Australian Society of Exploration Geophysicists

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PREVIEW

NEWS AND COMMENTARY

New national gravity maps

New data on the North West Mineral Province

New model needed for geoscience education in Australia

Drillhole geophysics

FEATURES

2020 Student theses

Mark Lackie's best of *Exploration Geophysics*

Divination: A geophysicist's view

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FRONT COVER

Don Emerson experimenting with dowsing. See Don's article "Divination: A geophysicist's view" in this issue for more information.

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Editor's desk

This issue of *Preview* is a bumper issue - in our best Christmas tradition! Don Emerson investigates divination and, as is apparent from the image on our cover, clearly enjoyed putting a number of divining rods through their paces on the geophysical test range just outside of Sydney – deerstalker and all!! Mark Lackie, the current Editor-in-Chief of *Exploration Geophysics*, makes the final selection in our "best of" series marking the 50th anniversary of the establishment of the Australian Society of Exploration Geophysicists. Don Emerson gets a guernsey – another reason to have Don on our front cover!

We also feature our annual summary of theses completed in Australia that are based on, or use, geophysical methods. Thirty-two students submitted abstracts and, as Michael Asten (*Education matters*) remarks, all of these students are to be congratulated for getting across the finish line in what has been a very difficult year for our universities. There can be no doubt that the global pandemic has shaken up the university sector, and that more change is on the horizon. David Cohen, President of the UNSW Academic Board and the Australian Geoscience Council, considers the consequences of these changes for geoscience education in his article "A new model needed for geoscience education in Australia". David suggests that societies such as the ASEG could have important role to play in providing vocational training - training that might also assist our Members with negotiating the twists and turns of a career in the geosciences.

David Denham (*Canberra observed*) introduces Australia's new Chief Scientist, and muses on Canberra politics. Mike Hatch (*Environmental geophysics*) has a play with some data from the new Loupe system. The Loupe system is also investigated in one of the student projects (Fionnuala Campbell, Curtin University). Terry Harvey (*Mineral geophysics*) reviews drillhole geophysics. Mick Micenko (*Seismic window*) reflects on the seismic method – pun intended! Tim Keeping (*Data trends*) takes a look at pseudo data, artefacts and recursion, and Ian James (*Webwaves*) celebrates a great leap forward in *Preview's* presence on the ASEG website.

As this issue marks the end of the calendar year (and what a year..), it is an appropriate time to thank all those who have contributed to the ongoing success of *Preview* – our Associate Editors in particular. Unfortunately, one of our Associate Editors, Michael Asten, is retiring at the end of this year. His contribution has been greatly valued and I, for one, am sad to see him go. Happily a replacement, Marina Pervukhina, has been found, and Michael introduces her to readers in his column in this issue. Marina is particularly keen to explore the options available to ASEG Members for self-directed learning and micro-credentialling. I look forward to reading her columns in the future.

On behalf of the *Preview* team, a very happy festive season and a happy New Year to you all!!

Lisa Worrall
Preview Editor
previeweditor@aseg.org.au

The Editor getting into the festive spirit!

Free subscription to *Preview* online

Non-members of the ASEG can now subscribe to *Preview* online via the ASEG website. Subscription is free. Just go to https://www.aseg.org.au/publications/PVCurrent to sign up. You will receive an email alert as soon a new issue of *Preview* becomes available. Stay informed and keep up-to-date by subscribing now!!

NB: ASEG Members don't need to subscribe as they automatically receive an email alert whenever a new issue of Preview *is published.*

President's piece

At the time of writing in mid-November, 2020 had 50 days remaining. Ordinarily, this would be time to prepare for the end of the year and a break. However, if 2020, has taught us (me …) anything, it is to expect the unexpected from any quarter; given the previous 11 months, we may not be done in any sense just yet.

Typical fare for end of year columns is membership renewals, and this column is no exception. Following the 2020's COVID-19 shut down, the Federal Executive made the decision to retain fees at 2019 levels. We also made the decision to advance the early-bird period by one month, leaving December for Members to renew at normal rates before the fees become overdue in January, 2021. I would also like to reiterate the importance of ASEG membership. In addition to free access to articles in *Exploration Geophysics*, a monthly newsletter, reduced entry to AEGC conferences, and free entry to face-to-face technical meetings which have recently restarted, to name but a few benefits, membership of the ASEG is a clear statement of commitment. This commitment is employed by the ASEG in forums such as the Society of Exploration Geophysics' (SEG) Council and the Australian Geoscience Council (AGC) to make the case for support and recognition of exploration geophysics as an active vibrant field which is critical to many domains in the future. This last point will become increasingly important in coming months as the effects of recent, continuing upheaval in the education sector begin to be realised. With diminished opportunities to study at the tertiary level, the ASEG must take the initiative to ensure that exploration geophysics remains a viable career option.

I would also like to acknowledge the ASEG's Corporate Members. HiSeis, TotalSeismic and Velseis have renewed for 2021 as Corporate Plus Members, while Santos and Southern Geoscience Consultants have renewed as Corporate Members. New Corporate Members DUG and Transparent Geophysics joined towards the end of 2020. The majority of fees from corporate memberships are directed to the ASEG's Research Foundation, which funds industry-relevant student research projects. Previous issues of *Preview* have described many of these projects, which run the gamut from BSc (Hons.) to PhD, in minerals, hydrocarbon and environmental domains. I would also note in passing that most of the corporate sponsors are in the service sector. Over the ASEG's 50 years, Corporate Members have included major explorers and government agencies. With increasing priorities placed on social license to operate and corporate citizenship, I am hopeful that such organisations will re-join the ranks of ASEG Corporate Members in coming years. I would also like to acknowledge and thank the many sponsors of individual branches. Too numerous to mention without trying the reader's patience, these sponsors are given prominence in every ASEG webinar.

Nominally, 2020 marks the end of the ASEG's 50th Anniversary. Despite the major left-field disruption of operations from COVID-19, there is much to reflect upon. The first virtual AGM allowed all Members to attend instead of only those travelling, or living in the hosting state. The ASEG awarded a Gold Medal to Dr Brian Spies in a hybrid ceremony drawing together presenters and participants from Australia and overseas. We also realised the promise and capability of webinars to transcend state and international boundaries, and I would like to thank all presenters for their time and effort. At the time of writing, 24 webinars hosted by NSW, SA/NT, Victorian, WA Branches and the Federal Executive, have been directly viewed by around 1100 people from 30 countries, and have attracted around 3000 subsequent views on the ASEG's YouTube channel. Figure 1 compares webinar registration and attendance for Members and non-members and offers a number of takeaways. Firstly, that webinars covering interesting, relevant topics acquire a large audience in terms of simple attendance and, by proportion, attendance of ASEG Members. Secondly, comparing Figure 1 to Figure 1 in my PV 208 President's Piece shows that presenters can use their social media network to promote their work. For students, a YouTube presentation is a profoundly positive statement of commitment to any prospective employer.

Finally, I would like take this opportunity to wish Members the best of success for 2021. May any breaks taken be safe, relaxing and restful. I look forward to welcoming 2021, the ASEG's 51st year, the 3rd AEGC in Brisbane, and the dawn of a new decade.

David Annetts
ASEG President
president@aseg.org.au

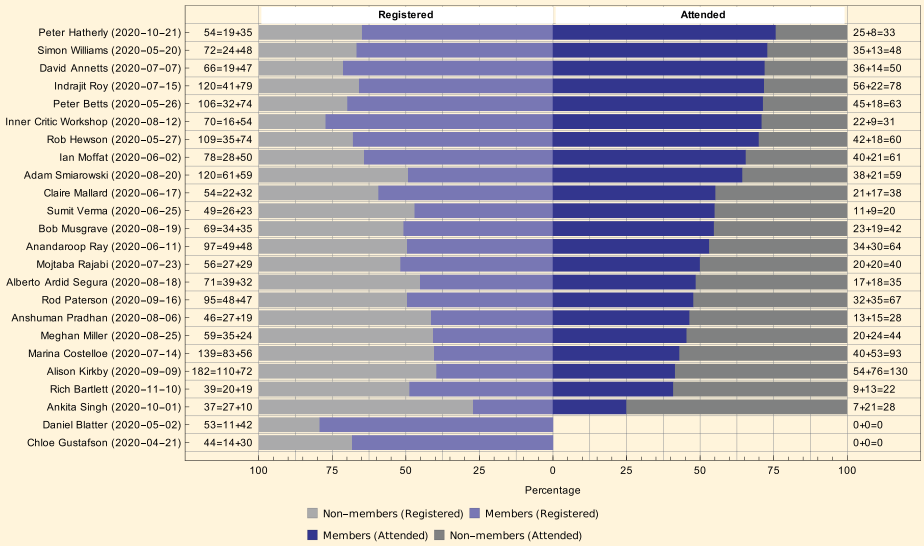

Figure 1. *Comparison of registration and attendance for all ASEG webinars at the time of writing. Bars show Member/non-member attendance and registration as percentages and numbers at their end show that there is little correlation between a well-attended webinar and the proportion of ASEG Members attending a webinar.*

Executive brief

The Federal Executive of the ASEG is the governing body of the ASEG. It meets once a month, via teleconference, to deal with the administration of the Society. The following brief reports on the monthly meetings that were held in October and November 2020. If you wish to know more about any ASEG matters, please contact Leslie at fedsec@aseg.org.au.

Finances

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

Year to date income: $211 277

Year to date expenditure: $184 154

Net assets: $1 102 320

Due to the lack of branch meetings during the COVID-19 restrictions, the total expenditure is well down on the budgeted amount.

Membership

As at 12 November, the Society had 880 financial Members, compared to 951 at this time last year. The ASEG currently has seven Corporate Members, including three Corporate Plus Members. A huge thanks to all our Corporate Members for your continued support in 2020. Don't forget to have a look for our Corporate Members on the contents page of *Preview* and support them as much as you can. Our state branches also have additional local sponsors, and these are shown at all branch meetings and at the beginning of all webinars.

We are coming up to that time of year when membership renewals are due. ASEG has again provided an early-bird rate, but this has been brought forward a little this year. The early-bird rate is now available until 30 November and is being offered to our International Members for the first time. Look out for your renewal email and act quickly to secure the discounted rates. Remember, 5-year membership packages are available to Active/Associate and Retired Members, with early-bird rates also applying.
As always, we are grateful to all our Members for their continued support of our organisation.

Early and mid-career Members can also join the ASEG Young Professionals Network at www.aseg.or.au/about-aseg/aseg-youngprofessionals.

Social Media

Stay up-to-date with all the happenings of your Society on social media. You can connect to us on LinkedIn, Facebook and Twitter for all the latest news and events.

Online Events

Even though COVID restrictions are being eased in many states, the ASEG has continued the webinar series with some interesting talks. These have been coordinated and run at both state and federal level. The sessions are all recorded and available for viewing at the ASEG website or on our YouTube Channel. It is great to see face-to-face meetings have started to return in some states. Keep a look out for notifications from your state branches to see what is coming, and get out there and reconnect with your colleagues.

The SA_NT Branch 2020 wine offer has been distributed. I hope you are all enjoying the fantastic selection that was provided this year.

Coming into Christmas for 2020, I wish you all a very happy festive season with your loved ones, and please stay safe.

Leslie Atkinson
ASEG Secretary
fedsec@aseg.org.au

Welcome to new Members

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

First name	Last name	Organisation	State	Country	Membership type
Jennifer	Chandra	University of Western Australia	WA	Australia	Student
Victoria	Cousins	University of Western Australia	WA	Australia	Student
Ovie	Eruteya	University of Geneva	Geneva	Switzerland	Active
Nathan	Gardiner	Monash University	VIC	Australia	Active
Bowen	Mi	University of Western Australia/Resource Potentials Pty Ltd	WA	Australia	Assoc (Grad)
John	O'Donnell	Geological Survey of South Australia	SA	Australia	Active
John	Shepherd	University of Western Australia	WA	Australia	Student
Gabriel	Yieljak	Nile Petroleum Corporation		South Sudan	Active

ASEG Young Professionals Network: YPN 3.0

At the time of writing the second reboot of the ASEG YPN Special Interest Group is in full swing! The member database has had a thorough spring clean and, in fact, a couple of databases were found and combined and so we now have a total of 85 members. By the time you read this, those 85 members should all have received an email from ypadmin@aseg.org.au. So, if you think you're a member and you haven't received that email then please check your spam folder or send me an updated email address.

The recent email-out reminded YPs of our strategic mantra: Mentoring – Networking – Training. The network operates on two levels: 1) on the ground in the states and regions where we have a quorum; and 2) on a federal level, most noticeably through the conferences such as the AEGC. The table below serves as a reminder of the type of events and services you should expect from the YPN at this point in time.

Regional events	Conference events
Mentoring (face2face or remote)	Booth/meeting spot
Social/networking events	Networking event
YP focussed seminars	YP focussed workshops

The graph in Figure 1 shows the geographical breakdown of our membership and highlights some challenges we face. We have a quorum of members in WA, QLD, SA and NSW, although we need to establish local leadership in the latter two states. In VIC, ACT, TAS, NT and internationally, we have too few (or no) members to run local events. In these states/regions, it seems that online webinars and remote mentoring could help to serve the members based there. In the more active states, mentoring and social events have and should continue in person (COVID permitting).

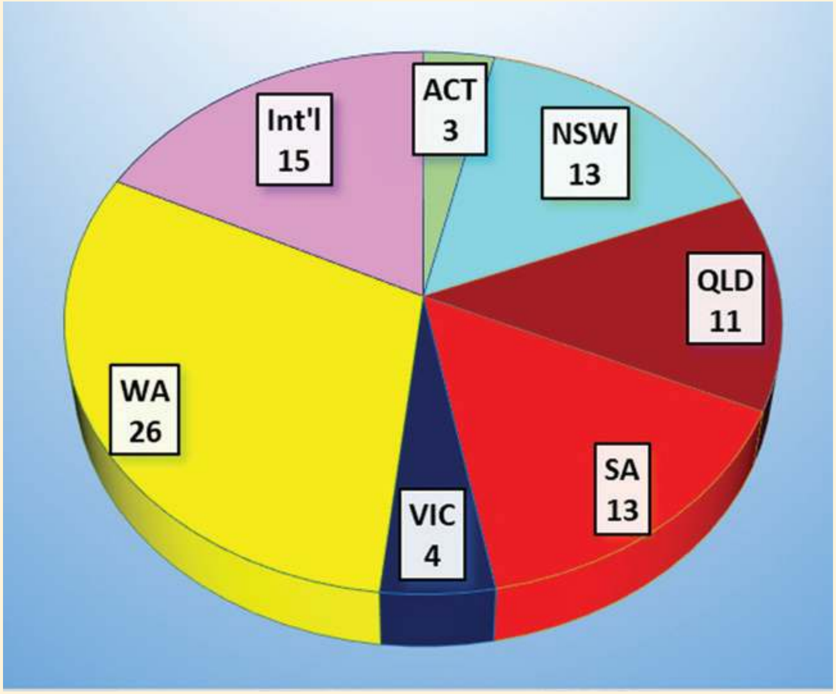

Figure 1. *ASEG YPN membership by region.*

We also have a shortlist of 72 amazing mentors – thanks to everyone who volunteered! Fortunately, their geographical spread matches the spread of YPs quite well, although we could probably use a few more mentors in SA. Over the next year, we will try to make sure that every YP who requests a mentor has access to a mentor, either in person, or remotely. If you wish to volunteer as a mentor, or to request remote mentoring, please email ypadmin@aseg.org.au.

Also, I am currently recruiting or re-affirming our state leaders and setting up more efficient lines of communication, so that YP news makes it into *Preview* on a more timely and regular basis.

In other news this month, Janelle Simpson reports that the QLD mentoring programme is back up and running and is being run cooperatively with ASEG/PESA/SPE/QPEX/FESQ. From WA, Carolina Pimentel reports similarly that a mentoring pairing night was held on November 16 with PESA and SPE.

For the upcoming AEGC conference, Kat Gioseffi and Nick Josephs are representing YPs on the organising committee and have thus far successfully lobbied for early career registration rates. They will also be organising a networking event and we shall keep you informed of any other incentives for YPs to attend the conference planned for next September.

That's it for now. Next edition I will hopefully be ready to write about the YP plans for 2021.

Jarrod Dunne
ASEG Young Professionals Network Federal Chair
ypadmin@aseg.org.au.

ASEG Technical Standards Committee: AuScope/ARDC GeoDeVL

The Technical Standards Committee has been observing the AuScope/ARDC Geoscience Data Enhanced Virtual Laboratory (GeoDeVL) project, which brought down its final report in October 2020. Though mainly focused on the research and public sector as opposed to the exploration industry more generally, some project outcomes have implications for technical standards in some geophysical methods currently seeing rapid growth in exploration applications.

Of four work packages, two dealt with magnetotellurics and passive seismic respectively. In MT, lack of agreed community standards was identified as an obstacle to the vision of making time series data sets FAIR (Findable, Accessible, Interoperable and Reusable) and developing a "dirt to desktop" workflow. In contrast, passive seismic was seen to have coalesced internationally around FDSN (Federation of Digital Seismograph Networks) standards and protocols (as previously indicated in *Preview*, from discussions the ASEG Technical Standards committee has had with a range of practitioners over the last few years, passive seismic in the Australian exploration industry still has some way to go in this regard).

Another potentially significant international development identified is a just-announced merger of UNAVCO (geodesy/GPS/GNSS data focus) and IRIS (seismology/MT) to form the EarthScope Consortium. According to the GeoDeVL final report, they "are already planning to develop a generalized container for geophysical time series, which will possibly be called GeoHDF and will be based on netCDF4. This would help overcome issues this project has faced with the debates over PH5, MTH5, ASDF and netCDF/HDF." One format to rule them all! But the key is developing universally approved vocabularies to support the metadata, thus making the data self-describing, machine-readable and interoperable.

A primary motivation for the GeoDeVL project was to make the power of high-performance computing (HPC) more available and applicable to the mineral exploration industry, as it has been in the petroleum industry for decades. Extending the ability of explorers to grapple with larger volume, rawer geophysical data, as opposed to more highly processed derivative data products and models, is seen as a means of achieving this. A successor Australian Research Data Commons project, '2030 Geophysics', has been announced. Involvement of the EarthScope Consortium promises to help the project take advantage of the work done internationally on MT and passive seismic data standards. Watch this space for news of further developments, including avenues for industry participation in 2030 Geophysics.

Mark Duffett
ASEG Technical Standards Committee
technical-standards@aseg.org.au

ASEG Branch news

New South Wales

We trust all ASEG Members are virus free and have settled into their "new normal", whatever that actually is. As we type this, the borders between NSW and Queensland and NSW and WA are still closed (depending on which direction you are travelling), but perhaps by the time you read this they will be open.

Over the last couple of months we have had one speaker who gave their presentation via zoom.

In October, **Peter Hatherly** gave a talk entitled "Stranded stream channels investigated by LiDAR mapping, some geophysics and good old leg work. Insights into the Lapstone Structural Complex west of Sydney". Peter walked us through the Blue Mountains, showed us the Lapstone Structural Complex and discussed the timing of its formation. After looking at recent LiDAR data and doing some detailed mapping he was able to pin down an age range for the complex. Many questions were asked and answered. Peter also inadvertently provided some inspiration for day trips to the beautiful Blue Mountains - useful given the border closures!

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Queensland

Members of the Queensland Branches of the ASEG and PESA came together on Thursday 5 November for our first event since restrictions were imposed way back in March. We gathered at the Stock Exchange Hotel for an evening of trivia hosted by our local quizmaster extraordinaire, **Henk Van Paridon**. Over 40 participants were quizzed about a broad span of categories including sports, geography, music, famous Australian rocks and geological landmarks. Victory went to team "Schrodinger's Cats" who amassed an impressive score of 86 out of a possible 100 points. A huge thank you to Henk and to **Nick Josephs** for organising and ensuring the night was a success.

We look forward to seeing more of everyone in 2021 as we continue to resume operations in our new normal and wish all our Branch members a Merry Christmas and a Happy New Year.

