NEWS AND COMMENTARY
Vale Marion Rose
Decline in Australian research investment
LIN approximation
Too good to be true
Spectral decomposition

FEATURES
2017 student theses
Haematite: the bloodstone

ASEG CORPORATE PLUS MEMBER

PREVIEW
**MS2/MS3** Magnetic Susceptibility System for laboratory, field and borehole applications. Resolution down to 2x10^-4 SI. Used in environmental magnetics and oil & gas exploration. Deep borehole tool, with operation to 6000m, for use in mineral exploration.

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**Helmholtz Coils** Diameters from 350mm to 2m. Used with power amplifier and control unit for the generation of precise magnetic fields. For calibration of magnetic field sensors including directional drilling tools.
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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.
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 become 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).

<table>
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<tr>
<th>First name</th>
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Thank you to our past, present and future clients

We wish you all a safe and prosperous 2018
ASEG Federal Executive 2017–18

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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 $112,519

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.

NSW Geoscience Data Workshop

Organised by the Geological Survey of NSW (Department of Planning and Environment)

22 Feb 2018
(following AEGC)
Sydney

Visit goo.gl/toCpjy to view the program and register

For information on future workshops contact geosurvey.events@industry.nsw.gov.au
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 classsy 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.

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
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 Morión-Polanco (Melbourne University) ypadmin@aseg.org
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

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 learnt 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’.

The student presentation night in Western Australia.
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
qldpresident@aseg.org.au

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, Lecton 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
sa-ntpresident@aseg.org.au

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 Østersen will present aspects of
ASEG national calendar

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.

Mark Duffett
taspresident@aseg.org.au

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!

Seda Rouxel
vicpresident@aseg.org.au

ASEG national calendar: technical meetings, courses and events

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

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

Mark Lackie
Co-Chair Minerals
mark.lackie@mq.edu.au

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**

**Morning tea**

<table>
<thead>
<tr>
<th>1000-1045</th>
<th>CONCURRENT SESSIONS</th>
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<tbody>
<tr>
<td><strong>Keynote Presentation</strong></td>
<td>Coal in NSW Kevin Rumming</td>
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<tr>
<td><strong>Keynote Presentation</strong></td>
<td>Coal West Australian Basin: Implications for petroleum systems Nodge Rollett</td>
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<tr>
<td><strong>Symposium</strong></td>
<td>Regional geology and stratigraphy of the eastern, central and southern Gondwana since the Jurassic - Simon George</td>
</tr>
<tr>
<td><strong>Keynote Presentation</strong></td>
<td>Keynote Presentation: The use of FWI in coal exploration Mehdi Angharzadeh</td>
</tr>
</tbody>
</table>

| 1040-1120 | **Symposium** Airborne Gravity, Electrical Methods Regional Mapping Methods Groundwater Tracking the Diprotodon - Palaeomagnetic test of oroclinal rotation in the Dundas Trough, Tasmania Karol Czamota |
| 1040-1220 | **Symposium** East Australian Basins, Coal West Australian Basins Environmental Tracking the Diprotodon - Palaeomagnetic test of oroclinal rotation in the Dundas Trough, Tasmania Karol Czamota |
| **Symposium** | Geochemical Case History Airborne Gravity, Electrical Methods Regional Mapping Methods Groundwater Tracking the Diprotodon - Palaeomagnetic test of oroclinal rotation in the Dundas Trough, Tasmania Karol Czamota |

**Lunch**

| 1200-1330 | **Poster Sessions** Seismic data capture and processing for improved coal structure detection in complex geological environments Bo-Hsin Zhou |
| 1200-1330 | **Poster Session** Evolution of the Triassic: a large mid-ocean ridge collisional zone in the southern part of the Gondwana mosaic Richard Hillis |
| 1200-1330 | **Poster Session** Controls on Mesozoic rift-related sedimentation in the Springbok Sandstone, Northern Cape, South Africa Natalie Debenham |

**Afternoon tea**

| 1330-1410 | **Poster Sessions** Seismic data capture and processing for improved coal structure detection in complex geological environments Bo-Hsin Zhou |
| 1330-1410 | **Poster Session** Controls on Mesozoic rift-related sedimentation in the Springbok Sandstone, Northern Cape, South Africa Natalie Debenham |
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**1410-1500**

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**1500-1530**

| **Afternoon tea** | **Poster Session** Controls on Mesozoic rift-related sedimentation in the Springbok Sandstone, Northern Cape, South Africa Natalie Debenham |
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**Tuesday**

