for this work. The writer is grateful to Phil Schmidt for advice on the magnetic characteristics of haematite. Tested materials were in the writer's collection or obtained from dealers. References to the measurement techniques applied here to haematite may be found in the *Preview* article on lapis lazuli: *Preview* **179**, December 2015, p. 73. The source of the BIF outcrop image to the left of the title is Alexandr Makarov/Shutterstock.com.

Latin

The writer translated the Latin passages herein; the Latin, of course, being an optional extra. In the sixth line of Marbod's poem note that *glarea* (gravel) has been deemed to be equivalent to the French *glaire* (eggwhite) as this is how it appears in a medieval French version of the poem, otherwise a mix of shell grit (*glarea ovi*) and fragmented haematite would have been applied to the eyes – which is highly unlikely. Bauschio (1665) mentions eggwhite being used in this context.

Addendum

An informative outline of colour in haematite was received too late to be considered in this article, see Voynick, S., 2017, *Rock & Gem*, **47**, 11, 34.

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[1]The author is indebted to Phil Schmidt and Dave Clark for pointing out that large crystals of haematite have low coercivities with many mobile domain walls, and these are quite different to single domain haematites, which are very hard magnetically and have much lower susceptibilities. Grainsize, crystallinity, purity, and defects all greatly affect the susceptibility of haematite which mostly – as commonly encountered by geophysicists – is impure and defective, thus wall movements are blocked, coercivity increases, and susceptibility decreases.

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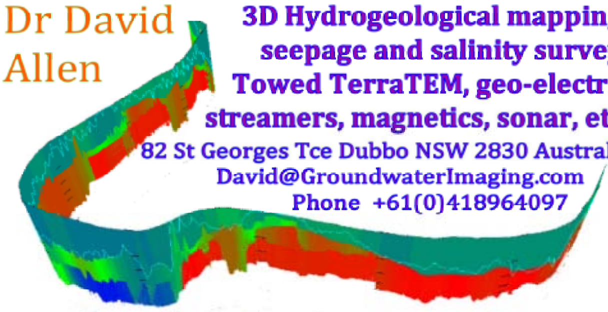

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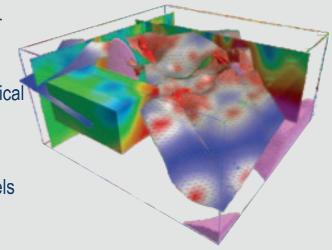

December	2017		
4–6	Full Waveform Inversion: What are we getting? http://seg.org/Events/FWI2017	Manama	Bahrain
11–15	2017 AGU Fall Meeting https://fallmeeting.agu.org/2017/	New Orleans	USA
February	**2018**		
18–21	Australasian Exploration Geoscience Conference http://www.aegc2018.com.au/	Sydney	Australia
26–28	AAPG/SEG/SPE: Professional Development Symposium	Dubai	UAE
TBA	Third EAGE Workshop on Naturally Fractured Reservoirs Calibration Challenges	Dubai	UAE
March	**2018**		
1–2	GeoTHERM – expo and congress 2018 http://www.geotherm-germany.com/	Offenburg	Germany
20–23	OTC Asia http://2018.otcasia.org/	Kuala Lumpur	Malaysia
April	**2018**		
8–11	Fifth Australian Regolith Geoscientists Association Conference http://www.regolith.org.au/conference2018.html	Wallaroo	Australia
8–13	EGU https://www.egu2018.eu/	Vienna	Austria
11–12	EAGE-HAGI 1st Asia Pacific Meeting on Near Surface Geoscience and Engineering http://events.eage.org/en/2018/EAGE%20HAGI%20Near%20Surface%20Geoscience%20and%20Engineering%202018	Yogyakarta	Indonesia
24–27	CPS/SEG Beijing 2018 International Geophysical Conference and Exposition http://seg.org/events/IGC18	Beijing	China
May	**2018**		
20–23	AAPG 2018 Annual Convention and Exhibition http://www.aapg.org/events/conferences/ace	Salt Lake City	USA
June	**2018**		
10–13	The 8th International Conference on Environmental and Engineering Geophysics (ICEEG)	Hangzhou	China
10–16	16th Castle Meeting - New Trends on Paleo, Rock and Environmental Magnetism http://castle2018.igf.edu.pl	Chęciny	Poland
11–14	80th EAGE Conference & Exhibition 2018 http://www.eage.org/	Copenhagen	Denmark
18–21	GPR 2018 https://www.gpr2018.hsr.ch/	Rapperswil	Switzerland
22–24	Global Symposium on Millimeter Waves (GSMM) 2018 http://www.gsmm2018.org	Boulder	USA
August	**2018**		
27–29	EAGE/SEG Workshop on Marine Multi-Component Seismic https://events.eage.org/	Kuala Lumpur	Malaysia
September	**2018**		
2–7	36th General Assembly of the European Seismological Commission http://www.escmalta2018.eu	Valletta	Malta
10–12	Near Surface Geoscience 2018 https://events.eage.org/	Porto	Portugal
23–25	SPE Annual Meeting	Dallas	USA
October	**2018**		
14–18	AGC Convention http://www.agc.org.au	Adelaide	Australia
14–19	SEG Annual Meeting	Anaheim	USA

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