Roger Cant
QLD Branch committee member
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South Australia & Northern Territory

Whilst the year has been quiet, we were delighted to be able to host the SA-NT Branch annual Melbourne Cup Luncheon on Tuesday November 3. The event was generously sponsored by Terrex Seismic who sent five staff-members to attend, **Chris Kneipp**, **Ben Shave**, **Richard Barnwell**, **Megan Nightingale** and **Anthony Goodall.**

After a year full of mostly virtual events the lunch was greatly appreciated by all who attended. It was a great opportunity to catch up with old friends and meet new ones, with 55 people attending. This year we were impressed with the food, venue and service of The Gallery.

As usual, **Neil Gibbins** from Vintage Energy was a fantastic MC for the event, which was organised by **Sam Jennings**, with **Adam Davey**, **Josh Sage**, **Ben Kay** and **Mike Hatch**, all providing invaluable assistance to making the day run so smoothly.

Have a safe and relaxing Christmas break and, pending restrictions, we look forward to returning to a usual busy calendar of technical and networking events in 2021.

Kate Robertson
ASEG SA-NT Branch committee member
Kate.Robertson2@sa.gov.au

Josh Sage (with microphone) and Neil Gibbins (MC) with participants in the ASEG SA-NT Branch Melbourne Cup lunch.

MC Neil Gibbins (with microphone) and participants in the ASEG SA-NT Branch Melbourne Cup lunch.

ASEG news

'Laundering' money after one of the participants in the ASEG SA-NT Branch Melbourne Cup lunch mistakenly put their team's funds into an empty (full) water glass.

Tasmania

Tasmania Branch members and guests enjoyed a most pleasant and convivial dinner celebration of the ASEG's 50th anniversary, at the University of Tasmania Club on Friday 20 November. Between three delicious courses, **Tara Martin** of CSIRO entertained and educated the gathering with a run-down of *RV Investigator*'s impressive geophysical capabilities, followed by some tales of adventure and misadventure from a career in Antarctic waters and elsewhere. A good time was had by all, as they say in the classics.

Meeting notices, details about venues and relevant contact details can also be found on the Tasmanian Branch page on the ASEG website. As always, we encourage members to keep an eye on the seminar/webinar 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

The Victorian quarantine diaries

What was supposed to have been a 42 day hard lockdown for Victorians became 112 protracted grinding days of anguish, distress and suffering for most of Victoria's 6.35 million inhabitants. But Melbourne is finally back on the beers! Not only have Victorians beaten the 'second-wave' of the pandemic but we have crushed it! As I write, Victoria has just recorded 37 "double-doughnut" days. That is, 37 straight days of zero infections and zero COVID-related deaths. Thank you to the people of Victoria as we solemnly begin the job of making all beers endangered species.

So, there were a lot of "firsts" during the second Victorian lockdown. The AFL Grand Final was played outside of Victoria for the first and only time ever… in BrisVegas…with the first bounce at twilight. Don't get too used to hosting so many AFL games Queensland…alright? OK, so I falsely named Port Adelaide in the last edition of *Preview* as this year's AFL premiers. I must have bought an inaccurate copy of Gray's Almanac 2000-50 as it also stated that The Donald was a two consecutive term President of the United States. Looks like I will have to find other more traditional means of helping to generate funds for the ASEG.

In another first, it was a different Cup this year, a Cup like no other. For the first time in its 159 year history, the famed Melbourne Cup was celebrated with no crowds, no Birdcage and no fizz. Wow! There was no extreme pluvio event, as expected by racegoers every early November. There were no reckless intoxicated men and women performing various despicable acts in front of the horses on racecourse grounds. There was certainly no unforgivable sea of trash strewn across the normally pristine lawns of the Club Stand. Of course, the only thing that did remain unchanged was that international horses took out the race honours.

It was also the first time in its celebrated history that the Victorian Branch failed to host any (face-to-face) technical meetings during an entire calendar year. Not exactly how your committee envisaged 2020 was going to pan out at all. As Branch President, I will stoically go down in infamy. Finally, I want to thank all our members for their support, trust, and mateship during what will certainly go down in history as a year of incredible adversity, hardship, and peril for everyone. Have a safe and enjoyable festive season. Your committee looks forward to happier times with all our members. Now, GET ON THE BEERS!

Thong Huynh
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Celebrating the ASEG's 50th anniversary from left: ***Mark Duffett, John Bishop, Anya Reading, David Rigg, Michael Roach, Gerrit Olivier, Wei Xuen Heng, Matthew Cracknell, Tara Martin*** *and* ***Catherine Duffett****.*

Western Australia

Greetings once again from Perth and WA. WA has just lifted most of its interstate bans, so I expect we'll be seeing (healthy) family and friends from the rest of Australia very soon. Also, since the 2021 AEGC in Brisbane is now a go, we are going ahead with our Student Award programme, which will fund two deserving local students to travel to Brisbane next year. More to follow.

In terms of activities, on November 10, **Rich Bartlett** of Shearwater gave a talk (webinar) on the practicalities of imaging through and around lava flows, "Pre-stack Depth Imaging: Challenges in exploration-scale volcanic geobody model-building in the Potiguar Basin, Brazil". Rich walked us through a case study detailing the concepts and methodology developed for the project, from start to finish.

On Friday the 13th our PESA-ASEG 33rd Annual Golf Classic was held in Secret Harbour, and was a definite success, with a very worthwhile link to a local charity. PESA-ASEG partnered again with our charity of choice, Parkerville Children and Youth Care. The charity is a 115-year-old non-for-profit organization, based here in WA. With one quarter of girls and one sixth of boys affected by child abuse and trauma by the age of 18, Parkerville has a huge role within our community; to raise awareness of child abuse, provide services for those in need and grow the network of support in providing a future for our WA children, young people, and families.

On November 27, due to the relaxing protocols, we will also had our first face-to-face technical night. Students from Curtin and UWA presented on their research and study topics. Our very first tech night since pre-COVID days!

And lastly, we are currently working out the final details of this year's combination AGM and 50th year ASEG Anniversary Party on December 17. Again, due to the corralling of local COVID, this will be a face-to-face event, with a bit of memorabilia for our WA members. Details forthcoming, of course!

Happy holidays, everyone, and keep staying safe!

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Australian Capital Territory

The ACT Branch celebrated the ASEG 50th Anniversary in early November at the Marquee, Lake Burley Griffin. **Tim Barton** gave a fantastic speech entitled "Brave Geophysics" outlining the nationwide impacts ACT ASEG geophysicists have made over 50 years. Tim generously spoke to the influence and leadership of the ACT Branch geophysicists, contractors, academia and Federal Government in its role in resource exploration over 50 years. Tim included our important cousins BMR/AGSO/Geoscience Australia, AuScope, ANU, ANSIR, State and Territory Geological Surveys and the CRCs (a short list here) AGCRC, pmdCRC, MinEx CRC.

The strong message Tim spoke to was that geophysicists are innovative and brave and we have impact, even in our "small" numbers. Contributions to national geophysical datasets and knowledge including: magnetics, radiometrics, gravity, airborne electromagnetics, AusLAMP, deep crustal seismic, passive seismic, offshore, integration (and decision making tools) to name a few highlights.

Tim Barton speaking at the ACT Branch's 50th anniversary celebration.

The ACT Branch celebrates the ASEG's 50th anniversary.

A toast was made to those who have passed away, we miss them.

Brave ASEG Members in attendance were: **Marina Costelloe** ACT Branch President, **Mike Barlow** ACT Branch Secretary, **Ross Costelloe** ACT Branch Treasurer, **Yvette PoudjomDjomani** Federal Executive, **Adam Kroll**, **Phillip Wynne**, **Grant Butler**, **Ian Hone**, **James Goodwin**, **Tim Barton**, **Yusen Ley-Cooper**, **Ron Hackney**, **Ken Horsfall**, **Richard Almond**, **John Peacock**, **Andrew Owen**, **Ned Stolz** and **Ted Lilley**.

In early December we will have our Christmas celebration. We wish all brave geophysicists a Merry Christmas and an awesome safe 2021.

Marina Costelloe
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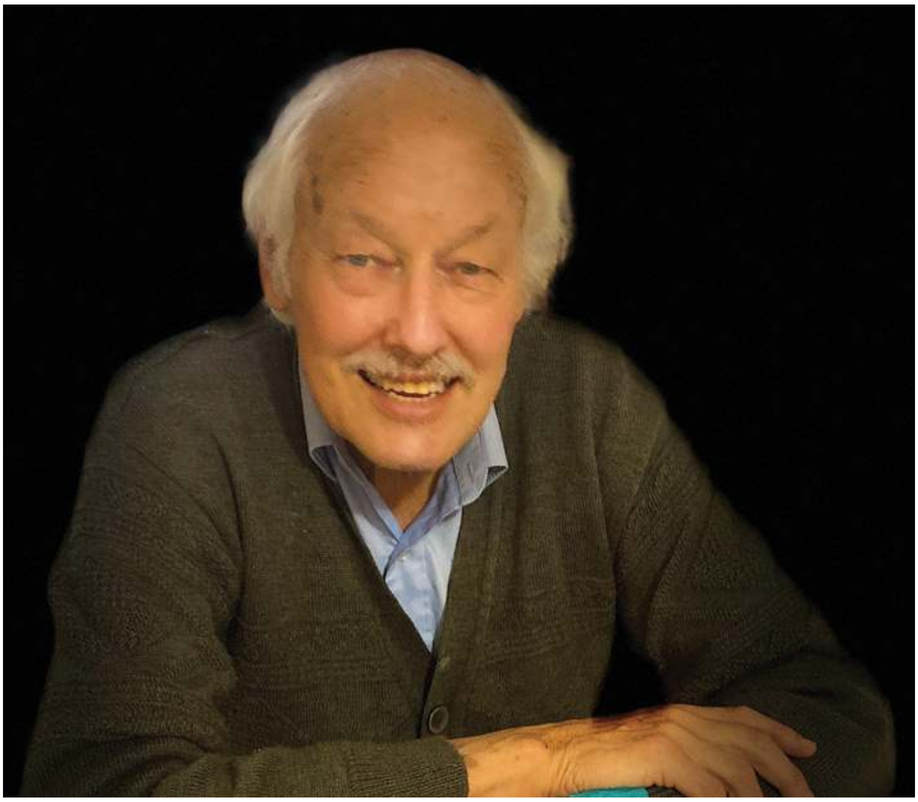
ASEG national calendar

Date	Branch	Event	Presenter	Time	Venue
ASEG Branch face-to-face meetings have resumed in SA, WA and Tasmania. All other State Branch meetings are on hold till further notice. Most branches are still hosting webinars. Registration is open to Members and non-members alike, and corporate partners and sponsors of state branches are acknowledged before each session. Recorded webinars are uploaded to the ASEG's website (https://www.aseg.org.au/aseg-videos), as well as to the ASEG's YouTube channel (https://bit.ly/2ZNglaZ). Please monitor the Events page on the ASEG website for information about upcoming webinars and other on-line events					
03 Dec	ACT	Christmas Party			Pomegranate Restaurant, Kingston
17 Dec	WA	AGM and ASEG 50th Anniversary Dinner	TBA		TBA

Vale: Patrick R Hillsdon (1947-2020)



Pat Hillsdon.

'Pat' as he was better known to all his colleagues and friends, died at his home in Bowral NSW on 11 September 2020.

Pat started his career in geophysics with BHP's Exploration Division, undertaking a wide variety of surveys throughout Australia. In 1979 he joined Tony Cram, the head of Engineering Computer Services (ECS) in Bowral, where he remained for 26 years. He was producing computer- drawn contour maps for ECS from the early 1980s.

For many years Pat led the technical but highly practical training programmes and workshops for ECS clients using MINEX software. His engagement with clients all over the world about their experience with MINEX led to the sharing of many new processing ideas and software innovations. Pat and Tony Cram led the Annual ECS Users Group Workshop at Bowral - it became a great annual geophysical processing think-tank that drove processing innovations. Pat's command of the accompanying social programmes was legendary.

Pat worked in Indonesia and Mozambique with SRK Consulting during 2005 and 2006 before a stroke led to his early retirement.

Pat served on the ASEG Federal Executive as 1st Vice-President from 1981-82, and was an active member and supporter of the NSW Branch for over 30 years. In particular, he served on the organising committees for ASEG conferences held at the Sydney Conference and Exhibition Centre, taking on the onerous role of Co-Chair or Coordinator of Exhibitions on no fewer than four occasions – 1991, 1997, 2004 and 2010. Pat had a strong understanding of the fine details of exhibition management, and always sought to ensure that exhibitors saw every ASEG event as both personally and commercially rewarding. He also maintained strong working relationships with the representatives of the Professional Conference Organisers to ensure smooth running of bookings and all logistic arrangements.

An ASEG Service Certificate for distinguished service by a Member to the ASEG, was awarded to Patrick at the ASEG conference in Melbourne in August 2013 for his valuable contributions over many years to ASEG Conferences.

Pat obtained a BSc in geophysics from University of Sydney in 1968. Prior to that he attended St Joseph's College at Hunters Hill where he played rugby, a game he then followed all his life. Since his marriage to his loving wife, Margaret, in 1972, their family grew to seven children and, so far, eight grandchildren. Pat loved and supported them all, despite tormenting them with his awful "dad jokes".

A survey of some of Pat's many ASEG colleagues and friends has brought out the following comments about him.

Ted Tyne noted that when Pat was at ECS, "I could always call him and ask for advice and guidance on how to do things with the ECS processing software". Dave Pratt noted that Pat never sought the spotlight or accolades because he has always been a private but welcoming member of our community. Steve Webster recalls "reliable Pat" who ensured that the exhibition booths were sold out early in the campaign. Phil Harman wrote "He was responsible for getting exploration into the computing age and got me back into geophysics after my first few years practising geology". Dave Isles said "Pat was a great bloke and very helpful to me as a young upstart". Doug Morrison: "I always enjoyed his company". And John Denham: "Pat always brightened up the atmosphere of any group he was in".

Pat Hillsdon and his wife Margaret in 1977.

Pat's friendly nature and love of life will be sorely missed by all who knew him.

Roger Henderson and those colleagues above.

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Vale: Michael John Sexton (1952-2020)

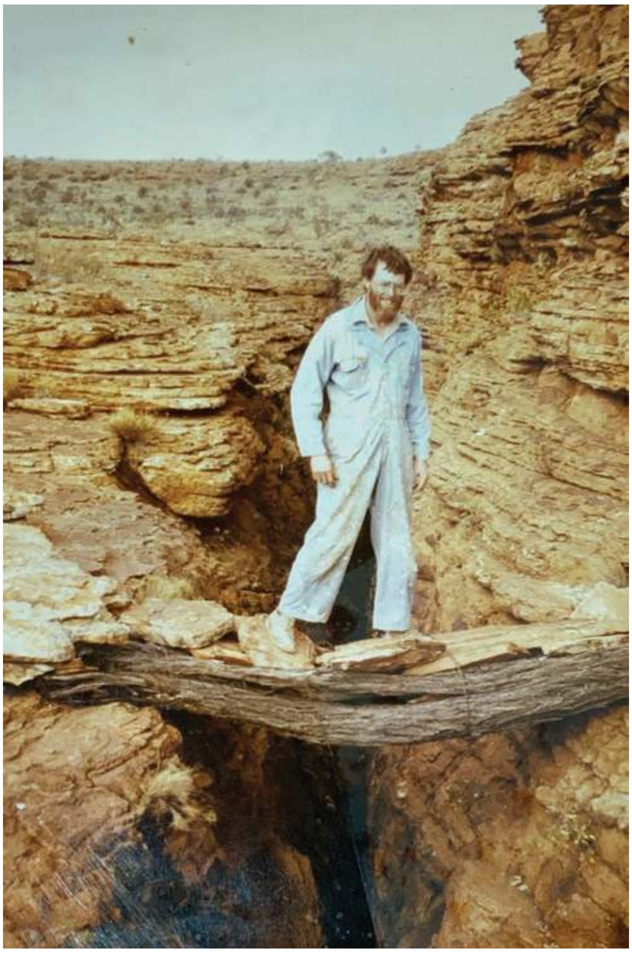
Mike Sexton

Michael John Sexton, known to his former BMR/AGSO/GA colleagues as Mike, sadly passed away in October this year. Mike had been diagnosed with multiple myeloma in October 2016. Despite years of treatment, including a stem cell transplant and ongoing chemotherapy, he acquired an infection his body could not overcome and he passed away on 25 October 2020, four years to the day of his diagnosis.

Mike grew up in Melbourne and attended St Bernard's College in Essendon, from where he matriculated in 1969. As with most people completing secondary education at the time, knowing what to do next was a pretty daunting task, and for many Melbournians you just went and got a job somewhere and got on with suburban life. However, after being encouraged to attend a Melbourne University Open Day, Mike had the good fortune to speak with a lecturer who posed two questions: 'Do you have good marks in physics and maths, and do you like the outdoors?' And so, a geophysicist was born!

After graduating from the University of Melbourne Mike received an offer of two postgraduate scholarships: one at the Imperial College London, and another at the University of Hawaii. Naturally adventure rather than prestige enticed him to the more exotic destination, where a more practical rather than theoretical approach to geophysics was taken. Here he undertook his first marine geoscience survey in the Pacific Ocean on the research vessel Kana Keoki. In order to join the cruise Mike had an interesting journey from Honolulu to Valparaiso in Chile, whilst carrying a suitcase full of contraband magazines for the crew. As a young 22 year old Australian, travelling alone with no Spanish, he faced many challenges before arriving at the port to board the ship, which was rather smaller than he had imagined. Thus began Mike's long association with marine geoscience. Mike never managed to finish his Masters because there were too many more adventures to be had.

Mike joined the Bureau of Mineral Resources (BMR) in 1976 after seeing an advertisement in the paper for a geophysicist's position in the Australian Antarctic Division. At the time he thought 'I am built for this job'. He went to Macquarie Island in 1977 and in 1978,



Mike Sexton in Kings Canyon during the 1985 BMR Central Australia seismic survey.

whilst conducting a First Order Regional Magnetic Survey, he criss-crossed the Australian continent in the familiar yellow BMR Land Rovers of the day. He returned to Mawson Base in Antarctica in 1979, which was one of the highlights of his career.

In 1980 he joined the Land Seismic section at the BMR. Between 1980 and 1982 Mike was geophysicist and then Party Leader on a series of surveys in SE Queensland. These surveys formed the basis for the first major deep crustal seismic profile, the Eromanga – Brisbane Transect, undertaken in Australia with coincident seismic refraction and deep sounding MT stations. When completed this survey was around 1000 km in length. Deep crustal land seismic surveying continued with the 1985 Central Australian transect survey and then, in 1988, the Canning Basin regional survey, which consisted of two transects across the entire basin and was the first to image the basement under the Fitzroy Trough. Mike was the Party Leader for this survey and, as the field season was longer than six months, Mike was able to have his young family with him for part of the time - no doubt a special experience for his children.

In 1990 Mike joined the Petroleum and Marine Division, working in marine seismic acquisition and processing. Also, in the early 1990s, Mike served on the ASEG ACT Committee in the position as Treasurer. In 1996 he went on his first AGSO marine survey with the *RV Rig Seismic*. This survey, for the Law of the Sea project, was conducted around New Caledonia and New Zealand. Despite being very prone to seasickness Mike loved going to sea. In 1998 he visited the seas to the east and west of North Korea. In 2002 he returned to Antarctica on a marine survey traversing the Southern Ocean from Hobart to Durban. He went on a number of smaller marine surveys after that, his last being the multichannel sub-bottom profiling component of the Petrel Sub-Basin Survey in 2012.

During his last few years at GA Mike compiled accurate meta –data, including navigation data, for all of the marine surveys in GA's possession. He also converted the survey data to the WGS84 datum, which meant the data could be easily interrogated and visualised using *kml* files in Google Earth. This made pin-pointing a marine survey's location extremely easy, and the system Mike developed is still being used in submissions to the National Offshore Petroleum Information Management System (NOPIMS). Mike also extended this system for use by marine biologists.

Mike was passionate about geophysics, and his career introduced him to people from all walks of life. From indigenous leaders and pastoralists to scientists from around the world, he enjoyed meeting and talking to people no matter who they were. Of particular note was his time working with North Korean scientists aboard the *Rig Seismic* where, despite language, cultural and political barriers, he spoke highly of GA staff setting the standard for diplomacy and friendship.