<table>
<thead>
<tr>
<th>Time</th>
<th>Concurrent Sessions</th>
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</thead>
<tbody>
<tr>
<td>08:30-08:55</td>
<td>Keynote Presentation&lt;br&gt;Onshore inventory - targeting new basins (Offshore, Perth, Canning Basin)</td>
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<tr>
<td>08:55-09:00</td>
<td>Indoor view - using new basin software to target new basins (Offshore, Perth, Canning Basin)</td>
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<tr>
<td>09:00-09:30</td>
<td>Linear trends of paleo-pockmarks and fluid flow pipes in the Jurassic and Triassic sediments of offshore northwest Australia&lt;br&gt;Tayallen Velyvasham</td>
</tr>
<tr>
<td>09:30-09:55</td>
<td>Using multiazimuth seismic data for anisotropy estimation in an unconventional reservoir&lt;br&gt;Surabhi Mishra</td>
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<tr>
<td>09:55-10:10</td>
<td>Keynote Presentation&lt;br&gt;Characterizing the Spiritwood Valley&lt;br&gt;Aquifer, North Dakota, using helicopter time-domain EM&lt;br&gt;field data, 2005-2008&lt;br&gt;Lidena Carr&lt;br&gt;Shastri Nimmagadda&lt;br&gt;Roger Decker&lt;br&gt;James Hansen</td>
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<tr>
<td>10:10-10:40</td>
<td>Keynote Presentation&lt;br&gt;Rare earth element deposits - aspects of their evaluation, diversity, geochemistry and genesis</td>
</tr>
<tr>
<td>10:40-11:05</td>
<td>Keynote Presentation&lt;br&gt;What we know, what we don’t know, and things we do not know about hydraulic fracturing in high stress environments&lt;br&gt;Raymond Johnson</td>
</tr>
<tr>
<td>11:05-11:30</td>
<td>Keynote Presentation&lt;br&gt;Creating a new frontier in exploration through cover&lt;br&gt;Los Crisoles&lt;br&gt;Depositional and stratigraphic controls on porosity development in the Ungani Field, Canning Basin&lt;br&gt;Jordan Joiner</td>
</tr>
<tr>
<td>11:30-11:55</td>
<td>Keynote Presentation&lt;br&gt;Estimating cover thickness in the southern Thomson Orogen – a comparison of applied geophysics estimates with borehole results&lt;br&gt;Compressional evolution of the Pilgangoora Lithium-Belt&lt;br&gt;Depositional, diagenetic, and stratigraphic controls on porosity development in the Ungani Field, Canning Basin&lt;br&gt;June Then</td>
</tr>
<tr>
<td>11:55-12:20</td>
<td>Keynote Presentation&lt;br&gt;A multi-disciplinary study of groundwater conditions in sedimentary strata at The Miners Lakes&lt;br&gt;iFault®&lt;br&gt;Depositional and stratigraphic controls on porosity development in the Ungani Field, Canning Basin&lt;br&gt;June Then</td>
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<tr>
<td>12:20-12:45</td>
<td>Lunch</td>
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<td>Time</td>
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<td>13:20-13:45</td>
<td><strong>PNG and NZ</strong></td>
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<td>13:20-13:45</td>
<td><strong>International</strong></td>
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<td>13:20-13:45</td>
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<td>13:20-13:45</td>
<td><strong>Geochemistry</strong></td>
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<td>13:20-13:45</td>
<td><strong>Brine Deposits</strong></td>
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<td>13:20-13:45</td>
<td><strong>EM Inversion Modelling</strong></td>
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<td>13:20-13:45</td>
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<td>13:20-13:45</td>
<td><strong>Innovation</strong></td>
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<td><strong>14:10-14:35</strong></td>
<td><strong>Concurrent Sessions</strong></td>
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<tr>
<td>14:10-14:35</td>
<td>A method for assessing earth model uncertainty in the Taranaki Basin, New Zealand Edward Lewis</td>
</tr>
<tr>
<td><strong>14:35-15:00</strong></td>
<td><strong>Modelling and visualising distributed lithofacies deformation of Australia and Zealandia using GIaRє2.0 Dietmar Muller</strong></td>
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<tr>
<td><strong>15:00-15:30</strong></td>
<td><strong>Afternoon tea</strong></td>
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<tr>
<td><strong>15:30-15:55</strong></td>
<td><strong>PNG and NZ</strong></td>
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<td><strong>Geochemistry</strong></td>
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<td>15:30-15:55</td>
<td><strong>Industrial and Borehole</strong></td>
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<td>15:30-15:55</td>
<td><strong>New Airborne EM Techniques</strong></td>
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<td>15:30-15:55</td>
<td><strong>Regional Gawler Isa Halls Creek</strong></td>
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<td>15:30-15:55</td>
<td><strong>Innovation</strong></td>
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<tr>
<td><strong>15:55-16:30</strong></td>
<td><strong>Concurrent Sessions</strong></td>
</tr>
<tr>
<td>15:55-16:30</td>
<td><strong>Investigation of possible shallow gas accumulations associated with pockmarks on the Otogo slope southeast of New Zealand Jasper Hoffmann</strong></td>
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<tr>
<td><strong>16:20-16:45</strong></td>
<td><strong>Concurrent Sessions</strong></td>
</tr>
<tr>
<td>16:20-16:45</td>
<td><strong>Characterisation of focused gas hydrate accumulations from the Pegasus Basin, New Zealand, using high resolution and conventional seismic data Andrew Goman</strong></td>
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<tr>
<td><strong>16:50-17:10</strong></td>
<td><strong>Concurrent Sessions</strong></td>
</tr>
<tr>
<td>16:50-17:10</td>
<td><strong>Comparing shale gas ratio and juxtaposition analysis using stochastic trap analysis: Examples from Gippsland, Taranaki, Otway and Southern North Sea Basins Titus Murray</strong></td>
</tr>
<tr>
<td>16:45-17:10</td>
<td><strong>New method for monitoring steam injection for Enhanced Oil Recovery (EOR) and for finding sources of geothermal heat Gordon Stove</strong></td>
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### Wednesday