Mike very much saw GA not only as an organisation that could produce great science, but one that could do good for other people. He was always invested in the next generation, and taught so much to all those in his team and beyond. He was more focused on the job to be done and the needs of his colleagues rather than his own self advancement. Mike was an inexhaustible source of geophysical knowledge and could discuss meaningfully many other areas of science. He was a wizard of the most obscure techniques for the extraction of data from the most recalcitrant data sources. He was knowledgeable, warm and empathetic, and will be sorely missed by all those who knew and worked with him at GA.

Mike retired from GA after 38 years of service in 2014.

Compiled by Tim Barton (on behalf of the ACT ASEG Branch)

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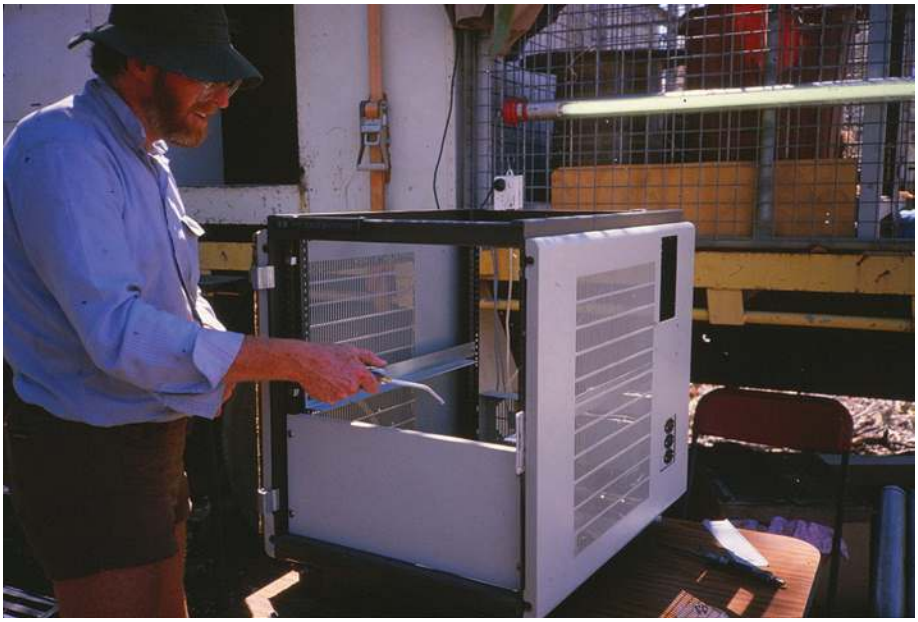

Mike Sexton "servicing" the HP1000 seismic processing computer with compressed air in camp during the 1988 BMR Canning Basin seismic survey. The computer had stopped working so Mike felt there was nothing to lose by stripping it down, removing all the cards and cleaning all the dust out before we sent it off to be repaired. However, when we re-assembled it and turned it on it didn't miss a beat for the rest of the survey!

Geoscience Australia: 2020 GADDS release and new national gravity grids

It goes without saying that it has been very challenging year for our industry, particularly for acquisition. Nevertheless, GA teams have continued to complete and release a vast array of high-quality technically-robust geophysical products; all geared towards better informed decision-making for Australian mineral, energy and groundwater resource development. With our key collaborative State Agency partners in Western Australia, South Australia, Northern Territory, Queensland, New South Wales, Victoria and Tasmania, we have seen the completion and delivery of AusAEM2, joint magnetic and gravity inversions across Northern Australia, solid progress on the WA airborne EM program (AusAEM20) and the updated national gravity compilations – just to name a few. The survey locations are shown in Figure 1 and information about the surveys can be found in the tables updating progress in the following section.

In this month's *Preview*, we are also pleased to announce the public release of the new GA geophysical archive data delivery system (GADDS) on December 9. The release will be held in conjunction with an ASEG webinar to highlight some of the new options and capabilities.

2020 GADDS release

The new GADDS, to be released on December 9, comes with:

- The release of approximately 360 new products, including various filtered derivatives of the national compilations
- An improved graphical/GIS – based interface, facilitating the choice of datasets
- Superior data selection mechanisms, including user-imported windows
- Enhanced pre-delivery filtering including data age, grid spacing, re-gridding algorithm, survey location and data type, to name just a few
- Ongoing development into 2021, with the capability to deliver airborne EM, inversions and other multi-dimensional datasets

New national gravity grids

Geoscience Australia was pleased to release the 2019 national gravity compilation on October 7. The release represented the first time ground gravity, airborne gravity/gravity gradiometry, satellite and marine gravity observations have been combined to produce a series of national gravity grids covering an area more than twice the size of the country (see Figure 2). GA's electronic catalogue provides a full suite of these grids, including processing notes and

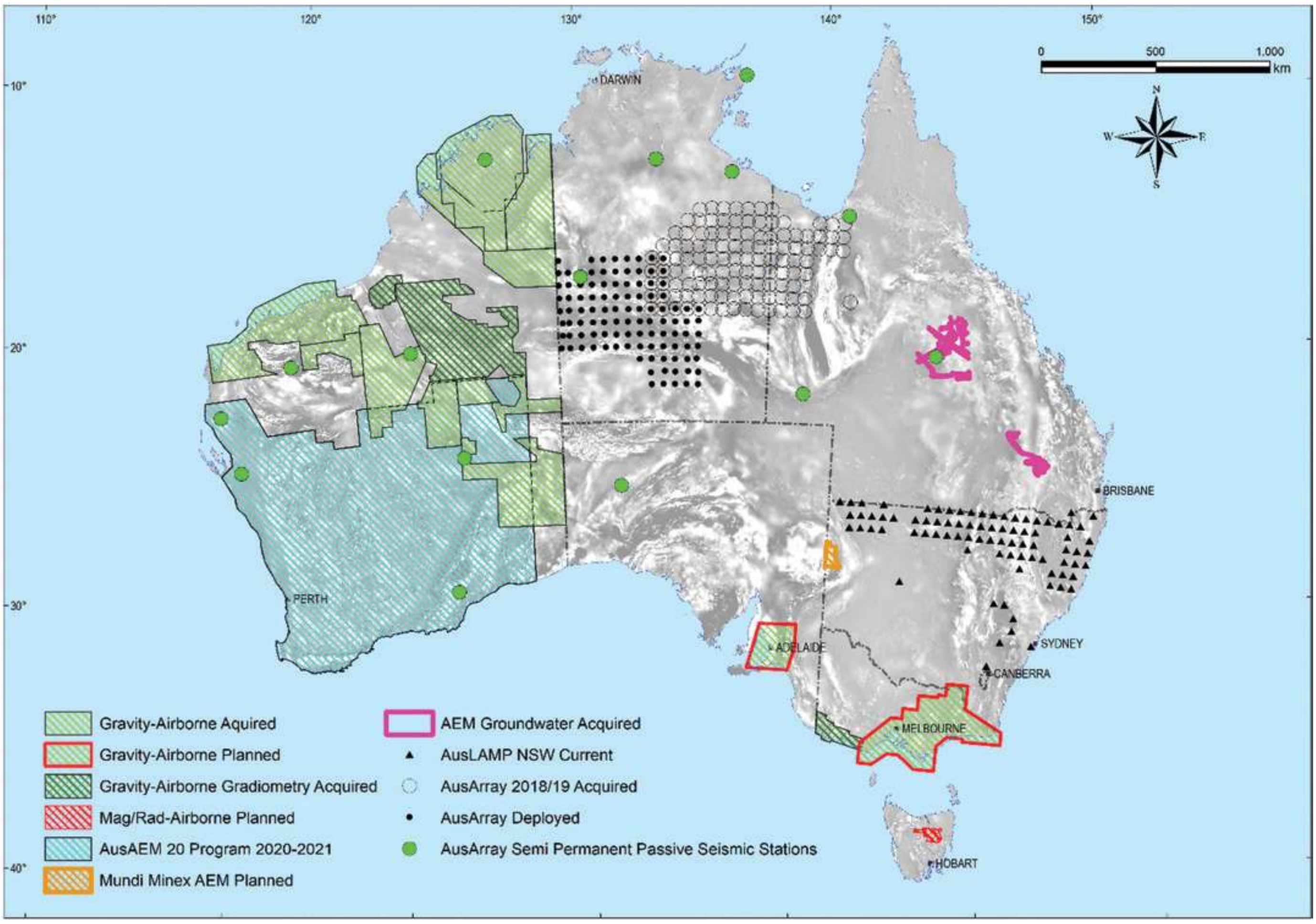

Figure 1. *2019 -2021 geophysical surveys – in progress, planned or still for release by Geoscience Australia in collaboration with State and Territory agencies.*

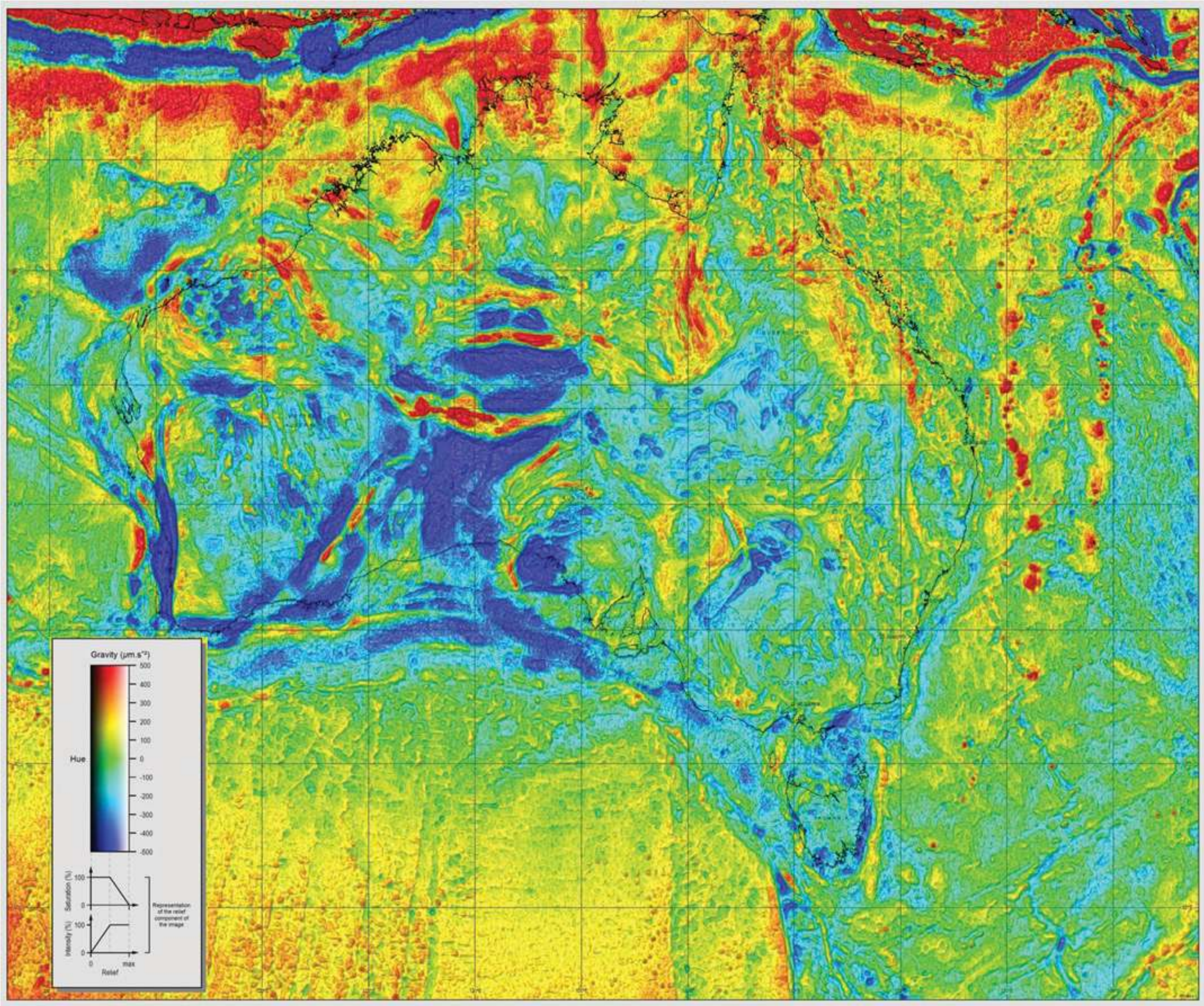

Figure 2. *B-series de-trended global isotatic residual gravity map of Australia, 2019 (Lane et al 2020).*

intermediate to final products (see http://pid.geoscience.gov.au/dataset/ga/133023).

The catalogue summary explains:

"The 2019 Australian National Gravity Grids are two sets of grids (the "A" and "B" Series) covering the continent of Australia and surrounding region (108 to 164 degrees East Longitude, -48 to -8 degrees North Latitude). Each of the two series consist of five grids - three gravity grids and two supplementary grids defining the observation surface of the gravity grids. The gravity grids provide values of Free Air Anomaly (FAA), Complete Bouguer Anomaly (CBA), and De-trended Global Isostatic Residual (DGIR). The first of the supplementary grids defines the height of the observation surface with respect to the geoid vertical datum, whilst the second supplementary grid defines the height of the observation surface with respect to an ellipsoid vertical datum (i.e., the GDA94 datum which employs the GRS80 ellipsoid). The A Series grids were produced from a combination of ground gravity data for continental Australia and data from a global gravity grid for the surrounding region. The observation surface was the ground or ocean surface. The B Series grids used the same data as the A Series grids with the addition of data from twelve airborne gravity surveys and two airborne gravity gradiometer surveys. The observation surface for the B Series grids was a smooth drape surface with a minimum surface clearance of 250 m." (Lane *et al* 2020).

The above data release was accompanied by a public seminar covering the basics of gravity correction, through to the methodology and applications of the new continent-wide dataset (see https://youtu.be/3CyqrqBM0xg). Also released was the updated portal to support the Australian Fundamental Gravity Network (AFGN), the series of absolute gravity stations across the country used to level the numerous individual and relative gravity surveys that make up the compilation and provide calibration points for industry surveys (https://portal.ga.gov.au/persona/afgn). The new portal gives unparalleled access to station information, locality and condition (see Figure 3).

Together, the national coverage and the AFGN represent one of the most detailed gravity coverages in the world. They provide an unprecedented picture of Australia's gravity field that will help map

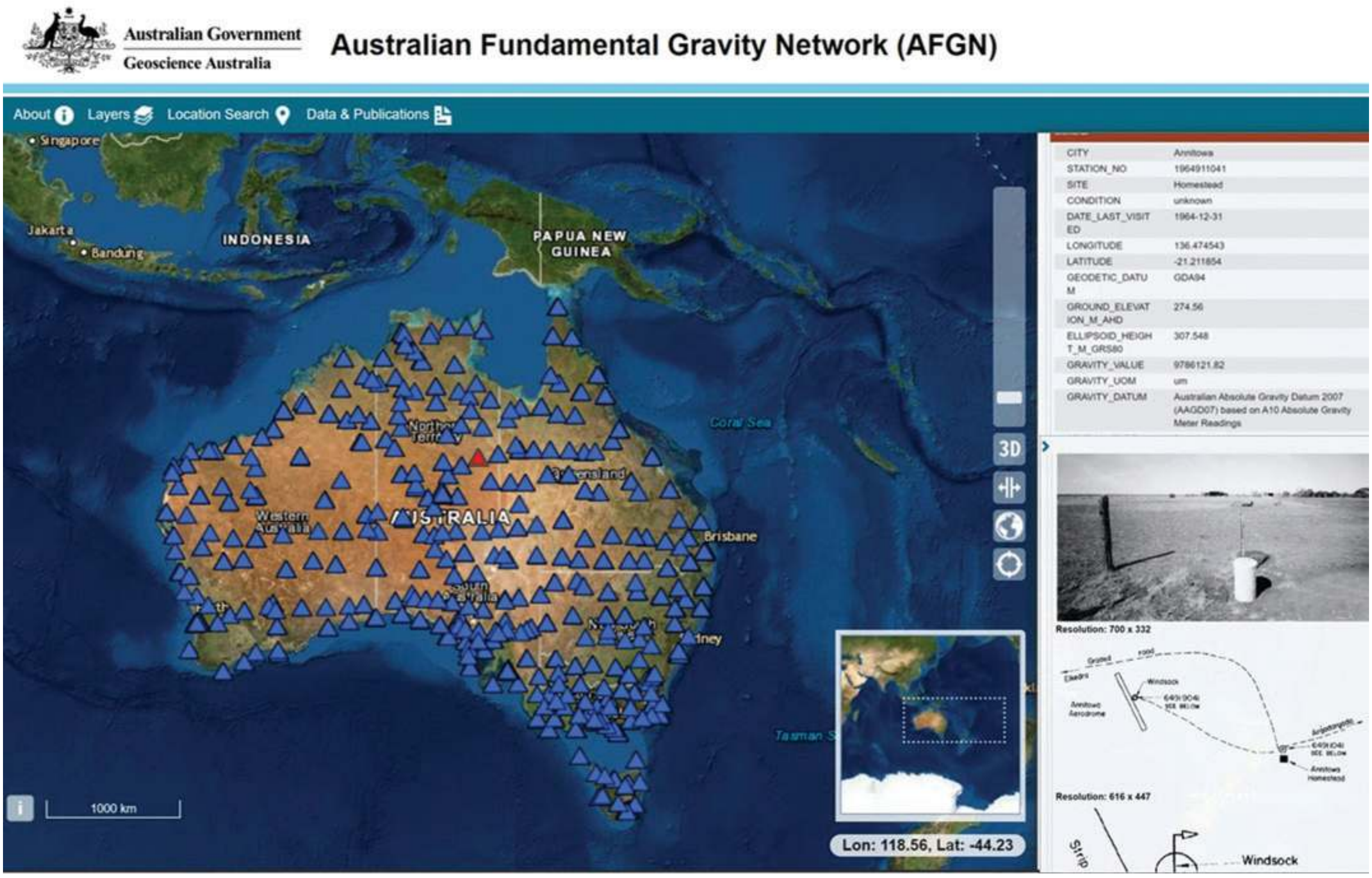

Figure 3. *The Australian Fundamental Gravity Network portal. Station details (right, shown for the station marked in red) convey a wealth of information to help identify the location.*

geology and aid exploration for energy and mineral deposits into the future.

Reference

Lane, R. J. L., Wynne, P. E., Poudjom Djomani, Y. H., Stratford, W. R., Barretto, J. A. and Caratori Tontini, F. 2020. 2019 Australian national gravity grids explanatory notes. Record 2020/22. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/Record.2020.022.

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Update on geophysical survey progress from Geoscience Australia and the Geological Surveys of Western Australia, South Australia, Northern Territory, Queensland, New South Wales, Victoria and Tasmania (information current on 11 November 2020).

Further information about these surveys is available from Mike Barlow Mike.Barlow@ga.gov.au (02) 6249 9275 or Marina Costelloe Marina.Costelloe@ga.gov.au (02) 6249 9347.

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Line spacing Terrain clearance Line direction	Area (km^2)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Tasmanian Tiers	MRT	GA	MAGSPEC	Feb 2021	Up to an estimated 25 000	200 m 60 m N–S or E–W	4300	Before end of 2021	TBA	See Figure 1 in previous section (GA News)	TBA
Cobar	GSNSW	GA	TBA	TBA	46 000	200 m	9200	Before end of 2021	TBA	See Figure 1 in previous section (GA News)	TBA

TBA, to be advised.

Table 2. Ground and airborne gravity surveys

Survey name	Client	Project management	Contractor	Start survey	Line km/ no. of stations	Line spacing/ station spacing	Area (km^2)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Melbourne, Eastern Victoria, South Australia	AusScope	GA	TBA	~Dec 2020	137 000	1–5 km	146 000	TBA	TBA	See Figure 1 in previous section (GA news)	TBA
Kidson Sub-basin	GSWA	GA	CGG Aviation	14 Jul 2017	72 933	2500 m	155 000	3 May 2018	15 Oct 2018	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	Set for release before Jun 2021
Little Sandy Desert W and E Blocks	GSWA	GA	Sander Geophysics	W Block: 27 Apr 2018 E Block: 18 Jul 2018	52 090	2500 m	129 400	W Block: 3 Jun 2018 E Block: 2 Sep 2018	Received by Jul 2019	195: Aug 2018 p. 17	Set for release before Jun 2021
Kimberley Basin	GSWA	GA	Sander Geophysics	4 Jun 2018	61 960	2500 m	153 400	15 Jul 2018	Received by Jul 2019	195: Aug 2018 p. 17	Set for release before Jun 2021
Warburton-Great Victoria Desert	GSWA	GA	Sander Geophysics	Warb: 14 Jul 2018 GVD: 27 Jul 2018	62 500	2500 m	153 300	Warb: 31 Jul 2018 GVD: 3 Oct 2018	Received by Jul 2019	195: Aug 2018 p. 17	Set for release before Jun 2021
Pilbara	GSWA	GA	Sander Geophysics	23 Apr 2019	69 019	2500 m	170 041	18 Jun 2019	Final data received Aug 2019	See Figure 1 in previous section (GA News)	Set for release before Jun 2021
SE Lachlan	GSNSW/ GSV	GA	Atlas Geophysics	May 2019	303.5 km with 762 stations	3 regional traverses	Traverses	Jun 2019	Jul 2019	See Figure 1 in previous section (GA News)	Set for incorporation into National database by Dec 2020

TBA, to be advised

Table 3. Airborne electromagnetic surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Mundi	GSNSW	GA	NRG	Feb 2021	1900	2.5	~ 5000	May 2021	TBA	See Figure 1 in previous section (GA News)	TBA
Surat-Galilee Basins QLD	GA	GA	SkyTEM Australia	2 Jul 2017	4627	Variable	57 366	23 Jul 2017	Nov 2017	188: Jun 2017 p. 21	TBA
AusAEM20	GSWA	GA	CGG & SkyTEM	Aug 2020	62 000	20 km	1 240 000	Dec 21	TBA	See Figure 1 in previous section (GA News)	TBA. Survey in production

TBA, to be advised

Table 4. Magnetotelluric (MT) surveys

Location	Client	State	Survey name	Total number of MT stations deployed	Spacing	Technique	Comments
Northern Australia	GA	Qld/NT	Exploring for the Future – AusLAMP	366 stations deployed in 2016–19	50 km	Long period MT	The survey covers areas of NT and Qld. Data to be released early 2021.
AusLAMP NSW	GSNSW/ GA	NSW	AusLAMP NSW	224 stations deployed in 2016-19	50 km	Long period MT	Covering the state of NSW. Acquisition ongoing. Phase 1 data release: http://pid.geoscience.gov.au/dataset/ga/132148.
Southeast Lachlan	GSV/GSNSW/ GA	Vic/ NSW	SE Lachlan	Deployment planned to commence early/mid-2021	~4 km	AMT and BBMT	~160 stations in the Southeast Lachlan. Acquisition delayed due to COVID-19 travel restrictions.
AusLAMP TAS	GA	TAS	King Island MT	4 sites completed	<20 km	Long period MT	Covering King Island. Acquisition completed.
Cloncurry	GSQ/GA	QLD	Cloncurry Extension	500 stations have been acquired	2 km	AMT and BBMT	Data acquisition complete.
Spencer Gulf	GA/GSSA/ UofA/ AuScope	SA	Offshore marine MT	12 stations completed	10 km	BBMT	This is a pilot project for marine MT survey https://www.auscope.org.au/news-features/auslamp-marine-01

TBA, to be advised

Table 5. Seismic reflection surveys

Location	Client	State	Survey name	Line km	Geophone interval	VP/SP interval	Record length	Technique	Comments
Eastern Goldfields	GSWA	WA	L132 1991 Eastern Goldfields Seismic	260	40 m	160 m	20 s	2D deep crustal seismic explosive reflection seismic	GSWA and GA signed an MoU to reprocess legacy explosive data acquired by GA's predecessor agency, the Bureau of Mineral Resources in 1991. GSWA contracted Velseis Processing Pty Ltd. to reprocess these data set using modern processing techniques, which were unavailable at the time of the original data acquisition and initial processing. GA will provide Quality Control and monitoring of the data reprocessing; and provide ad hoc advice for the project. The improved seismic data will complement other geoscience datasets in GSWA's Eastern Goldfields Reinterpretation Project, and GSWA's Accelerated Geoscience Program. The work is funded by the WA Government's Exploration Incentive Scheme.

(*Continued*)

Table 5. Seismic reflection surveys (*Continued*)

Location	Client	State	Survey name	Line km	Geophone interval	VP/SP interval	Record length	Technique	Comments
South East Lachlan	GSV/ GSNSW/ GA/ AuScope	Vic/NSW	SE Lachlan	629	10 m	40 m	20 s	2D deep crustal seismic reflection	The survey covers the Southeast Lachlan Orogen crossing the Victoria–New South Wales border. Data acquisition was completed in April 2018. Raw and processed seismic data are available from Geoscience Australia and state geological surveys: http://pid.geoscience.gov.au/dataset/ga/122684
Kidson	GA/ GSWA	WA	Kidson Sub-basin	872	20 m	40 m	20 s	2D deep crustal seismic reflection	The survey is within the Kidson sub-basin of the Canning Basin and extends across the Paterson Orogen and onto the eastern margin of the Pilbara Craton. Data acquisition was completed in Aug 2018. Raw and processed seismic data are available from Geoscience Australia and the Geological Survey of Western Australia: http://pid.geoscience.gov.au/dataset/ga/128284
Barkly/ Camooweal	GA/NTGS	NT	Barkly Sub-basin	813	10 m	30 m	20 s	2D deep crustal seismic reflection	The aim of the project was to acquire 2D land reflection seismic data to image basin and basement structure in the Barkly region in the Northern Territory. Data acquisition was completed in Nov 2019. Raw and processed seismic data are available via Geoscience Australia and the Northern Territory Geological Survey: http://pid.geoscience.gov.au/dataset/ga/132890

Table 6. Passive seismic surveys

Location	Client	State	Survey name	Total number of stations deployed	Spacing	Technique	Comments
Northern Australia	GA	Qld/NT	AusArray	About 135 broad-band seismic stations	50 km	Broad-band 1 year observations	The survey covers the area between Tanami, Tennant Creek, Uluru and the Western Australia border. The first public release of transportable array data is expected by the end 2020. See: http://www.ga.gov.au/eftf/minerals/nawa/ausarray Various applications of AusArray data are described in the following Exploring for the Future extended abstracts: http://pid.geoscience.gov.au/dataset/ga/135284 http://pid.geoscience.gov.au/dataset/ga/135130 http://pid.geoscience.gov.au/dataset/ga/135179 http://pid.geoscience.gov.au/dataset/ga/134501
Northern Australia	GA	Various	AusArray, semi-permanent	12 high-sensitivity broad-band seismic stations	~1000 km	Broad-band 4 years observations	Semi-permanent seismic stations provide a back-bone for movable deployments and complement the Australian National Seismological Network (ANSN) operated by GA, ensuring continuity of seismic data for lithospheric imaging and quality control. Associated data can be accessed through http://www.iris.edu" www.iris.edu

Geological Survey of South Australia: SAEMC 2020, AusArray SA, Central Delamerian Broadband MT transect

SAEMC 2020 cancelled

The South Australian Exploration and Mining Conference (SAEMC) has been held annually near the end of the year since 2004. It is preferably held on Saint Barbara's Day – St Barbara being the patron saint of miners – on the first Friday in December. This year it was scheduled for November 27.

The conference is designed to provide an opportunity for active South Australian mineral explorers and miners to present succinct technical updates to their peers of activities on their flagship mines and exploration projects. Participants gain a comprehensive appreciation of the diverse activities in South Australia and gain ideas from each other, which collectively improves our chances of mineral discovery and improved mining developments.

The conference is organised by a voluntary committee representing four local branches of professional associations:

- Australian Institute of Geoscientists (AIG)
- Australian Society of Exploration Geophysicists (ASEG)
- Australasian Institute of Mining and Metallurgy (AusIMM)
- Geological Society of Australia (GSA)
- Representatives from the South Australian Department for Energy and Mining (DEM) and University of Adelaide have also joined the committee.

Conference registration fees are kept low to encourage a broad attendance and the modest surplus is invested in student-related activities by the local professional associations.

Unfortunately, a COVID-19 outbreak on November 16 sent Adelaide into lockdown. The committee explored the possibility of holding a purely digital conference, but concluded that this was untenable in the short time-frame available, specifically taking into account our sponsors and exhibitors, who would not get the same value for money from a purely online event. SAEMC's key strength has always been the networking opportunities the event provides, and the ability for all attendees to see and hear what is going on in the SA mining and exploration space, something that cannot be achieved as effectively through an online-only platform. The event was, therefore, cancelled for 2020, and the committee is organising refunds for all delegates, sponsors and exhibitors.

Thank you everyone for your support and understanding, and we look forward to seeing you at SAEMC 2021!

Philip Heath
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Department for Energy and Mines Executive Director for Minerals Alex Blood presents SAEMC 2019

AusArray SA passive seismic array

It has been established that the locations of giant magmatic- and sediment-hosted ore deposits show a correlation with craton margins (e.g. Griffin *et al* 2013, Hoggard *et al* 2020). Thus, although the specific geological ingredients and processes responsible for ore generation remain enigmatic, favourable regions for exploration can nevertheless be identified via the craton margin proxy.

From a seismic perspective, the thick, cold and geochemically-depleted lithospheric mantle keels of cratons exhibit a readily discernible signature, facilitating their delineation in 3D. This geophysical delineation is especially pertinent in places like South Australia where extensive cover largely precludes direct geological sampling. Motivated by this, the GSSA deployed the AusArray SA broadband seismic array across the eastern-central Gawler Craton over two weeks in October 2020 (Figures 1 and 2). The 38-station array is designed to acquire seismic data at the same station spacing (~0.5°) as the AusLAMP magnetotelluric (MT) array.

In conjunction with partners at ANU (lead by Dr Caroline Eakin), the composite AusArray SA and Lake Eyre Basin arrays will shed light on the 3D seismic structure of the eastern Gawler Craton and its margins. Data from the permanent stations of the Australian National Seismic Network and Australian Seismometers in Schools program, and from preceding temporary arrays, will also be leveraged (Figure 1). A host of passive seismic modelling techniques will be applied to map the 3D-structure of the eastern Gawler Craton from the upper crust to the lithosphere-

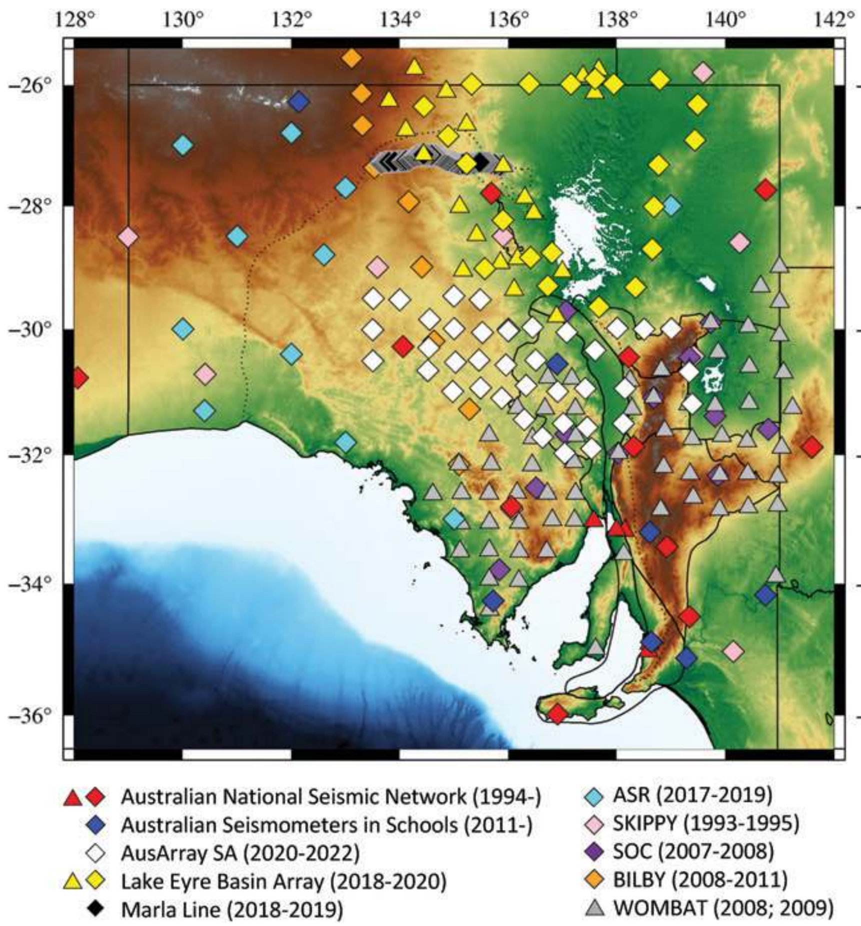

Figure 1. *Past and present passive seismic arrays in South Australia.*

Figure 2. *An AusArray SA seismic station on Yudnapinna Station.*

asthenosphere boundary (e.g., body and surface wave tomography, variably using teleseismic earthquakes, local earthquakes and the ambient noise field for illumination; receiver functions; noise autocorrelation; shear wave splitting; seismicity mapping). Furthermore, the contrasting sensitivities of seismic and MT data to factors including temperature, composition, fluids and melt will facilitate a more robust identification of primary indicators of mineral prospectivity such as metasomatism and fluid pathways.

The AusArray SA stations will record passive seismic data continuously for 18 months in order to record sufficient earthquake and noise data for modelling purposes. Service runs will be at six month intervals. The raw seismic data will be housed on the AusPass passive seismic data server and the derived model outputs will be made available on SARIG.

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Central Delamerian Broadband MT transect

In September (and again in October due to surprisingly high rainfall!) a team from GSSA along with Goran Boren, University of Adelaide, acquired the Central Delamerian broadband MT transect consisting of 63 stations extending 100 km along a southeast profile from Manna Hill, South Australia. Most of the Lemi instruments used were from the AuScope pool of instruments, supplementing the GSSA-owned pool of Lemi recorders (Figure 1). The survey was designed to traverse the transition between the eastern hinge of the Nackara Arc into the less understood rocks hidden beneath the Murray Basin sediments across the Loch Lily Kars Belt (Figure 2). Inversion of the data using 2D and 3D inversion methods is underway and results were presented at GSSA's online Discovery Day. All videos from the day can be found on the Department for Energy and Mining YouTube channel.

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Figure 1. *An induction coil to measure the magnetic field, with Anabama Hill in the background.*

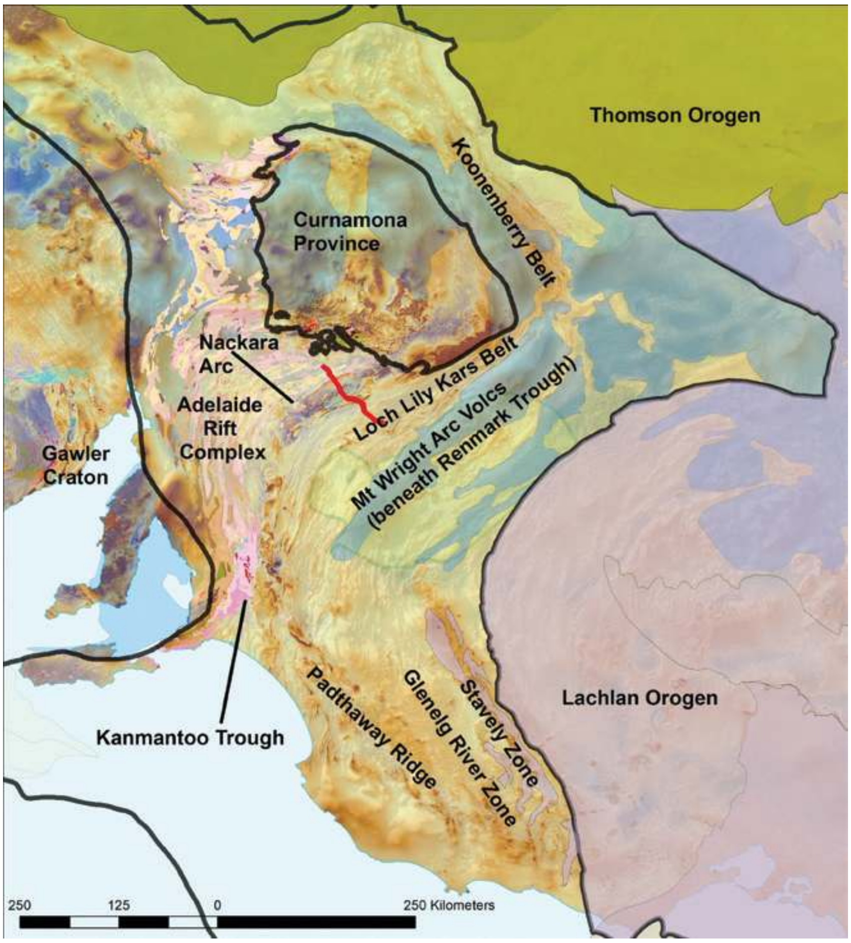

Figure 2. *A map showing the outline of Delamerian Orogen in black along with the Curnamona Province. The MT survey line is in red.*

Geological Survey of Western Australia: AusAEM20 - WA progress update

The Australian Airborne Electromagnetic Survey (AusAEM20) has the objective to acquire airborne electromagnetic data at 20 km or closer line spacing across the entire Australian continent (*Preview*, 2020:**205**, 18, doi: 10.1080/14432471.2020.1751781).

The AusAEM20 - WA program, funded by the Western Australian Government's Exploration Incentive Scheme, is contributing to this national objective by flying those parts of Western Australia that were not covered by Geoscience Australia's Exploring for the Future (EFTF) AusAEM Northern Australia survey program, 2017–19.

AusAEM20 - WA Phase 1 for the 2020–21 financial year began in August 2020 with survey contracts awarded to CGG Aviation Australia Pty Ltd for the coverage of the East Yilgarn – Fraser Range area, and to SkyTEM Australia Pty Ltd for the Southwest–Albany area (*Preview*, 2020:**207**, 23, doi: 10.1080/14432471.2020.1800395).

Both contracts were extended in October 2020 to increase coverage over almost all of the southern half of Western Australia (Figure 1). Surveying of the East Yilgarn – Fraser Range block with the CGG TEMPEST system is complete, and survey of the "TEMPEST Phase 2" area commenced in October. SkyTEM also commenced flying over the Southwest–Albany block in October.

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

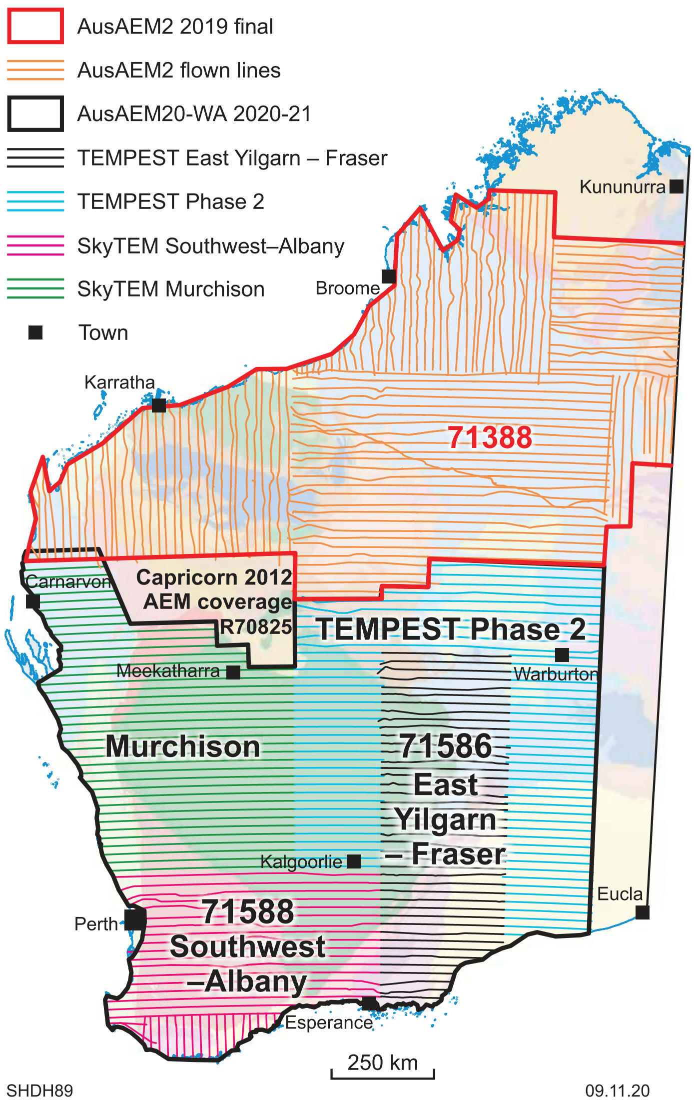

Figure 1. *Location of AusAEM20 - WA extended survey areas 2020–21.*

The ASEG in social media

Have you liked/followed/subscribed to our social media channels? We regularly share relevant geoscience articles, events, opportunities and lots more. Subscribe to our Youtube channel for recorded webinars and other content.