#### 0800-0855

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<tr>
<td>Broadband least-squares wave-equation migration</td>
<td>Rock-physics based time-lapse inversion</td>
<td>Evolving exploration methods in the hydrocarbon play within the Patchewarra Formation on the Western Rank, Cooper Basin</td>
<td>Keynote Presentation Ocean and atmosphere chemistry drive cycles of basin-hosted ore deposits through time Ross Large</td>
<td>Constrained 3D modelling and geochemical analyses of the Horshoe Range BIF tools for evaluating magnetic signatures under cover Ben Paterson</td>
<td>Potential of full waveform inversion of vertical seismic profile data in hard rock environment Anton Egrov</td>
<td>Impact of airborne electromagnetic (AEM) surveys in groundwater management in the Lower Plateau South natural resources district, Nebraska, USA Jared Abraham</td>
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#### 0855-0920

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<tr>
<td>A new system for efficiently acquiring vertical seismic profile surveys</td>
<td>Application of time-lapse full waveform inversion of vertical seismic profile data for the identification of changes introduced by CO2 sequestration</td>
<td>Stromaticite construction, bioclasts and biomarkers in the lower Cambrian Hawker Group, Amadeus Basin, South Australia</td>
<td>Keynote Presentation Earth and atmosphere chemistry drive cycles of basin-hosted ore deposits through time Ross Large</td>
<td>Comparing responses from different AEM systems and derived models at the Sunnyside Nickel Project, Botswana</td>
<td>The rise of 3D seismic in hardrock mineral exploration Frank Blikie</td>
<td>Aquifer delineation using the tempest AEM system Adam Smiarowski</td>
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#### 0920-0945

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<tr>
<td>Quantitative Interpretation: Use of seismic inversion data to directly estimate hydrocarbon reserves and resources</td>
<td>3D vertical seismic profiling acquired using fibre-optic sensing DAS – results from the CO2CRC Otway project</td>
<td>Reservoir modelling, structural history and volumetrics of the Jerbo Area, Eyre Sub-Basin Jordan McGlew</td>
<td>Keynote Presentation What is ZTEM seeing over this tropical porphyry? Chris Wijmans</td>
<td>Fast-tracking gold exploration below 300m – 3D seismic case history from Darlot gold mine Greg Turner</td>
<td>Resolving changes to freshwater lens systems in a “sea of salinity” using multi-date airborne EM Timothy Munday</td>
<td>An integrated hydrogeophysical approach to exploring for groundwater resources in southern Northern Territory Laura Gow</td>
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#### 0945-1010

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<tbody>
<tr>
<td>Solid substitution: Theory versus experiment</td>
<td>Geochronology of storing CO2 and N2 in the deep Precipice Sandstone</td>
<td>Tertiary deepwater coral supports cold seeps in the Ceduna Sub-Basin</td>
<td>Keynote Presentation Ten years in the wild: The P-223 experiment David Annetts</td>
<td>Airborne geophysics over the Dolly Varden VMS and low sulphidation epithermal silver deposits, Northwestern B.C, Canada Jean Legault</td>
<td>Distributed acoustic sensing for mineral exploration: Case study Andrej Bona</td>
<td>Stretching AEM near-surface resolution limits related to low-and very high resistivity contrasts Andi Pfaffhuber</td>
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#### 1010-1040 Morning tea