Email our Communications Chair Millicent Crowe at Communications@aseg.org.au for suggestions for our social media channels.

Facebook: https://www.facebook.com/AustralianSocietyOfExplorationGeophysicists

LinkedIn company page: https://www.linkedin.com/company/australian-society-of-exploration-geophysicists/

Twitter: https://twitter.com/ASEG_news

YouTube: https://www.youtube.com/channel/UCNvsVEu1pVw_BdYOyi2avLg

Instagram: https://www.instagram.com/aseg_news/

Geological Survey of Queensland: Newly released airborne data and MT survey in the North West Mineral Province

The Geological Survey of Queensland has recently completed two new geophysical programmes in the Mount Isa Region. The Central Isa airborne magnetic and radiometric survey was released in late September, and data for the Cloncurry Extension Magnetotelluric (MT) survey will be released by the end of the year.

The Central Isa airborne magnetic and radiometric survey is the fourth in a series of higher resolution regional surveys covering parts of the Mount Isa region at line intervals of 100 m or lower. The survey consists of 88 000 line km of data that was acquired at 100 m line spacing with a 60 m terrain clearance and provides new high-resolution coverage in the area to the north and east of Mount Isa. The logistics report, DEM, magnetic and radiometric geodatabase as well as a collection of grid files (TMI, RTP, 1VD, K/Th/U/Dose) and GeoTIFF files are all available for download from the new GSQ Open Data Portal (https://geoscience.data.qld.gov.au/magnetic/mg001391). We will be covering the new open data portal and how to find data in a future *Preview* article.

The Central Isa survey adjoins other recent high-resolution regional survey conducted by the GSQ including the Cloncurry North (2018), Cloncurry South (2017) and Mary Kathleen (2017). These new surveys show a marked improvement in data quality compared to the previous Mount Isa Mines Open Range survey acquired in the early 1990s. The data for these surveys, and some large open-file exploration surveys, have been used to form a large high-resolution merge.

The Mount Isa Airborne Data Merge 2020 covers ~30 000 km^2 of the North West Mineral Province (Figure 1). The merge covers the region from Mount Isa in the west, well past Cloncurry in the east, and runs from Cannington Mine in the south up to near Capricorn Copper in the north. The merging of the grids was performed in Intrepid GridMerge using the gridded data from seven different airborne surveys. As a first step all input grids were re-projected to GDA2020 Map Grid of Australia Zone 54 (ESPG: 7854). During the merge the 1990-1992 MIM Open Range survey was used as a base map in the merging processes, while the other grids were shifted, scaled and surface adjusted to ensure a neat merge. As the original grids have been scaled and adjusted to facilitate this merging process, it is suggested that any highly detailed interpretation be performed on the original grid products rather than the regional merge.

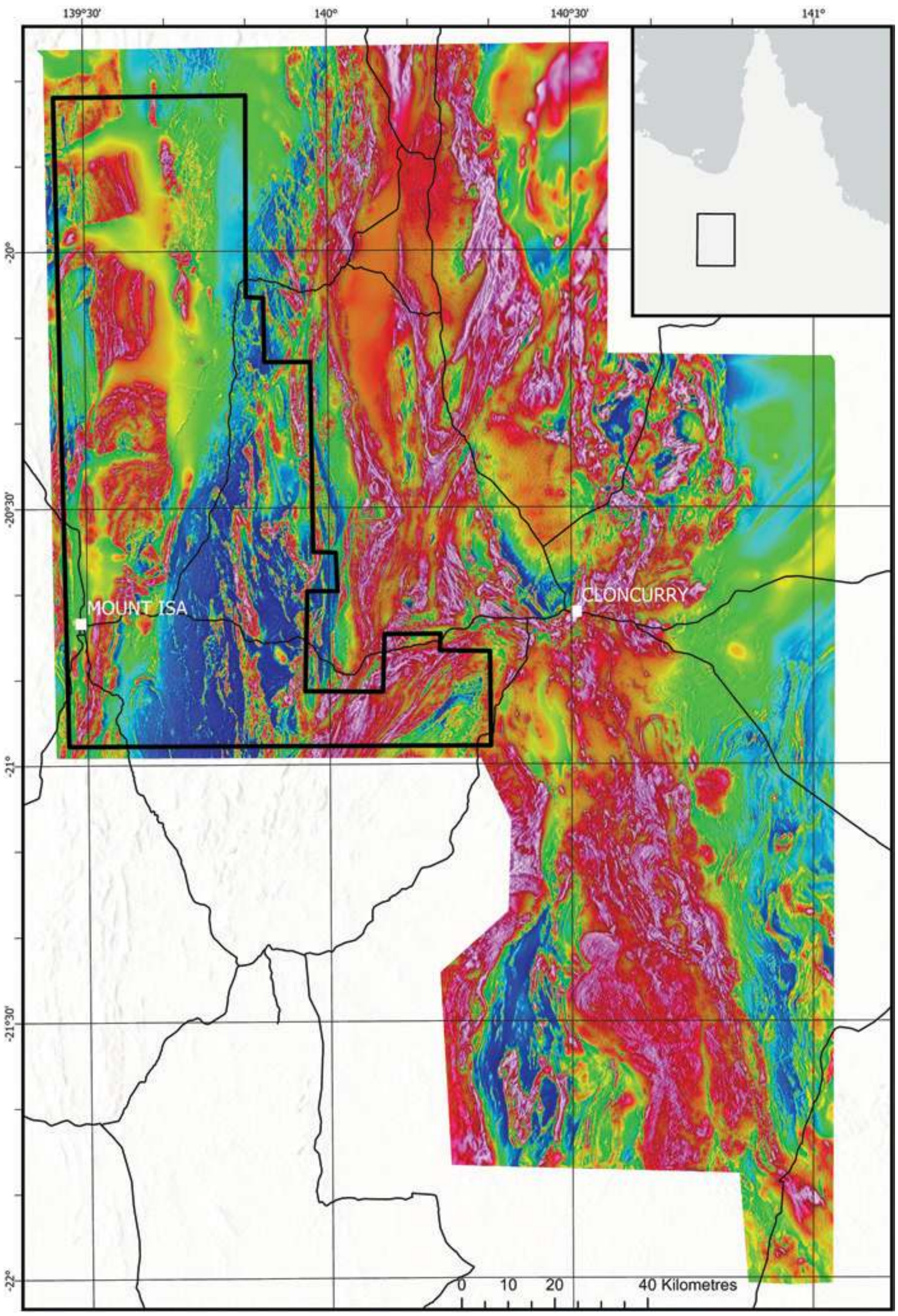

Figure1. *Reduced to pole magnetic intensity grid (overlain with first vertical derivate greyscale) of Mount Isa Airborne Data Merge 2020 product. The extents of the newly released Central Isa Airborne survey are shown in black outline.*

The dataset contains a set of merged ers grid files (TMI, RTP, 1VD, K/Th/U/Dose/DEM) and GeoTIFF files and is available for download through the open data portal (https://geoscience.data.qld.gov.au/dataset/ds000057).

The Cloncurry Extension MT Survey is located north of the township of Cloncurry, in the Eastern Succession of the Mount Isa Province (Figure 2). The survey expands MT coverage to the north and west of the 2016 Cloncurry MT survey.

The survey was funded by the Queensland Government's Strategic Resources Exploration Programme, which aims to support discovery of mineral deposits in the Mount Isa Region.

The survey area is predominantly covered by conductive sediments of the Carpentaria Basin. The cover thickness ranges from 0 m in the extreme south west of the survey, to over 345 m in the north.

Acquisition started in August 2019 and was completed in late October 2020 by Zonge Engineering and Research Organization. Data were collected at 2 km station spacing on a regular grid with a target bandwidth of 10^{-4} – 10^{3} s. Instruments were left recording for a minimum of 24 hours unless disturbed by animals. The low signal strength posed a significant impediment for acquiring data to 1000 s, even with the 24-hour deployments. Almost all sites have data to 100 s, with longer period data at numerous sites. Data are due for release by the end of December and will be available on the open data portal.

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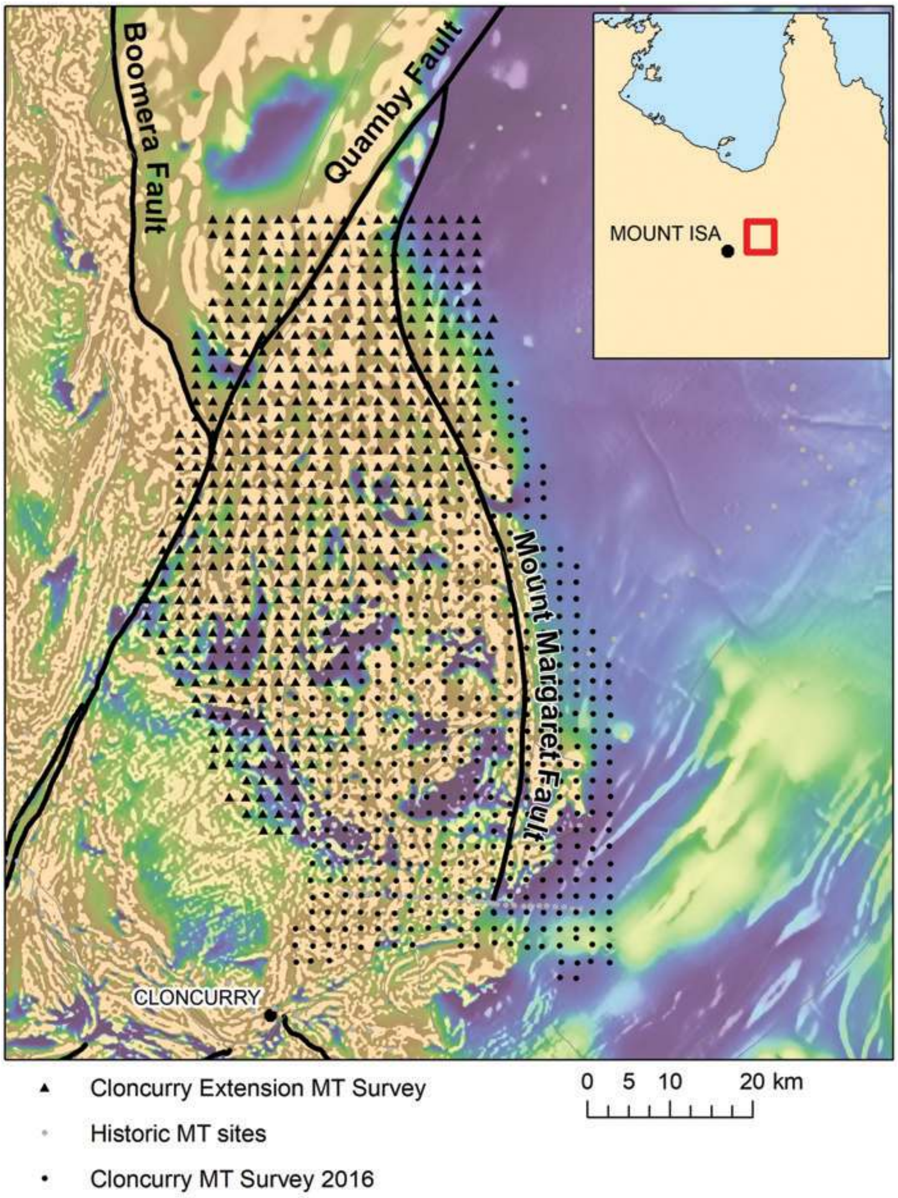

Figure 2. *Location of the Cloncurry Extension MT survey over a composite TMI and TMI 1VD magnetic image.*

Canberra observed

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Cathy Foley appointed Australia's 9th Chief Scientist

Cathy Foley AO, PSM, FAA, FTSE has been appointed Australia's 9th Chief Scientist, taking over from Alan Finkel when his five-year tenure ends in December 2020.

Science is having an increasingly important impact in framing several policy areas that are the Australian Government's responsibility, and the role of the Chief Scientist is now more complex because of the interaction between science and politics.

Cathy Foley been around long enough to deal with the politics associated with the job. She has worked with CSIRO in several roles since 1985, and was appointed CSIRO's Chief Scientist in 2018. With this experience she should do well as Australia's Chief Scientist.

According to her CSIRO biography, Cathy has a link with geophysics through her "contributions to the understanding of superconducting materials and to the development of devices using superconductors to detect magnetic fields and locate valuable deposits of minerals". This work led to the development of very sensitive magnetometers, which are still used today.

As well as her post-nominal awards, Cathy has obtained outstanding success outside of her research work. She won the NSW Telstra Business Women of the year award in 2009, the Agenda Setter of the Year in the Women's Agenda Leadership Awards in 2019, the Australian Institute of Physics Medal for Outstanding Service to Physics in 2016, and the Clunies Ross Medal of the Australian Academy of Technological Science and Engineering in 2015. And that's only some of her achievements!

I suspect winning all these awards will have been easy compared to dealing with the politics of issues such as biodiversity, water management, climate change and renewable energy. Even her statement to reporters, after her appointment was announced, could cause stirrings from the government's back bench when she said:

"I think everyone agrees climate change is something that has to be dealt with and it's not something which has a single solution."

Most people would agree that climate change has to be dealt with, but with Craig Kelly and George Christensen as elected representatives in the Parliament you shouldn't say everyone.

Alan Finkel the previous Chief Scientist caused a stir when he advocated using gas as an interim short-term solution to any short-term energy supply problems. So, it will be interesting to see how Cathy handles the difficult issues.

As an addendum; the Chief Scientist reports to the Minister for Industry, Science and Technology, and also works closely with the Prime Minister both in her role as Executive Officer of the National Science and Technology Council and in order to provide detailed scientific advice. She will have a staff of 15.

Cathy Foley

COVID-19 - just a blip in the share market?

The economic effect of the COVID-19 pandemic has produced some bizarre results. Just as millions of people around the world lost their jobs or were struggling to get by on government handouts, a report by Swiss bank UBS found that billionaires had increased their wealth by more than a quarter (27.5%) at the height of the crisis from April to July 2020. They simply bought into the share markets at that time and were rewarded accordingly (see *The Guardian* 9 October 2020). There are now reportedly approximately 2200 billionaires worth a total of $10 trillion.

It is easy to be wise after the event but, look at the COVID-19 blip in Figure 1. If you bought at the bottom of the blip,

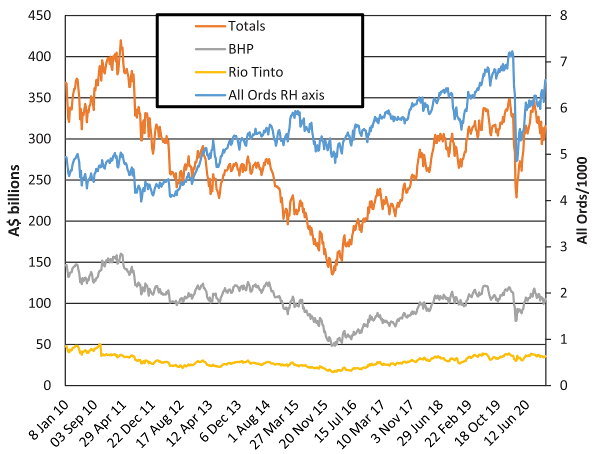


Figure 1. *All Ords on ASX (RH axis) and total market capital of listed resources companies in the top 150 companies on the ASX between 2010 and 2020 (LH axis).*

you would be doing very well now. And of course, the very wealthy would always have funds to do that.

The All Ords trend is continuing to rise, and looks likely to approach record levels very soon as effective vaccines are developed to keep the virus at bay. The COVID-19 blip may soon be just that, a small blip that happened in the past.

Perhaps we shouldn't be surprised by the success of the billionaires. After all, the Matthew effect (*For to everyone who has will more be given, and he will have abundance; but from him who has not, even what he has will be taken away. Matt25, 29)* has been known for at least a couple of thousand years.

Furthermore, governments frequently take action to encourage wealth disparity.

Our current government wants to give tax cuts to those who have jobs and income, and reduce the funds provided who have no jobs and no income.

Eventually these, and similar actions, could weaken our social cohesion by impoverishing and disempowering the many poor for the benefit of the few who are better off. It doesn't seem to make much sense.

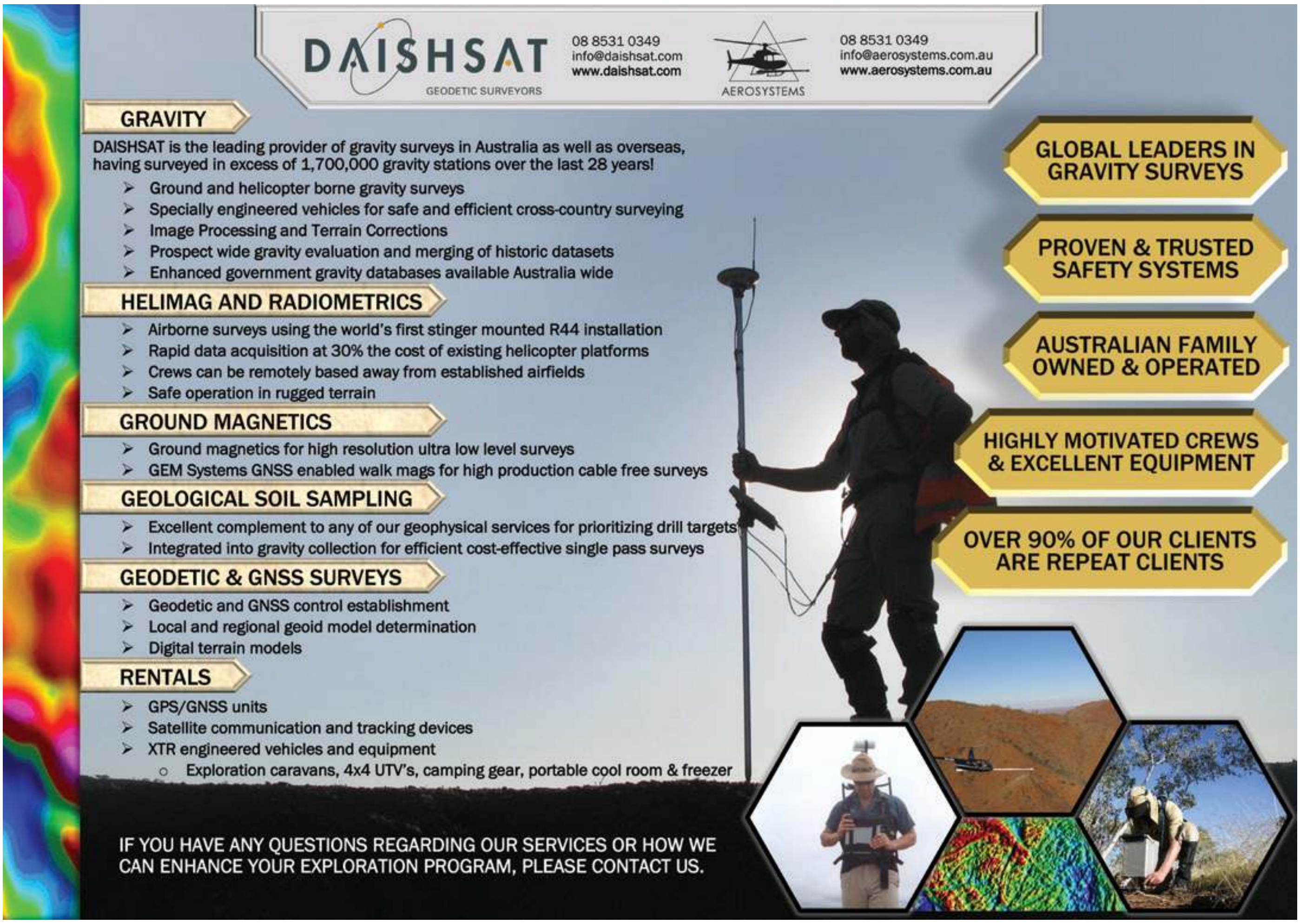
Not much sense in the Regional Comprehensive Economic Partnership either

With much publicity, Australia is now part of 15 Asian nations who have signed up to a free-trade deal along with China, Japan and Korea. We are told the Regional Comprehensive Economic Partnership (RCEP) was signed after eight years of secret negotiations. The benefits are not evident and, as our coal, copper, wine, barley, sugar, timber and lobsters are still being held up outside Chinese ports, it doesn't seem to have helped us with our relationships with China.