#### 1040-1220 CONCURRENT SESSIONS

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</thead>
<tbody>
<tr>
<td>Keynote Presentation</td>
<td>Regional migration and trapping frameworks in the front</td>
<td>Exploration Strategy</td>
<td>Geophysical Case History</td>
<td>Petrophysics</td>
<td>Groundwater</td>
<td>Groundwater</td>
<td></td>
</tr>
<tr>
<td>Multi-component seismic Applications and new developments Natasha Hendrick</td>
<td>A double double-porosity model for wave propagation in patchy-saturated tight sandstone with fabric heterogeneity Mengjui Guo</td>
<td>Keynote Presentation</td>
<td>Mike McWilliams</td>
<td>Imagining high conductors at Golden Grove Neil Hughes</td>
<td>The use of petrophysical data in mineral exploration: A perspective Michael Dentith</td>
<td>The use of airborne IM to investigate coastal carbonate aquifers, seawater intrusions and sustainable borefield yield at Exmouth, Western Australia Karen Gilgallon</td>
<td>Comparative evaluation of 1D, 2.5D and 3D inversions for resolving tectonic elements in floodplains and near-surface inverted sedimentary basins Ken Lawrie</td>
</tr>
</tbody>
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Marine vibrator concepts for modern seismic challenges
Andrew Long

Application of passive seismic in determining overburden thickness: North West Zamibia
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 Smailowski

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

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Conferences and events
News

1155-1220
Methods for reducing unwanted noise (and increasing signal) in passive seismic surveys
Tim Deen

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 geo-systems 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

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CA-IDTMS and biostratigraphy: Their impact on exploration
Tegan Smith

Mathematical properties and physical meaning of the gravity gradient tensor eigenvalues
Carlos Cevallos

Dyles, synclines and geophysical inversion - is geology important?
Desmond Fitzgibbon

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
New Technology CO2
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 (IDEEMs method) for precise tracing of boundaries in geoelectrical sections
Igor Ingerov

Common uncertainty: Research explorer uncertain estimation in geological 3D modelling
Evren Pakyuzy-Charrer

Geophysics for sediment hosted copper and gold mineralisation, the role of TDEM
Barry Bourne

Using AMS and paleomagnetic data to assess tectonic rotation: A case study from Savannah Nickel Mine, WA
Jim Austin

Magnetocardiogenic inversion for characterisation of complex aquifer systems
Ralf Schaa

Recent advancements and applications of logging and surface magnetic resonance for groundwater investigations
Elliott Granewald

1435-1500
New Technology Minerals
Modelling complex near-surface features to improve shallow seismic exploration
Shaun Strong

Integrating geophysical monitoring data into multiphase fluid flow reservoir simulation
Trevor Iorns

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

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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!
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

<table>
<thead>
<tr>
<th>Survey name</th>
<th>Client</th>
<th>Project management</th>
<th>Contractor</th>
<th>Start flying</th>
<th>Line km</th>
<th>Spacing AGL (m)</th>
<th>Area (km²)</th>
<th>End flying</th>
<th>Final data to GA</th>
<th>Locality diagram (Preview)</th>
<th>GADDS release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fowler</td>
<td>GSSA</td>
<td>GA</td>
<td>Thomson Aviation</td>
<td>18 Feb 2017</td>
<td>95 009</td>
<td>60 m E–W</td>
<td>17 360</td>
<td>2 Jun 2017</td>
<td>Final radiometric data QA/QC in progress</td>
<td>183: Aug 2016 p. 34</td>
<td>TBA</td>
</tr>
<tr>
<td>Tasmanian Tiers</td>
<td>MRT</td>
<td>GA</td>
<td>TBA</td>
<td>TBA</td>
<td>Up to an estimated 66 000</td>
<td>200 m N–S or E–W</td>
<td>11 000</td>
<td>TBA</td>
<td>TBA</td>
<td>TBA</td>
<td>TBA</td>
</tr>
<tr>
<td>Isa Region</td>
<td>GSQ</td>
<td>GA</td>
<td>GPX</td>
<td>3 Jul 2017</td>
<td>120 062</td>
<td>50 m E–W</td>
<td>11 000</td>
<td>5 Nov 2017</td>
<td>TBA</td>
<td>188: Jun 2017 p. 21</td>
<td>TBA</td>
</tr>
<tr>
<td>Tallaringa N (1A)</td>
<td>GSSA</td>
<td>GA</td>
<td>TBA</td>
<td>26 Oct 2017</td>
<td>97 762</td>
<td>60 m E–W</td>
<td>17 320</td>
<td>6.7%</td>
<td>TBA</td>
<td>190: Oct 2017 p. 26</td>
<td>TBA</td>
</tr>
<tr>
<td>Tallaringa S (1B)</td>
<td>GSSA</td>
<td>GA</td>
<td>TBA</td>
<td>26 Sep 2017</td>
<td>145 042</td>
<td>60 m E–W</td>
<td>26 010</td>
<td>19%</td>
<td>TBA</td>
<td>190: Oct 2017 p. 26</td>
<td>TBA</td>
</tr>
<tr>
<td>Coober Pedy (8A)</td>
<td>GSSA</td>
<td>GA</td>
<td>TBA</td>
<td>18 Sep 2017</td>
<td>90 627</td>
<td>60 m N–S</td>
<td>16 140</td>
<td>55.1%</td>
<td>TBA</td>
<td>190: Oct 2017 p. 26</td>
<td>TBA</td>
</tr>
<tr>
<td>Billa Kalina (8B)</td>
<td>GSSA</td>
<td>GA</td>
<td>TBA</td>
<td>10 Oct 2017</td>
<td>90 625</td>
<td>60 m N–S</td>
<td>16 140</td>
<td>54.4%</td>
<td>TBA</td>
<td>190: Oct 2017 p. 26</td>
<td>TBA</td>
</tr>
<tr>
<td>Childara (9A)</td>
<td>GSSA</td>
<td>GA</td>
<td>TBA</td>
<td>5 Nov 2017</td>
<td>135 021</td>
<td>60 m N–S</td>
<td>23 910</td>
<td>3.6%</td>
<td>TBA</td>
<td>190: Oct 2017 p. 26</td>
<td>TBA</td>
</tr>
<tr>
<td>Lake Eyre (10)</td>
<td>GSSA</td>
<td>GA</td>
<td>TBA</td>
<td>2 Oct 2017</td>
<td>91 800</td>
<td>60 m E–W</td>
<td>16 180</td>
<td>25.3%</td>
<td>TBA</td>
<td>190: Oct 2017 p. 26</td>
<td>TBA</td>
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</table>