According to a Bloomberg report (*https://www.scmp.com/economy/china-economy/article/3109794/china-australia-relations-dispute-leaves-400-seafarers),* at least 21 bulk carriers are anchored off the Port of Jingtang and have been unable to offload their Australian coal that could be worth around US$200 million. Fifteen of the ships have been waiting since June, according to the Bloomberg analysis, while the remainder have been delayed at least four weeks. Most of the 2-3 million tonnes is coking coal used for making steel. If the RCEP can't help us solve these problems, what use is it?

It is high time our government changed tack on our relationships with China and does it quickly. I heard Geoff Raby talk at Press Club earlier this month. Raby is a former ambassador to China, and he is arguing that Australian diplomacy must be recalibrated to cope with the world as it is - not how we would wish it to be.

The get-tough policy on China with no apparent goal has left Australia isolated and vulnerable. It is probably too late for subtle diplomacy. It's time for action that can bridge the cultural gap, and maybe even a bit of grovelling.



Education matters

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A cloudy future for geophysics in universities, but a great set of 2020 theses showing our potential

This has been a remarkable year for all of us and, perhaps, especially for those doing research for a thesis during the various lockdowns. Not only have they had to cope with restrictions on travel, laboratory usage and campus access, but also with limited interaction between students (and supervisors). In the upper levels of academia, geophysics like many other branches of Science Technology Engineering and Mathematics (STEM) faces challenges for its survival in terms of both funding and enrolment of students. Prof **David Cohen** of the University of NSW provides a series of insights into the nature of these challenges (see below).

This is also the season for the submission of theses, and it is our pleasure to provide the abstracts for five PhD, 15 MSc/MPhil and 12 BSc (Honours) theses based on, or using, geophysical methods. These theses represent educational outputs from nine Australian universities. Our warmest congratulations to the 32 completing students for their success in a very difficult year.

Special congratulations to **Tom Zhao** of the University of NSW. Tom was recipient of an ASEG NSW Student Scholarship; the aim of this scholarship programme is to promote and encourage geophysics-related research and education in New South Wales. Tom has taken geophysical methodology into the sugar-cane fields of Queensland in order to study the physical properties of top-soil, and guide agricultural scientists in the development of nutrient management guidelines. Read about his MSc thesis below.

This year I complete five years in the role of *Preview*'s Associate Editor for Education and I am delighted to be able to welcome Marina Pervukhina as my successor. Marina is based in the CSIRO Division of Energy, Perth WA, and will no doubt bring new perspectives on education issues in geophysics, and how they relate to the critical requirements of Australia's energy future. Marina introduces herself in the last section of this column.

A new model needed for geoscience education in Australia

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The viability of geoscience programmes in many universities around the World is being called into question by university administrators. This reflects the ongoing general decline in enrolments at undergraduate and postgraduate levels in most countries. Geophysics is reportedly suffering a greater decline in the number of students and departments capable of delivering relevant majors than other geoscience disciplines. By contrast, the ageing professional geoscience workforce and predicted increasing demand for graduates across most of the geoscience spectrum will require increased numbers of geoscience graduates, especially in the earth resources and the environmental management sectors. In essence, a growing mismatch between supply and demand.

In Australian universities enrolments in geoscience majors since 2003 have been closely linked with the minerals exploration expenditure cycle (with a 2-year lag) and, to a lesser extent, expenditure in the petroleum exploration sector (Figure 1). This link is strong in the "resource" states but is becoming weaker in New South Wales and Victoria. There is little correlation between university enrolments and the number of students undertaking geoscience-based subjects in the latter years of high school. The UK has also seen a progressive decline in geoscience enrolments, though it has not suffered the dramatic swings experienced in Australia (Figure 2). Whereas undergraduate enrolments in US universities have doubled in the last 30 years and postgraduate enrolments have remained stable (Figure 3), the extensive job losses in the oil and gas sectors are expected to begin to have an impact (Keane 2018). These trends have prompted various groups such as the Australian Geoscience Council and associated industry bodies, and the Geological Society of London and University Geoscience UK joint working group (GSL-UGUK, 2019), to consider means of stemming the decline.

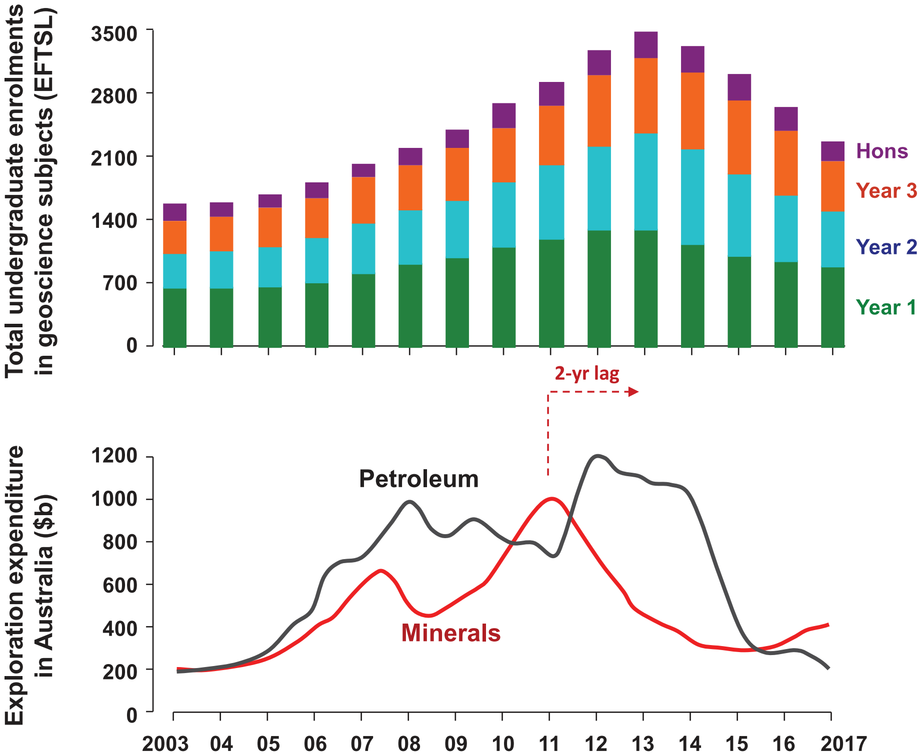

Figure 1. *Comparison between enrolments in geoscience courses in Australian universities and expenditure in the minerals and petroleum exploration sectors, 2003-2017 (from Cohen 2018).*

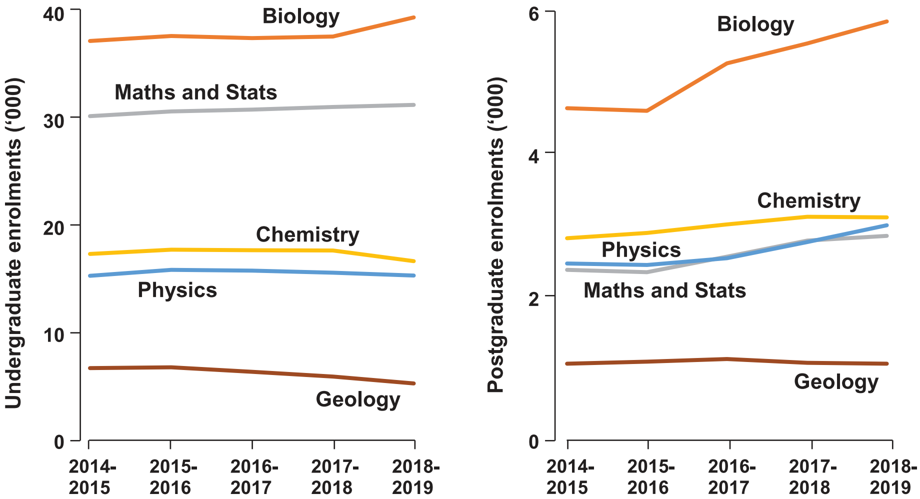

Figure 2. *Comparison between enrolments in undergraduate and postgraduate science programs with other disciplines from 2014 – 2019 in UK universities (based on HESA data: www.hesa.ac.uk/data-and-analysis/students/table-8).*

Australian universities are funded to teach students not to find them jobs. Within limits, enrolments are driven purely by the free market and not a centrally-controlled allocation of places linked to future national workforce needs. For decades, the geosciences in Australian universities have been cross-subsidised by major income-generating faculties such as business and engineering. In recent times this has been boosted by income derived from the massive influx of international students. The value proposition

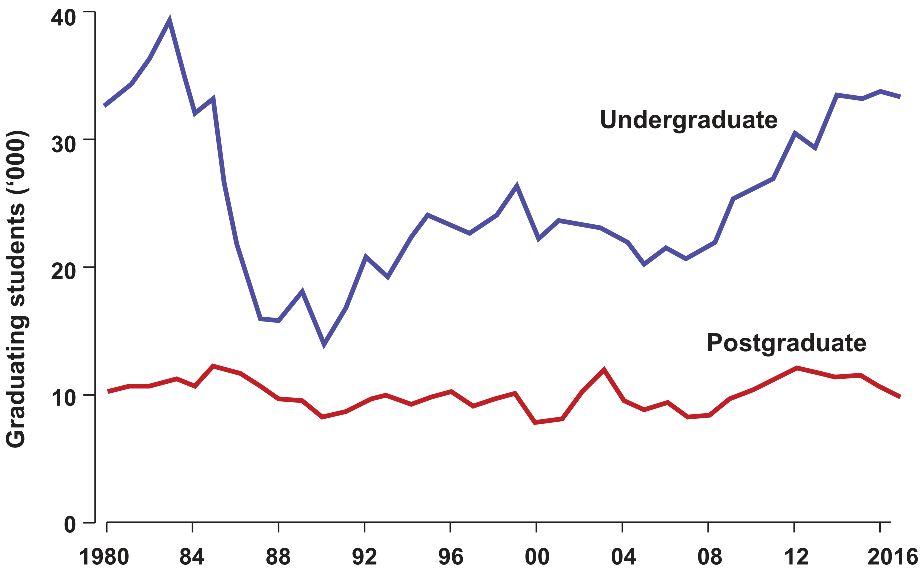

Figure 3. *Graduating students in undergraduate and postgraduate geoscience programmes in US universities (data from Keane 2018).*

to universities in subsidising the geosciences has been their capacity to generate substantial research funding and delivery of high quality research outputs. Both have assisted in improving our international university rankings, with ten of our geoscience departments regularly appearing in the geoscience top 100, based on research metrics, reputation and other factors. But there are limits to such largesse. In the short term, the effects of COVID-19 and the reduction in Federal Government funding of science degrees have not helped the geosciences as our universities scramble to find billions in savings. Two Australian universities are either disestablishing (or planning to disestablish) their geoscience majors and retain only those geoscience staff necessary to support their environmental science majors. Many other departments will lose a significant number of staff positions over the next six months.

The issue is not the quality of our geoscience programmes or the student experience. These are generally rated towards the upper end of university discipline rankings by industry and students. First year geoscience subjects are particularly well received by students and a high percentage of these students continue into geoscience majors in science degrees. The fact is that the mining and energy industries are no longer as attractive to 17 or 18 year old school leavers as in previous generations. The image of a Prime Minister holding a piece of coal aloft in parliament and praising its role in Australia's future energy supply simply does not make the geosciences attractive – you may as well be offering programmes leading to careers in intense whaling or baby seal clubbing.

What is the (realistic) solution to these problems? From the university perspective we are promoting the many exciting global challenges (e.g. finding the resources required to underpin a low-carbon economy and geological hazards) and fundamental scientific issues (e.g. the rise of life, earth and planetary evolution) to which the geosciences can contribute. The multitude of future careers that open up to graduates with geoscience majors are emphasised. The geosciences are, or can be made, more attractive to incoming undergraduates. But this will require a significant evolution and broadening of the syllabus. What should determine the balance between general scientific skills and knowledge, and geoscience-specific skills? What are the minimum capabilities that would permit a graduate to get a foot in the door to the profession? Would companies or government rather employ a graduate with a string of high distinctions in chemistry and maths, but who had completed just handful of geoscience units (e.g. basic mineralogy, petrology, structures) – or employ a graduate who completed a heap of geology subjects but bumped along with passes and a few credits?

These questions might (or should) receive different answers if graduates could access a comprehensive, nationally-based continuing professional development (CPD) system that span the geosciences – designed, delivered and with the option for micro-credentialling by a partnership involving industry, government, the professional societies and universities. The building blocks of such a CPD system are in place, courtesy of the short courses and other educational activities provided by professional societies in Australia and overseas. CPD is not only a means of converting capable scientists in other fields into geoscientists (bringing with them much-needed expertise in other fields) and deepening the skills of those already in the geosciences at all stages of their career, but also providing pathways for those wishing mid-career changes.

We have reached a point where the old model is at risk of failure. New models for training geoscientists and providing credible pathways into the geosciences must be developed – certainly in relation to the resources sector.

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David Cohen is President of the UNSW Academic Board and of the Australian Geoscience Council. He was previously Head of the School of Biological, Earth and Environmental Sciences at UNSW and is a Past-President of the Association of Applied Geochemists.

Theses in geophysics submitted to Australian universities in 2020

PhD theses

Hiwa Mohammadi, The University of Melbourne: Stress interactions in intraplate earthquakes

Australia is a seismically active continent with an intraplate compressive stress field primarily driven by far-field plate boundary interactions. Major (magnitude ≥ 5) surface-rupturing earthquakes are primarily sourced from reverse faults that perturb regional stress fields and influence the spatiotemporal properties of subsequent earthquakes. This thesis first contextualizes Australian earthquakes against global comparatives by investigating 257 finite-fault rupture models for 135 moment magnitude (M_w) 4.1 to 8.1 continental earthquakes worldwide.

I find that: (i) Australian earthquakes are amongst the most kinematically and geometrically complex for their Mw, (ii) upper-bounds and variance of the number of faults that rupture co-seismically increase with increasing Mw, and (iii) multi-fault rupture populations show no dependency on strain rate or proximity to plate boundaries. The thesis then presents a suite of studies that model static and visco-elastic coulomb stress changes (ΔCFS) imparted by major Australian earthquakes on to receiver faults and in the surrounding crust. I find that static ΔCFS models provide an informative physical-statistical basis for characterising many post-mainshock seismic sequences in Australia, with some exceptions. Aftershocks occur predominantly within positive static stress lobes and close to the advancing viscoelastic positive stress lobes, especially over the first few decades after major earthquakes in these regions. Earthquake triggering appears to occur under stress perturbations as small as ~ 0.001 to 0.01 bar, suggesting prevalent cratonic regions with critically stressed lithosphere. The effects of varying source fault geometries and kinematics on ΔCFS fields and subsequent seismicity are used to show how progressive refinement of source fault models using emergent data can reduce epistemic uncertainties in the role of ΔCFS in earthquake triggering. In some instances, increased source model complexity does not significantly impact on ΔCFS results and possible relationships to aftershocks relative to simple source models. The thesis finally investigates the role lithospheric-scale flexural bending due to eustatic sea level changes whether these impart ΔCFS perturbations on finite faults and in regions of similar magnitude to those imparted by preceding earthquakes. Preliminary age distributions of large paleo-earthquakes on these reverse faults are concurrent with ΔCFS peaks imparted by eustatic sea-level changes. ΔCFS of > 0.1 to > 1 bar on faults during the low-stand Marine Isotope (MIS) Stage 2 to Stage 4 interval (ca. ~30 to ~70 ka) provides tentative evidence that earthquake clusters could be stimulated by sea-level lowstands. This thesis demonstrates the power and utility of ΔCFS modelling to improve understanding of intraplate earthquakes.

Haibin Yang, The University of Melbourne: *The structure, rheology, and rupture mechanics of seismogenic faulting in continental lithosphere*

This thesis explores relationships between the structure, rheology, and rupture properties of seismogenic faulting in continental lithosphere from four different perspectives. First, I derive a scaling relationship that links the spacing between two nearly parallel strike-slip faults to the frictional strength, fault width, and lower crust viscosity for strike-slip shear zones. Based on the scaling law, I estimate a possible range of lower crust viscosity in the San Andreas Fault system (California), the Marlborough Fault Zone (New Zealand) and central Tibet (China). Second, using numerical modelling methods, I explore how lower crust rheology contrast may affect the long-term evolution of a major plate boundary fault. The case study is based on the San Andreas Fault, which is found to vary dipping angles (~50°-90°) along strike. The moderately dipping strike-slip fault is not consistent with Anderson faulting theory. This inconsistency may be reconciled if there are lateral variations in the lower crustal rheology across the fault plane that decrease fault dip with time. Third, in addition to strike-slip faults in active tectonic settings, my study also includes reverse faults in stable cratonic regions, especially for the cratonic areas of western and southern Australia. I apply statistical methods to investigate the co-seismic slip distribution of 11 surface-rupturing earthquakes in Australian stable regions and provide a link between the shape and characteristics of co-seismic slip distributions and the geophysical properties of the host crust. Fourth, using a comprehensive geophysical survey with the co-located 13GA-EG1 and 12GA-AF3 seismic reflection profiles and magnetotelluric profiles and regional gravity and magnetic maps in the Nullarbor Plain (Australia), I find that faults initiated back to the Proterozoic could still be reactivated in a Cenozoic convergent setting, especially for those major faults cutting to deep crust. Those deep-penetrating faults at terrane boundaries could be a potential channel for fluids to pass through, and thus further weakened by the fluids, which is revealed by high-conductivity anomaly in magnetotelluric profiles. The last research chapter of this thesis addresses a technical issue in the particle-in-cell finite element method, which is widely used in geodynamic numerical modelling. As mixing materials with contrasting viscosity within one element results in stress fluctuations, I assess different smoothing methods to reduce the spurious stress in mixed-material elements.

Mainak Mondal, Australian National University: *The role of convection on the basal melting of Antarctic Ice shelves*

Melting of the Antarctic ice-shelves has a large impact on ocean circulation, future sea level rise and the global climate. Most of the ice-shelves in

Antarctica are sloped forward into the ocean forming an ice cavity underneath. The turbulent transport of heat and salt into the ice interface melts the ice and drives convective wall plumes that play a crucial role in the basal melting. Ice-bathymetry and various ambient flows like tides, waves and sub-mesoscale eddies further modify the plumes. The regional and global ocean models work at scales over 100 meters and rely on crude sub-grid scale parameterization of convection and turbulent processes at the ice-ocean boundary layer, causing uncertainties in the estimation of the melt rate. Over the course of my dissertation I have examined the role of micro scale turbulent processes at the ice ocean boundary using Direct Numerical Simulation (fully resolving convection and turbulence). We carry out simulations by varying the slope of the ice shelves, changing the strength of ambient flow and including sub glacial discharge. Our results show that the melt rate is controlled by the slope of the ice-face with decreasing melt rate at shallower slopes. Over the geophysical flow regime, convection is still a key parameter that controls the heat and salt transfer into the ice-face and hence the melt rate. The results from this study significantly widen our present understanding of the basal melting and can improve the ice-ocean parameterizations for large-scale models.

Thanh-Son Pham, Australian National University: *Advancing correlation methods of earthquake coda in seismic body wave studies*

The discovery of long-range spatial correlation in earthquake coda and ambient noise records has had far-reaching impacts on modern seismology. This approach provides a conceptual framework to extract information about the structure of the Earth from stacked cross-correlations as a function of inter-receiver distance (i.e., correlograms) using noisy seismic records. Early work concentrated on the retrieval of surface waves travelling between receiver pairs from ambient noise and used measurements of their dispersion in surface wave tomography applications. Later it was found that body-wave-like signals also emerge in correlograms. Intriguingly, many feeble signals that are sensitive to deep Earth structures can also be 'extracted' efficiently from late coda of large earthquakes. Yet, the nature of correlation features in coda correlograms has remained a puzzle. Disentangling that puzzle is a key to open new avenues for deep Earth studies.