TBA, to be advised.
Table 2. Gravity surveys

<table>
<thead>
<tr>
<th>Survey name</th>
<th>Client Project management</th>
<th>Contractor</th>
<th>Start survey</th>
<th>No. of stations</th>
<th>Station spacing (km)</th>
<th>Area (km²)</th>
<th>End survey</th>
<th>Final data to GA</th>
<th>Locality diagram (Preview)</th>
<th>GADDS release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanami-Kimberley</td>
<td>GSWA GA Thomson Aviation</td>
<td>16 Jun 2017</td>
<td>49 825</td>
<td>2500 m line spacing</td>
<td>110 000</td>
<td>31 Oct 2017</td>
<td>TBA</td>
<td></td>
<td>The survey area covers the Billiluna (all), and parts of the Lucas, Cornish, Mount Bannerman, Mount Ramsay, Noonkanbah, Lansdowne, Lennard River, Derby, Chamley and Yampi 1:250 k standard map sheets</td>
<td>TBA</td>
</tr>
<tr>
<td>Kidson Sub-basin</td>
<td>GSWA GA CGG Aviation (Australia)</td>
<td>14 Jul 2017</td>
<td>72 933</td>
<td>2500 m line spacing</td>
<td>155 000</td>
<td>TBA</td>
<td>TBA 70.7%</td>
<td></td>
<td>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</td>
<td>TBA</td>
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</table>

TBA, to be advised.

Table 3. AEM surveys

<table>
<thead>
<tr>
<th>Survey name</th>
<th>Client Project management</th>
<th>Contractor</th>
<th>Start flying</th>
<th>Line km</th>
<th>Spacing AGL Dir</th>
<th>Area (km²)</th>
<th>End flying</th>
<th>Final data to GA</th>
<th>Locality diagram (Preview)</th>
<th>GADDS release</th>
</tr>
</thead>
<tbody>
<tr>
<td>AusAEM (Year 1)</td>
<td>GA GA CGG</td>
<td>TBA</td>
<td>59 349</td>
<td>20 km with areas of infill</td>
<td>TBA</td>
<td>TBA 32.9%</td>
<td>TBA</td>
<td>188: Jun 2017 p. 21</td>
<td>TBA</td>
<td></td>
</tr>
<tr>
<td>Olympic Domain</td>
<td>GSSA GA SkyTEM Australia</td>
<td>14 Nov 2017</td>
<td>3181</td>
<td>1.5 &amp; 3 km E-W</td>
<td>33 200</td>
<td>TBA</td>
<td>TBA</td>
<td>190: Oct 2017 p. 27</td>
<td>TBA</td>
<td></td>
</tr>
<tr>
<td>Fowler Domain</td>
<td>GSSA GA SkyTEM Australia</td>
<td>Early Dec 2017</td>
<td>3057</td>
<td>5 km NW–SE</td>
<td>15 000</td>
<td>TBA</td>
<td>TBA</td>
<td>190: Oct 2017 p. 27</td>
<td>TBA</td>
<td></td>
</tr>
</tbody>
</table>

TBA, to be advised.

Table 4. Magnetotelluric (MT) surveys

<table>
<thead>
<tr>
<th>Location</th>
<th>State</th>
<th>Survey name</th>
<th>Total number of MT stations deployed</th>
<th>Spacing</th>
<th>Technique</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Australia</td>
<td>Qld/NT</td>
<td>AusLAMP</td>
<td>150</td>
<td>50 km</td>
<td>Long period MT</td>
<td>The survey covers the area between Tennant Creek and Mount Isa</td>
</tr>
</tbody>
</table>
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 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 28,000 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@dмиrs.wa.gov.au.

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

Table 1. Status of GSWA aerogravity surveys in Western Australia

<table>
<thead>
<tr>
<th>Survey name</th>
<th>Size (line km)</th>
<th>Contractor</th>
<th>Technology</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016 East Kimberley</td>
<td>38000</td>
<td>Sander Geophysics</td>
<td>AIRGrav</td>
<td>Complete; GSWA survey registration number 70156</td>
</tr>
<tr>
<td>2017 Surveys</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Tanami</td>
<td>25000</td>
<td>Thomson Aviation</td>
<td>GT-2A</td>
<td>Data processing; release: Dec 2017 (est.)</td>
</tr>
<tr>
<td>2. NE Canning</td>
<td>25000</td>
<td>Thomson Aviation</td>
<td>GT-2A</td>
<td>Data processing; data release: Feb 2018 (est.)</td>
</tr>
<tr>
<td>3. Kidson</td>
<td>70000</td>
<td>CGG Aviation</td>
<td>Falcon/sGrav</td>
<td>Data acquisition; release Mar 2018 (est.)</td>
</tr>
<tr>
<td>4. Kidson extension</td>
<td>55000</td>
<td>CGG Aviation</td>
<td>Falcon/sGrav</td>
<td>Data acquisition; release Mar 2018 (est.)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Registration number</th>
<th>Survey name</th>
<th>Line spacing</th>
<th>Size (line km)</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>70369</td>
<td>Amadeus SPA704.5 AG</td>
<td>5000 m</td>
<td>7780</td>
<td>GT-1A</td>
</tr>
<tr>
<td>70969</td>
<td>SPA-055 Falcon AGG</td>
<td>3250 m</td>
<td>4065</td>
<td>Falcon</td>
</tr>
<tr>
<td>70971</td>
<td>Canning Basin Falcon AGG</td>
<td>1000 m</td>
<td>43 880</td>
<td>Falcon</td>
</tr>
<tr>
<td>71162</td>
<td>Canning Basin EP450_451 AG</td>
<td>2500 m</td>
<td>11 100</td>
<td>GT-2A</td>
</tr>
<tr>
<td>71166</td>
<td>Canning Basin SPA-A AG</td>
<td>1500 m</td>
<td>12 900</td>
<td>GT-1A</td>
</tr>
<tr>
<td>71172</td>
<td>Canning Basin 2434 AGG</td>
<td>1500 m</td>
<td>3560</td>
<td>Falcon</td>
</tr>
</tbody>
</table>
Geological Survey of Victoria: new airborne survey for Otway Basin

GSV are planning an 18,000 km² 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).

Suzanne Haydon
Geological Survey of Victoria
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Victorian sedimentary basins; the Victorian Gas Program will focus on the Otway and Gippsland Basins.
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 spruik 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. 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%.

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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.

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

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

Table 1. GERD, by sector and as %GDP

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<tbody>
<tr>
<td>Business</td>
<td>$12.64</td>
<td>$17.29</td>
<td>$18.01</td>
<td>$18.32</td>
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<td>$8.89</td>
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<tr>
<td>Private non-profit</td>
<td>$0.61</td>
<td>$0.74</td>
<td>$0.91</td>
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<tr>
<td>Total</td>
<td>$21.78</td>
<td>$28.30</td>
<td>$30.91</td>
<td>$31.70</td>
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GERD/GDP %

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<td>2.00</td>
<td>2.25</td>
<td>2.19</td>
<td>2.12</td>
<td>2.11</td>
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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

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 km² compared with a surface outcropping of ~1 km². Geophysical forward modelling identified a close spatial relationship at depth between the highly magnetic Murmungee Granodiorite and the non-magnetic Beechworth Granite. 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: Geophysical 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

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, CO₂ 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 Sør Rondane 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.
on 140 core samples and 49 thin sections to characterise the carbonate facies. Porosity-depth analysis identified a point of geological significance at \(\approx 450\) 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.


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 analysis (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.


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.


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 demagnetisation 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 firm 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 μW/m² and 1.6 ± 0.5 μW/m² 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 norm and modal mineralogy. I find that SiO₂ 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 (SiO₂, Al₂O₃, FeO, Na₂O and K₂O) 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 along 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 geophones. 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 defined in the NW of the study area trendling 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 serpentinitised 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 CO2CRC site using electrical geophysics.

An ERI survey was completed at the CO2CRC Otway Site in order to assist in characterizing the shallow clay layer prior to a planned controlled release and monitoring experiment which would involve injecting CO2 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 Badammina 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.