This thesis presents a compilation of published works featuring methodological and theoretical advances for exploiting correlation methods for earthquake coda. The fundamental objectives include (i) improving data processing, (ii) understanding of the nature and generation mechanism of body-wave-like correlation features, (iii) applying new understanding to study Earth structures. In particular, the thesis contributes to local, regional and global scale problems. At the local and regional scales, contributions are made to the development of the teleseismic P wave coda autocorrelation method for imaging near-surface structures. At the global scale, a new concept the global correlation wavefield, which is relevant to studies of the deep Earth, is introduced.

Seismic waves from distant earthquakes illuminate stratified structures beneath a receiver in a nearly vertical fashion. Stacked autocorrelations of the portion of ground motion records immediately after the P wave arrivals (i.e., the P wave coda) are constructed to extract reflection signals from shallow subsurface discontinuities beneath individual stations. The processing incorporates a spectral whitening operation to enhance the quality of autocorrelation results. The feasibility of the method is demonstrated through synthetic and field data. The improved procedure is then applied to a large number of seismic receivers across Antarctica to obtain estimates of the thickness and the ratio of P to S wave speed for the ice cover. These estimates are in a good agreement with prior measurements mainly obtained from active seismic and radar methods. This successful application for the Antarctic ice cover proves the potential of the method for studying other shallow structures including sediment, regolith or ice covers in other continents and on other planets in future space missions.

Using the insights gained from the autocorrelation case study, the cross correlation of the late coda of large earthquakes recorded at seismic receivers around the globe is exploited. The global correlograms reveal a wealth of correlation features, including correlation phases that have timing properties similar to regular seismic phases from a surface source, and others that do not have counterparts in the direct wavefield. All features in the correlation wavefield are produced from the similarity of the waveforms of two regular seismic phases sharing a subset of propagation legs. These novel insights are then used to identify the presence of J (shear) waves in the Earth's inner core. These shear wave signals are direct evidence to confirm the solidity of the Earth deepest shell. To match the character of the observed correlograms a 2.5% reduction of inner core shear wave speeds relative to spherically symmetric models of the Earth is inferred. With further refinements, the correlation wavefield approach could lead to improved structural constraints on the Earth interior, especially for poorly sampled regions such as the lowermost mantle and core.

Chris Li, University of Adelaide: *Improving next-generation hydrogeological models with geophysics*

This thesis presents advancements to the disciplines of geophysics and hydrogeological modelling. There are three main scientific contributions in this work. Firstly, a method is presented to couple time-domain electromagnetics (TEM) and surface nuclear magnetic resonance (NMR) datasets with limited drillhole data to provide information on hydrogeological properties in a non-invasive manner, including groundwater salinity and hydraulic conductivity. This method reduces the ambiguity in the hydrogeological interpretations of TEM data by coupling with the porosity values independently estimated using surface NMR. The method was applied to a South Australian River Murray floodplain to investigate the impact of artificial watering on the shallow groundwater salinity. The second scientific contribution is evaluating the impact of incorporating TEM and surface NMR datasets on the prediction error and uncertainty of groundwater models under different hydrogeological conditions using a synthetic approach. A method is presented to couple TEM and surface NMR to derive hydraulic conductivity using the Markov-Chain Monte Carlo method. Thirdly, a modelling framework is presented to couple multiple geophysical techniques of TEM, borehole NMR and audio frequency magnetotellurics (MT) with stochastic groundwater modelling through the ensemble-smoother method. This approach allows the uncertainty in geophysical data to be expressed as a prior probability distribution that can be incorporated and accounted for in groundwater model inversion. This method was applied to a potential in-situ recovery site in Kapunda, South Australia to estimate the regional-scale impact of a hypothetical operation trial in a probabilistic manner. Together, these three novel studies represent a contribution to the coupling between geophysics and hydrogeological modelling.

MSc/MPhil theses

Tom Zhao, University of NSW: *Digital soil mapping of soil cation exchange capacity (CEC) using different models, sample sizes and transect spacing in a sugarcane field in Proserpine, QLD*

The soil cation exchange capacity (CEC) is an important property because it influences soil structural stability, nutrient availability, pH and reaction to fertilisers. To assist Australian sugarcane farmers balance sugarcane-yield and minimise fertiliser run-off, the six-easy-steps nutrient management guidelines were developed. In this research, a digital soil mapping (DSM) approach is used to understand the spatial variation in topsoil (0 – 0.3 m) and subsoil (0.6 – 0.9 m) CEC. With regard to DSM, various aspects of the current materials and methods are compared and contrasted, including choice of model (i.e. linear mixed model – LMM, regression kriging – RK, Cubist, random forest – RF and support vector machine – SVM), digital data (i.e. gamma-ray (g-ray) spectrometry and apparent conductivity (EC_a)) used in combination or independent of each other, suitable transect spacing of the digital data (i.e. 5, 10, 20, 30, 40, 60, 80 m) and number of soil samples (i.e. 120, 110,…, 10) for calibration. I test these using a validation (i.e. 40) data set. The comparisons were evaluated considering the agreement between measured and predicted CEC using Lin's concordance correlation coefficient (LCCC) and accuracy using root mean square error (RMSE).

The results indicate that for the DSM of topsoil CEC, the Cubist with an intermediate number of calibration samples (i.e. 80) using in combination both g-ray and EC_a was optimal in terms of agreement (LCCC = 0.79). For subsoil, a smaller number (i.e. 30) of soil samples for calibration was required to achieve good agreement (LCCC = 0.89). In terms of accuracy, the accuracy (RMSE = 5.42 cmol(+)/kg) of subsoil CEC was satisfactory, as it was less than half standard deviation (SD) (7.55 cmol(+)/kg) of measured CEC. While not the same for topsoil CEC, the accuracy (RMSE = 1.93 cmol(+)/kg) was not as satisfactory as it was over half measured topsoil CEC SD (1.68 cmol(+)/kg).

The results also showed that while g-ray alone was superior to EC_a data for prediction, better results were achieved when both digital data were used in combination. In terms of a suitable transect spacing for collection of digital data to predict topsoil CEC, the small transects spacing (i.e. 5 m) was recommended. For subsoil prediction, larger transect spacing may still be appropriate (i.e. 5 – 60 m). The DSM approach overall enabled topsoil and subsoil prediction of CEC with good accuracy and small residuals, particularly at large calibration data sets (i.e. > 80). The final DSM of topsoil and subsoil CEC therefore do allow for the implementation of the six-easy-steps nutrient management guidelines for lime. As the soil pH in most area here is lower than 5.5, the larger northern half (22.74 ha) requires a small (< 2.5 t/ha) application rate with the southern half requiring intermediate (3 – 5 t/ha) to large (5 t/ha) rates.

Matthew Shrimpton, The University of Melbourne: *Deep crustal architecture in south-eastern Australia: Insights from split-stream zircon analysis and potential field geophysics*

Understanding deep crustal architecture is an ongoing challenge in earth sciences, largely because in most cases these deep structures can't be sampled. The Durham Ox High is a geophysical anomaly interpreted in the deep crust that extends across the Stawell and Bendigo Zones in northern Victoria, and into southern NSW. The Durham Ox High is characterised by high amplitude, long wavelength magnetic and gravitational responses, and although several hypotheses have been proposed to explain these anomalies, it remains poorly understood. However, recent interpretations from deep crustal reflection seismic surveying, south of this anomaly, provided direct evidence for improved controls on the deep crustal architecture in the Stawell and Bendigo Zones. The seismic survey suggested that the mid to deep crust consists of dense, thick and imbricated block of Cambrian mafic volcanics. These mafic volcanics are overlain by Cambrian-Ordovician turbidites where Devonian (post-Tabberabberan) S-type granites have intruded through to the surface (e.g. Lake Boga Granite and Pyramid Hill Granite). This study aimed to resolve the geometry and depth for the deep crustal architecture associated with the Durham Ox High using potential field modelling and granite geochemistry. New petrophysical and high-resolution land-based gravity data were acquired from the overlying granites to constrain their geometries. Furthermore, this study provided insight into the source rocks causing the Durham Ox High, using a laser-ablation split-stream technique to simultaneously acquire U-Pb ages and Hf isotopic compositions on zircons extracted from the Lake Boga and Pyramid Hill Granite. These granites provided as compositional constraints because crustal melting to produce S-type granitic melts has been suggested to occur deeper in the crust.

Potential field modelling on newly acquired gravity data constrained the depth of Lake Boga Granite to 7-8 km and Pyramid Hill Granite to 5-6 km, which served as minimum depth constraints on the source of the Durham Ox High. This and a combination of other geological constraints, allowed potential field modelling of both gravity and magnetic data over the anomaly to suggest that the geophysical response of the Cambrian mafic volcanics are responsible for the Durham Ox High at shallower depths ranging from 14-15 km, and that these mafic units are thicker north of the seismic reflection survey. U-Pb dating constrained the age for Lake Boga Granite emplacement at 363 ± 4.9 Ma and Pyramid Hill at 371 ± 3.9 Ma. The Hf isotopic signatures of these granites suggested that they formed from a two component magma mixing process that involved the Cambrian-Ordovician turbidite sequences and the Cambrian mafic volcanics. The resolved geometries and magma mixing conclusions drawn in this research have economic implications for gold mineralisation, given these mafic rocks have been interpreted as the source for gold in the Bendigo Zone.

Mikayla Sambrooks, The University of Melbourne: *Geometry and emplacement of the Tarnagulla Granodiorite, central Victoria: Evidence from potential field modelling and CA-TIMS U-Pb geochronology analysis*

Igneous intrusions have the potential to provide valuable insights into deformation events, crustal architecture and composition of the lithosphere that existed at the time of their emplacement. The limitations of studying the geometry of buried intrusions makes it difficult to evaluate emplacement mechanisms that controlled their intrusion. The Tarnagulla Granodiorite is an intermediate felsic I-type intrusion which was emplaced during the Early Devonian in the Bendigo Zone of the western Lachlan Fold Belt. The Tarnagulla Granodiorite displays an intriguing magnetic response in the shape of a 'U' which contains magnetically fluctuating ring-shaped anomalies implying that magmatism migrated over time during emplacement. The Moliagul Granodiorite exists at the western end of the magnetic U-shape and contains ore-mineral occurrences including molybdenite, pyrite and wolframite. The 3D geometry and emplacement history which has led to the Tarnagulla Granodiorite's unusual geometry is poorly understood. Previous geochronology completed for the intrusion was incapable of resolving the path of emplacement. This study aims to resolve the geometry and path of emplacement of the Tarnagulla Granodiorite. High resolution land-based gravity data were acquired at 200 m spacing along 4 profile lines transecting the intrusion. The new gravity data were used in conjunction with data from previous gravity and aeromagnetic surveys, obtained through the online government portal GADDS, to form qualitative geophysical interpretations which characterised four distinct geophysical domains within the pluton. Precise geochronological analyses at MIT using the CA-TIMS method for U-Pb zircon dating reveals a clockwise path of emplacement from the north to the southwest between 406.62 ± 0.27 Ma and 399.3 ± 1.1 Ma and demonstrates a close temporal relationship exists between the Moliagul and Tarnagulla Granodiorites. Potential field profile modelling across five traverses that were constrained using measured density and magnetic susceptibility values demonstrate the subsurface geometry of the Tarnagulla Granodiorite varies in thickness from ~2 km in the north to ~6 km in the southwest. The models also show that the boundaries vary from sub-horizontal and tapered in the north to sub-vertical along the southeastern margin and, moreover, that the feeder zone likely resides in the southwest at the deepest modelled extent at ~8 km. Precise geochronological data were interpreted alongside the new defined 3D geometry of the Tarnagulla Granodiorite to examine the evolution of the pluton. The emplacement of the Tarnagulla Granodiorite likely involved active faulting which facilitated the clockwise movement of a hanging wall over a stationary magma source in the footwall, ultimately tracing the intrusion's U-shaped magnetic response. The geometry of the intrusion indicates components of sheet-intrusion and structural control were also involved in the emplacement of the Tarnagulla Granodiorite. Furthermore, the geophysical characteristics and path of emplacement together suggest that fractional crystallization influenced the formation of a relatively mafic, enriched final pulse of magma which resulted in the mineralisation of Mo, Cu and W at Mt Moliagul.

Kelly Vaughan-Taylor, Macquarie University: *Melting conditions beneath the Newer Volcanics Province from probabilistic inversions of lava compositions and geophysical data*

The Newer Volcanics Province (NVP) represents mainland Australia's youngest region of intraplate volcanism. Despite the numerous studies that exist on the origin and evolution of the volcanic centres, the exact mechanism of magma generation is heavily debated, with the exact source composition and melting environments remaining unclear. A few models have been developed in an attempt to explain the magma genesis and pathways beneath the NVP however, these models tend to focus on either geochemical or geophysical arguments. In this work, we use an integrated approach using both geochemical and geophysical observations to explain mantle processes. Geochemical data from the NVP is collated and screened to obtain a dataset containing samples younger than 2 Ma and representative of primitive melts from peridotitic sources. A new probabilistic inversion method is applied to the samples in conjunction with a recently developed mantle melting model to evaluate the melting conditions in the mantle; estimates of the composition of the source are also produced. A separate geophysical model of the present-day thermochemical structure of the lithosphere and sublithospheric upper mantle is created by jointly inverting available seismic and non-seismic datasets. The geochemical and geophysical models are then compared and jointly analysed to produce an integrated model of lithospheric structure, the melting conditions and mantle processes beneath the NVP.

Reuben Creighton, Australian National University: *Using 3D geodynamic slab models in tectonic reconstruction*

In this thesis, two regions of convergent Cenozoic tectonics are investigated, and recent subduction is reconstructed using 3D models that map the surface of subducted slabs in the mantle. In Iran, the subduction of the Neotethys ocean prior to the collision of the Arabian continent with Eurasia is reconstructed, and the debates regarding the age of continental collision, slab tearing, and the generation of adakitic magmatism are examined. From the magnitude of reconstructed subducted lithosphere, a younger collision 28-27 Ma is favoured. Tearing of the slab along the margin occurs post-collision, initiating in the north-west at ~ 22 Ma and in central Iran at ~18 Ma. The second region of study is the Pamir and Hindu Kush. Seismic velocity anomalies and active deep seismicity here have led to numerous interpretations of the morphology of the subducted lithosphere in this region. Two possible interpretations are modelled and evaluated with reference to evidence from surface geology. Recent extensional tectonics, evidenced by the exhumation of detachment fault-bounded metamorphic domes, and geodetic evidence both favour a single Eurasian slab rolling back, and producing oroclinal bending in the Pamir. In the proposed model an extended basin once joined the Tarim and Tadjik, floored by oceanic lithosphere. Subduction was triggered as it was overridden by the advancing Indian continent, around the time of the Oligocene-Miocene boundary. Rapid rollback of the Pamir slab ahead of the advancing Indian continent explains current available evidence for extension and exhumation during an episode of large-scale collisional tectonics in the Miocene.

Jack Muston, Australian National University: *Volcanoes, ore deposits, and the 3D slab geometry along the Andaman-Sumatran subduction system*

This thesis addresses several topics related to the tectonic history of the Sumatran-Andaman region. Firstly, I investigated the Martabe epithermal gold deposits using high-resolution 40Ar/39Ar geochronology in order to unravel the complex overprinting alteration system. The results indicate that there were five peak periods of alunite growth around the Martabe deposits at 1.40 to 1.70 Ma, 1.90 to 2.08 Ma, 2.12 to 2.51 Ma and 3.22 and 3.48 Ma. Analysis of the Arrhenius plots put the closure temperature of alunite ranging between 390C and 519C, which is above the temperature expected for the formation of the Martabe deposits. This result gives confidence that the measured ages from 40Ar/39Ar geochronology are for the formation of alunite and not an age at which the system has cooled below the closure temperature.

Secondly, I created a 3D model of the subducted slab beneath Sumatra and the Andaman Sea, and restored the modelled slab geometry to the Earth's surface. This enabled recognition that the former spreading centres and transform faults of the Wharton Fossil Ridge localised a potential slab tear, thus circumventing otherwise enormous distortions that would have occurred during subduction. Seismotectonic analysis suggests continuing movement during subduction, in particular on the transform faults that once separated the spreading centres between the Indian and Australian plates. The emanation of fluids from the deforming lithosphere may have localised both the Toba supervolcano and the epithermal gold deposits at the Martabe.

Thirdly, tomography in the Andaman region is not characteristic of a simple subducting slab. Instead there are unusual structures between 11N and 15N that have not been previously discussed. Tomographic anomalies can be misleading and might be erased with improvements in tomographic resolution. Nevertheless, we propose two interpretations of the slab morphology that explain a westward dip anomaly. Model 1 consists of overturning the subducted Indian slab, a geometry common for advancing hinges. However, an advancing Andaman trench is not consistent with the relative motion of the Indian plate. Instead, this morphology could arise from the northward motion of the Indian plate through the mantle rotating the edge of the Andaman slab, overturning the slab and producing slab tears. Model 2 interprets the anomaly as a westward dipping slab, required a slablet derived from the Andaman Sea to have punctured the subducted Indian plate. Model 1 fits within the tectonic reconstructions published for this region but requires a geodynamic mechanism to overturn the slab, while Model 2 requires an unrecognised sutured subduction zone within the Andaman Sea.

Lastly, I report on a geomorphic analysis aimed at assessing a different hypothesis for the evolution of the Sumatran Fault System. Extensional structures in and adjacent to restraining bends on the Sumatran Fault System are unusual in an overall transpressive wrench regime. In addition, NW-SE trending tectonic lineaments appear to connect to offsets of the Sumatran Fault. Such features could be explained by westward rollback of the hinge of the subducting Indian plate driving NW-SE extension across northern Sumatra. Slab-tearing may have localised rollback and created NW-SE trending left-lateral strike-slip faults that offset the Sumatran Fault, eventually requiring the formation of new relay faults to accommodate the ongoing relative motion of the Sunda Block. The new relay faults eliminate the obstacles caused by offsets of the main fault strand. However, this model requires switching between extended periods during which transverse left-lateral strike-slip faults driven by differential slab rollback offset the Sumatran Fault, alternating with periods during which there is a renewal of transpressional wrenching. Inferred switches in the stress trajectories are complementary to those documented in the Andaman Sea.

Suchir Patil, Australian National University: *Application of UAV coupled with SfM-MVS to delineate the changing landscape of Lake Mungo*

Lake Mungo is a dry lake in the semi-arid environment of southeast Australia located in southwestern New South Wales (NSW). It lies in the central portion of the Willandra Lakes World Heritage Site. This region contains some of the earliest evidence of Homo sapiens sapiens outside Africa, establishing that humans had dispersed as far as Australia by 42 000 years ago. Famous for its oldest known cremation in the world and its significant archaeological traces, the changing landscape in the recent years has posed a threat to its heritage and history. Significant denudation in the recent past and continued erosion has been a challenge in conserving the history of indigenous people of Australia. In this research, we explore the use of low-cost geomatic method by using Unmanned Aerial Vehicle (UAV) coupled with Structure from Motion techniques (SfM-MVS) and change detection algorithm to delineate the changing landscape of Lake Mungo. Topographic surveying is carried out from 2015 to 2018and a high-resolution (0.05m) 2.5-dimensional Digital Elevation Model (DEM) is generated from the three-dimensional point cloud data derived from the images captured by UAV. Each interval of the epochs over the three years is differenced using DoD, LS3D and ArcGIS methods and the resulting elevation changes are used to analyse the erosion and deposition of sediments at Joulni section of Lake Mungo. A SfM-MVS workflow is developed to improve the accuracy of the DEMs. LiDAR and SfM-MVS derived DEMs are compared with each other in this study. Our study shows that some regions of the lunettes having high denudation or aggregation show reliable estimates. However, changes less than ±16cm is hard to determine and quantify. With careful elevation modelling and consideration of spatial errors, SfM-MVS can successfully be used as a low-cost method in topographic surveying in comparison to LiDAR.