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 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 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. This understanding can be improved upon with additional data, therefore this method 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.
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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, and the primary (transmitted) magnetic field

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:

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

where $\delta$ is skin depth (in meters), $\rho$ is resistivity (in ohm-m), and $f$ is frequency in hertz. And it might be worth reminding readers that resistivity ($\rho$) and conductivity ($\sigma$) 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. $\rho$ is large (or $\sigma$ 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 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).](image-url)
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
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 lamp 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.

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

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.

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.
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

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>10</th>
<th>20</th>
<th>40</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuning thickness (m)</td>
<td>60</td>
<td>30</td>
<td>15</td>
<td>10</td>
</tr>
</tbody>
</table>

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!

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**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.

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

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 alerted 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.

Reference

Introduction

Any appreciation of significant members of the mineral kingdom should include the humble and ubiquitous sesquioxide of iron, Fe₂O₃ 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 ἀἷμα, genitive case ἀἷματος, 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 αἷματίτις· ἀότη δ’ αὐχμῶδης καὶ κατὰ τούνομα ὡς αἷματος ἐξηρὸν 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). Steelly 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 (μάλατος) 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.
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 incdible red herring diverts us from our proper purpose. 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 pulverulente, i.e. easily powdered. Haematite (Fe₂O₃) is the oxide in red ochre (redde, 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) → Fe₂O₃ + H₂O. The

<table>
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<th>Table 1. Haematite Fe₂O₃</th>
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<tr>
<td><strong>Chemistry</strong></td>
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<td><strong>Petrophysics categories</strong></td>
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<td><strong>Density</strong></td>
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<td><strong>Mag. susceptibility, k</strong></td>
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<td><strong>Remanence, Qn</strong></td>
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<td><strong>Conductivity/resistivity</strong></td>
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Notes:

• Haematite here is α-Fe₂O₃. It is one of the iron oxide “ferromagnetics” (actually canted antiferromagnetic). Maghaemite, γ-Fe₂O₃, 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-Fe₂O₃. Lepidicrocite, γ-FeO(OH), dehydrates to maghaemite, γ-Fe₂O₃. Magnetite, Fe₃O₄, oxidises to haematite (matte) or to kinomagnetite, 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.
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: \( \text{Fe}_2\text{O}_3 + 3\text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2 \). 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 haematitic 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.

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 (\( \text{FeCO}_3 \)) and limonite/goethite (\( \text{FeO(OH)} \)). 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).

Celsius (fl AD14–37), in his encyclopaedic compilation on ancient medicine, notes haematite’s use as an excdent (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, 1984; 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 hebetas, 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 pittitur quem femina fluxum,
Carnes crescentes in vulnere, pulveris huius
Vis premit, et ventrem retinet sine mora fluentem,
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).

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 garlic, could be deceived; therefore I think that they had some other kinds of Loadstone, 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 hindered by garlic, it follows not that it is hindered in none; and perhaps our garlic 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 adventurcensce, 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...
also displays unusual anisotropy of magnetic susceptibility (Guerrero-Suarez and Martin-Hernandez, 2012).

However, the low frequency electrical properties of haematite are another matter. From the physics viewpoint haematite is a narrow band 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 haemaites.

Physical properties of some haemaites

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 (Ω > 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 haematites, they could be due to the presence of minor amounts of magnetite and/or maghaematite and/or titanoaemaitite, 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. Titanoaemaitite 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 haemaites have the highest resistivities (100 000s ohm m); the black haematite resistivities are lower (1000s ohm m). The red haemaites 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 haemaites 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 haemaites 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 haemaites are very highly resistive and indeed are virtual dielectrics. Black haemaites 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 specularites 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 haemaites ( # 9, 10, 11) contain relic 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, Donez 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 142/5 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.
Haematite: the bloodstone

**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 Gerais, 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

<table>
<thead>
<tr>
<th>Group</th>
<th>Code</th>
<th>DBD (g/cc)</th>
<th>PA (%)</th>
<th>GDA (g/cc)</th>
<th>Bulk Resistivity</th>
<th>p_F (ohm m)</th>
<th>p_T (ohm m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthy, red haematite (dull, no lustre)</td>
<td>1</td>
<td>4.54</td>
<td>0.5</td>
<td>4.56</td>
<td>140</td>
<td>72 000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.74</td>
<td>36.1</td>
<td>2.72</td>
<td>7</td>
<td>341 538</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3K</td>
<td>1.71</td>
<td>38.4</td>
<td>2.77</td>
<td>17</td>
<td>440 000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.93</td>
<td>63.4</td>
<td>5.20</td>
<td>42</td>
<td>1 506 818</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.86</td>
<td>65.0</td>
<td>5.26</td>
<td>548</td>
<td>3 530 800</td>
<td></td>
</tr>
<tr>
<td>Red and black haematite mix (dull lustre)</td>
<td>2</td>
<td>4.19</td>
<td>3.0</td>
<td>4.32</td>
<td>115</td>
<td>10 309</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4.92</td>
<td>1.9</td>
<td>5.02</td>
<td>390</td>
<td>5990</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3K</td>
<td>3.37</td>
<td>6.2</td>
<td>3.59</td>
<td>168</td>
<td>10 700</td>
<td></td>
</tr>
<tr>
<td>Black haematite iron ore (martite/microplaty, dull to submetallic lustre)</td>
<td>3</td>
<td>4.13</td>
<td>19.0</td>
<td>5.10</td>
<td>444</td>
<td>5 736</td>
<td></td>
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<tr>
<td>Black and red haematite + some networked specularite</td>
<td>4</td>
<td>4.12</td>
<td>12.9</td>
<td>4.73</td>
<td>204</td>
<td>1959</td>
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</tr>
<tr>
<td></td>
<td>5</td>
<td>4.21</td>
<td>15.6</td>
<td>4.98</td>
<td>146</td>
<td>1131</td>
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<tr>
<td></td>
<td>6</td>
<td>4.51</td>
<td>12.0</td>
<td>5.12</td>
<td>142</td>
<td>938</td>
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<tr>
<td></td>
<td>7</td>
<td>4.92</td>
<td>5.8</td>
<td>5.22</td>
<td>1192</td>
<td>297</td>
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<tr>
<td>Intermediate haematite (polycrystalline, metallic lustre)</td>
<td>5</td>
<td>5.21</td>
<td>0.2</td>
<td>5.22</td>
<td>1517</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Black and red haematite + networked dissem./veinlet sulphides: cpw, bnn, cc</td>
<td>6</td>
<td>4.54</td>
<td>6.9</td>
<td>4.88</td>
<td>1326</td>
<td>19</td>
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<tr>
<td></td>
<td>10</td>
<td>4.98</td>
<td>0.6</td>
<td>5.01</td>
<td>8531</td>
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<tr>
<td></td>
<td>11</td>
<td>5.35</td>
<td>4.0</td>
<td>5.57</td>
<td>266</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Specular haematite (metallic lustre, platy, grey-black, crystalline)</td>
<td>7</td>
<td>4.62</td>
<td>2.0</td>
<td>4.72</td>
<td>998</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>4.32</td>
<td>15.7</td>
<td>5.13</td>
<td>2521</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>4.72</td>
<td>6.2</td>
<td>5.03</td>
<td>639</td>
<td>1.3</td>
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</tr>
<tr>
<td></td>
<td>15</td>
<td>5.20</td>
<td>1.3</td>
<td>5.27</td>
<td>3938</td>
<td>0.08</td>
<td></td>
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<tr>
<td></td>
<td>16</td>
<td>5.18</td>
<td>1.6</td>
<td>5.24</td>
<td>9339</td>
<td>0.003</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
- **DBD** – dry bulk density, 105°C dried; **PA** – apparent (water accessible) porosity; **GDA** – inferred grain density.
- Magnetic susceptibility, mag k, induction coil 460 Hz.
- Galvanic resistivity (ρ) measured after oven drying 105°C and cooling to room temperature (20°C) in desiccator → ρ_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, 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 suppliers.
- Grain sizes range from coarse (2 mm+) through fine (0.25–0.125 mm) to cryptocrystalline (<0.004 mm). Platey forms quite common with plate thickness 10s to 100s μm. 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.
magnetic susceptibility increases up to $10000 \times 10^{-5}$ 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 mineralogic polished blocks, Harvey (1928) found only very resistive haematites. Morin (1951) estimated that 1.0 atomic percent Ti, an $n$ type impurity, in pure $\alpha$ Fe$_2$O$_3$, improved its conductivity by many orders of magnitude (to 20 S/m). Shuey (1975) reported resistivities $\sim0.5$ ohm m, in the basal plane perpendicular to the trigonal axis, for $n$ type haematite crystals and resistivities $\sim0.15$ 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 Gogebic 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.
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 haemaites. 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

**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 10000 × 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.
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 specularities (#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 Fe_2 O_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 amorphous, 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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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.

References

Anon., 1491, *Hortus Sanitatis*, De lapidibus et in terre venis nascentibus: Jacob Meydenbach Mainz, (haematite is chapter 51, author not known with any certainty).


Bauschio, J. L., 1665, *De lapide haematet et schisto schediasma*, AN Cur, Lipssiae (Leipsig).


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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. Grain size, 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.


Wootton, D., 2015, *The invention of science*: Allen Lane.


Don Emerson is a geophysical consultant specialising in hard rock petrophysics. For a long time he has been interested in the mineralogical and geological information contained in ancient and Medieval Latin and Greek texts.
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