Manish Ghimire, Curtin University: *Draggable DAS vs fixed geophone reflection spread - a comparative analysis at Pineapple Hill*

Distributed acoustic sensing (DAS) possesses an undeniable aspect representing a significant potential in the field of mineral exploration in large scale. DAS systems were used with respect to the data receiving modes along with the geophones in Pineapple Hill area, Pilbara region, Western Australia. The field observation for data acquisition was held for 7 days and was fully sponsored by BHP Billiton, in their iron ore region. Aspect of this field is to obtain the comparative and qualitative seismic data from the DAS technology similar to that of 3-Component geophones. A 40kg PEG weight drop was used to generate seismic energy that propagates through the ground to backfire reflectors' signals that are recorded by 3 underlain receiving sensors. Survey was conducted for 1km length along E-W section along the field to identify the iron ore deposit beneath the sub-surface region with aims to correlate buried and draggable DAS sensors with three components geophones.

Seismic data are observed primarily for the near surface sections demonstrating vital reflecting surface at the depth of about 150 meters. A similar prominent feature is observed in 20° buried fibre optical DAS cable in same level of depth.

Despite being a hard rock environment, we observed high resemblances of the stacked images of geophone and DAS received dataset. Through the analysis of the dataset, it can be stated that DAS sensors can be trusted to be used as an essential seismic receiving sensor in the sector of mineral exploration in hard rock environment. While monitoring of the subsurface data, it can even outperform the geophones. On the basis of nature of measurement and state of field, DAS can be used being an inexpensive technology and competitive services.

Mudiyanselage Aruni Nilupa Rajanayake, Curtin University: *Acquiring high-quality data in UAV magnetic surveys*

Unmanned Aircraft Vehicles (UAV) are often used in acquiring magnetic data due to their light weight, ease of navigation in difficult terrain conditions, efficiency, and low cost compared to conventional magnetic surveys. But with the limited space in UAVs, the noise contribution is higher because of instrumentation noise, manoeuvre noise, terrain effect, and the type of magnetometer sensors. This study aims to quantify these noise sources by modelling studies and observing the spectral content to minimize noise through engineering and flying behaviour and not digital filtering. With the use of UAV acquired magnetic datasets, 3D inversion using VOXI was carried out to see the average susceptibility, which was used in forward modelling to identify the effect of varying flying heights on the magnetic response. Forward modelling the magnetic response for shallow magnetic bodies for constant flying height using ModelVision, assisted in quantifying the wavelengths of geological noise. The instrumentation noise and sensor noise were analysed by observing the spectral content using FFT1D on repeat lines flown in the same direction and multiple sensor readings for the same survey area respectively. The heading error is an average of 0.8 nT difference given that the flight is flown on favourable weather conditions. The VOXI modelling indicated that for varying flying heights the change in magnetic response is not that significant when changing the flying height +/-10 m from the original position. The use of different magnetometer sensors for the same survey gave a significant difference in the magnetic response and hence should be avoided or necessary digital filtering should be applied. These findings can be used when acquiring UAV based magnetic data to minimize the overall magnetic noise through engineering and flying behaviour.

MSc projects – supported by industry, contents remain confidential

Hassan Hamisi Ahmad, Curtin University: *Integration of magnetic and 2D seismic data to delineate potential hydrocarbon resource areas in North Rukwa Block, East Africa rift system-Tanzania.*

Manlio Castillo Torres, Curtin University: *Investigation into pre-stack wave equation datuming technique for imaging seismic data recorded over significant topographic variations in a hard-rock environment*

Manish Singh Chaudhary, Curtin University: *High-resolution hard rock seismic data processing supported by borehole supported by borehole measurements and refraction tomography*

Pablo Crespo Carrillo, Curtin University: *Application of isotropic pre-stack depth migration algorithms in hard rock geological settings*

Oscar Marino Leon Estacio, Curtin University: *Passive seismic imaging in mining applications*

Petro Madukwa Theonest, Curtin University: *Pre-stack inversion for 3D seismic to characterize the reservoir in Block 3 Offshore Tanzania*

BSc (Honours) theses

Wei Xuen Heng, University of Tasmania: *Geophysical investigation of the legacy Endurance mine site, northeast Tasmania*

The legacy Endurance mine site is an abandoned alluvial tin mine in northeast Tasmania. Between 1872 and 1985, mine waste was discharged into Ringarooma River and wherever was convenient on site. Previous studies have identified the production of acid mine drainage (AMD) from quartz-rich gravel mine wastes.

The lack of soil profile and presence of acidic waters have led to the failure of rehabilitation programs after mine closure. This study aims to define and characterise the thickness and internal structure of abandoned mine waste at the legacy Endurance mine site using four near-surface geophysical techniques: Direct-current (DC) resistivity, electromagnetics (EM), ground penetrating radar (GPR) and near-surface seismic.

DC resistivity was successful in detecting the contrasting apparent resistivities between dry and saturated mine waste, within 5–10 m of the surface. In addition, DC resistivity was able to differentiate a kaolinitic clay layer, weathered granite and fresh granite to depths of ~20–30 m. Those layers are verified by drilling from on-going hydrogeological study. Due to the un-differentiable resistivity values between saturated mine wastes and weathered granite, the method does not show the boundary between both compositional layers. An EM38 was used to map the change in of apparent conductivity across the Endurance site. EM was useful for defining areas of AMD, and the spatial distribution of clay materials and dry mine waste within 1 m depth. However, much of these data were unreliable, due to cultural noise and instrument failure. GPR signals were used to delineate the location of the water table and to depths of ~15 m. GPR has been proven to be a quick and reliable way to detect the boundary between the quartz-rich mine waste and kaolinitic clay layers. Refraction seismic analysis indicates the presence of weathered granite overlying granitic basement and is useful for inferring basement depth.

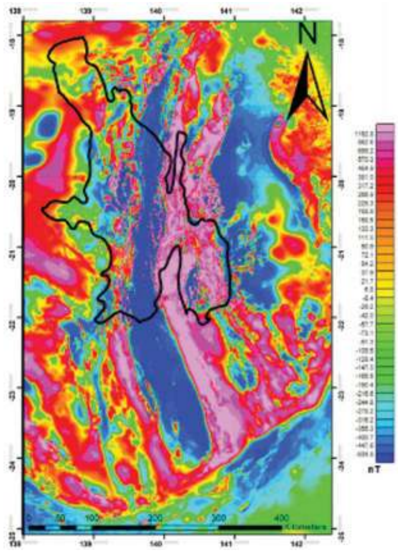
By integrating interpretation of the geophysical data and models produced in this study, a three-dimensional model of depth to the base of mine waste, the water table and granitic basement is created. This three-dimensional model was used to estimate the mass of mine waste at the legacy Endurance mine site ~4 Mt and provide constraints for concurrent hydrogeological and sediment geochemistry honour projects. Collectively, the results of these projects will inform rehabilitation strategies at the legacy Endurance mine site.

Shannon Brown, Monash University: *Causative relationship between shear zones and plutons: Examples from the Borborema Province, NE Brazil*

Ternary RGB radiometric image of the Borborema Province, NE Brazil

The Borborema Province, NE Brazil, is characterised by a continent-scale anastomosing shear zone network activated during the Brasiliano Orogeny, during which province-wide intrusion of predominantly granitic plutons occurred. Previous studies have used the apparent close spatial and geometric relationship between plutons and shear zones in the region to argue for a causative relationship between the two, however other studies suggest these relationships do not exist. This study aims to compare the spatial distribution and geometry of pre-, syn- and post- kinematic plutons, as well as undated plutons, to determine whether plutons are geometrically, spatially or temporally related to shear zones in the Borborema Province. Using detailed maps produced through interpretation of aeromagnetic and radiometric data, sub-domains with the greatest cumulative shear zone length were found to contain the highest percentage area of plutons, indicating that plutons and shear zones have a close spatial relationship. Furthermore, the vast majority of plutons with high aspect ratios were found to intersect or occur within 200m of a shear zone. A linear relationship between pluton ellipticity and distance to shear zones was also established, indicating a strong geometric relationship where the most elliptical or circular plutons tend to be further from the shear zones. Finally, 70% of syn-kinematic plutons and 38% of pre-kinematic plutons were found to occur within 200m of a shear zone, suggesting that shear zones may control the emplacement of syn-kinematic plutons, or they nucleate on existing syn-kinematic plutons. It also indicates that shear zones preferentially nucleate away from pre-kinematic plutons. This temporal relationship therefore demonstrates a causative relationship between shear zones and plutons in the Borborema Province.

George D Manton, Monash University: *What is the southern extension of the Mount Isa Fault Zone? – Implications for sediment hosted massive sulphide Pb-Zn-Ag exploration strategies*



A RTP image of magnetic data of NW Queensland with the outcrop extent of the Mount Isa terrane superimposed

Regional aeromagnetic and gravity datasets indicate that the Mount Isa Inlier extends ~300 km south under sedimentary cover. Although the buried extent of the terrane is very likely to be well endowed, there has been relatively little mineral exploration due to challenges associated with exploring under cover. There is a strong spatial link between giant sediment hosted massive sulphide Pb-Zn-Ag mineral systems and the Mount Isa Fault Zone (e.g. Mount Isa deposit). Within the exposed extent of the Mount Isa Inlier, the Mount Isa Fault bifurcates into the Rufus Fault and Wonomo Fault. Both splays can be mapped using regional aeromagnetic date into the southern, buried extent of the Mount Isa terrane. Determining the southern extension of the Mount Isa Fault may reduce exploration cost and mitigate exploration risk, creating a more efficient exploration strategy. This study focused on formulating a new structural and lithological aeromagnetic and gravity interpretation of the southern, Western Fold Belt and Sybella Domain within the Mount Isa Inlier. The interpretation reveals a complex fault evolution and was used to inform relationships observed between regional scale faults within the study area. Discrete geophysical domains were identified and were linked to known lithological domains. Both the Mount Isa Fault and the Wonomo Fault are defined as steeply west dipping structures with a protracted history of early normal movement and reverse reactivation. The Rufus Fault was interpreted as a steeply west-dipping structure with a protracted history of normal movement and reverse/dextral reactivation. A rose diagram structural analysis was conducted on segments of the Mount Isa, Rufus and Wonomo Faults and it was determined that the Wonomo Fault Zone had more similar surrounding structural architecture compared to that of the Rufus Fault Zone. This study recognised that the Wonomo Fault is the likely southern extension of the Mount Isa Fault due them sharing: more similar surrounding structural architecture, similar domain bounding characteristics, protracted movement histories and the same steeply west-dipping, north-south orientation. The Rufus Fault Zone is interpreted to be the same structure as the Fountain Range Fault, linked through a regional scale contractional strike-slip duplex and overprints the Mount Isa/Wonomo Fault Zones.

Leon Bilton, Australian National University: *Oceanic anisotropy from PS splitting: Towards global models of upper mantle convection*

Observations of seismic anisotropy (e.g. shear wave splitting) can provide direct insights into the relationship between mantle convection in the Earth's interior and plate motions at the Earth's surface. Receiver based seismic observations over oceanic plates are however currently restricted due to the concentration of seismic receivers on land. This project suggests a method to overcome this limitation by utilising the distribution of surface reflected seismic phases, such as PS, which bounce once between the source and the receiver. From these information is extracted about the seismic anisotropy beneath oceanic bounce-points, which is used to construct an observational dataset of hundreds of manually analysed shear-wave splitting results with direct implications for mantle convective patterns beneath oceanic plates. We observe bi-modal fast directions, however are unable to rule out systematic errors. Delay times are comparable with previous shear-wave splitting studies (≈2 s). Results suggest potential deviations of the anisotropic fabric from absolute plate motions, however more favourable agreement is found for zonal comparisons with surface-wave anisotropy. We suggest that more careful investigation of anisotropy below old seafloor is necessary in order to determine the presence of small-scale convective patterns and layered anisotropy.

Claire Flashman, Australian National University: *Investigating seismic anisotropy across the Australian continent through SKS splitting from the BILBY array*

Most regions on Earth display apparent anisotropy in the upper mantle, and surface waves studies indicate that Australia is no exception. Anisotropy has been recorded down to 250 km depth beneath Australia, with anisotropic fast direction correlated to Australia's absolute plate motion. Yet, previous shear wave splitting analysis using SKS and SKKS waves have produced results which suggest apparent isotropy potentially due to multiple layers of anisotropy beneath Australia. There is however a lack of knowledge on how local geology and frozen-in anisotropy contributes to lateral heterogeneities in seismic anisotropy across the continent. This thesis therefore further investigates the structures governing seismic anisotropy beneath Australia and attempts to validate existing models of Australian anisotropy based on newer collections of seismic data. The present research indicates that although local geology can impact anisotropy in local regions, these results are consistent with two layers of anisotropy, with absolute plate motion (APM)aligned flow in the asthenosphere and likely contribution from frozen-in anisotropy in the continental lithosphere. We propose that anisotropy beneath Australia maybe appropriately modelled using a two-layer model, with the lower layer aligned with the APM and an upper layer orientated non-perpendicular to this, possibly with a counter-clockwise rotation. Although the present work cannot adequately constrain the fast direction for the upper layer in a two-layer anisotropic model for Australia, these results suggest that the previously assumed perpendicular upper layer for the two-layer anisotropic model should be revisited. Local geology also appears to have a significant impact on anisotropy; fast directions from splitting results in central Australia appear to correlate well with gravity anomalies in the region, and regions in southern Australia and near Mt Isa exhibit behaviours which suggest geological interference with anisotropic sign

James Sweetman, Australian National University: *Energetics of internal waves*

Internal waves are ubiquitous throughout the interior of stratified fluids. These waves possess the unique quality of anisotropic dispersion that enables for both horizontal and vertical propagation. Prominent in the global oceans, their generation is primarily caused by vertically disturbing isopycnals (surfaces of constant fluid density) via bottom flows interacting with topography. Internal waves are of critical interest in the context of climate because they can enhance deep-ocean mixing, thereby influencing the Meridional Overturning Circulation, the leading-order process by which the ocean impacts Earth's climate on centennial timescales.

In this study, by way of idealised laboratory experiments the energetics and dynamics of internal waves generated simultaneously from two distinct topographic generation sites are investigated. This work extends on previous work pertaining to the energetics of internal waves generated from a single topographic generation site. The primary focus here is exploratory, chiefly motivated towards determining which of the dimensionless parameters that characterise internal wave dynamics support conditions necessary for the breaking of waves through the non-linear interactions of colliding wave beams and the subsequent production of turbulence.

The experiments presented here span a multi-dimensional parameter space representing the geometry of the topography, and the tidal forcing frequency and amplitude. The results include, (i) identifying that existing linear theory is applicable at low forcing amplitudes, and that (ii) some non-linear effects may be represented by including an enhanced viscous dissipation, and (iii) the identification of the parameter regimes in which a recently discovered non-linear wave interaction occurs.

Christopher Alfonso, University of Sydney: *The influence of dynamic topography, climate, and tectonics on the Nile River source-to-sink system*

At a length of over 6000 km, the Nile is the longest river in the world, and has long been of crucial importance to human civilisation in northern Africa, thanks both to the river's fresh water and to the Nile Delta's hydrocarbon reserves.

Evidence from the Nile Delta places the river's age at over 30 Ma, implying that its genesis may be intricately linked with the eruption of the massive Ethiopian Plateau flood basalts at this time. The longevity of the Nile, which persisted through such events as the opening of the Red Sea and the aridification of the Sahara Desert, may be explained by the existence of a long-lived, large-scale mantle convection cell beneath northern Africa. This convection cell was responsible for a persistent downward dynamic topographic gradient between the Afar Plume beneath the Ethiopian Plateau and the Tethys slab in the eastern Mediterranean since at least 40 Ma.

In this work, the influence of dynamic topography – among other factors – on the evolution of the Nile River was investigated, using the open-source Badlands surface processes modelling software package (https://badlands.readthedocs.io). Badlands simulates the erosion, transport, and deposition of sediments in a self-consistent manner, allowing the interrogation of spatial and temporal patterns of sediment erosion and deposition, river catchment morphologies, and stratigraphic structures. A range of forcing conditions were incorporated into the Badlands models, including paleoclimate, spatially variable lithology and thus erodibility, and three-dimensional motions associated with both tectonic activity and dynamic topography.

Model results were evaluated by comparison to real-world sedimentation maps and cross-sections derived from seismic data, in addition to the present-day morphology of the Nile River catchment. Sequence stratigraphic analyses were also performed on the modelled Nile Delta in order to investigate the possible relative contributions of various factors to the stratigraphic structure of the region. This marks one of the first instances of sequence stratigraphy being applied to the results of a self-consistent, realistic (as opposed to generic) numerical model.

Two different dynamic topography scenarios for the region, derived from geodynamic models, were tested. These two geodynamic models differ most significantly in the presence or absence of a well-defined Afar Plume beneath the Ethiopian Plateau. A third scenario, incorporating elements from both of the geodynamic models, was also developed. This hybrid scenario, which included both a distinctive positive dynamic topography signal from the Afar Plume and a strong negative signal associated with Tethyan subduction, produced the best match with the real-world Nile River and Delta, and is therefore considered to be the preferred dynamic topography scenario for this region.

Fionnuala Campbell, Curtin University: *Comparison, evaluation, and optimisation of the near surface Loupe TEM system for underground nickel sulphide detection*

Conventional transient electromagnetic methods are limited by substantial mobilisation requirements, long collection times and large footprints, making them impractical for shallow conductivity investigations and used in dense vegetation, enclosed or urban environments.

The applications of portable EM systems are expanding, ranging from mineral exploration and hydrogeological investigations, to shallow geotechnical and archaeological survey applications. The Loupe EM system is a portable time domain electromagnetic system, designed for rapid data collection in a variety of applications. The primary research objective is to determine the applicability of this system and compare the Loupe EM system with electrical conductivity measurements. This research presents two major case studies within logistically challenging environments included saltwater interface mapping at Woodman Point, Cockburn, Western Australia and the Nova Underground Mine site (IGO Limited) located in the Fraser Range, Western Australia.

In April 2020 over 3.5 km of Loupe EM data was acquired at Woodman Point in approximately 1 hour. Inversion models for the Loupe EM data were created and compared to Coogee 1A and Coogee 1B induction well logs, NanoTEM and ERI inversion models. The Loupe EM system showed promising results in mapping the geometry of the electrically conductive saline water wedge and delineating the high conductive layer at depths of approximately 25 m. Small (5 m) transmitter-receiver separations highlighted the saline water wedge, while larger separations (12 m) resolved the impermeable high conductivity layer at depth.

The Loupe EM data was collected by IGO Limited at the Nova Underground Nickel Sulphide mine along two mine drive levels in September 2020. Time constants were calculated for the Loupe EM measurements and compared to Ni-Cu content and Ore grade deposit models. High Tau values appear to correlate in areas of high Ni-Cu contents and high Ore grade. Low Tau occur in the absence of Ore. The choice of vertical or horizontal transmitter configuration affects the coupling, and subtle difference in Tau values are observed.

This research demonstrates the successful application of the Loupe EM system for conductivity mapping in both hydro-geological applications, and underground mine environments.

Bodee Bignell, University of Queensland: *Analysis of teleseismic earthquake recordings on nodal seismic sensors*

In the past few years, nodal sensors have emerged as the default for seismic exploration. These systems record continuously, and hence record a range of passive events. We have examined data from a number of such surveys in Queensland's Bowen Basin. Although the sensor is designed for higher-frequency events, with appropriate pre-processing it is possible to extract high quality records of teleseismic (distant) earthquakes which are of potential interest in analysis of the crust and upper mantle near the receivers. Aspects of the pre-processing are of interest. Cross-correlations of the earthquake P-wave reveal inter-node time variations which resemble statics contours from conventional reflection processing. Examination of time-distance variation across the survey area provides an estimate of apparent slowness of the arriving P-wave, useful for confirmation of theoretical travel-time models.

Because of the large channel counts in modern surveys, stacking the teleseismic event can provide significant improvement in signal-to-noise. We have used stacked nodal records to infill between recordings made at permanent seismographs. Relative travel-time residuals between stations in Queensland show variations of order 1-2 s. Teleseisms arriving from different azimuths produce conflicting relative-residual patterns. However, ray-path back projection to upper-mantle depths reveals coherent delay patterns. The observations are consistent with velocity variations of order 10% occurring in the depth zone 200 - 300 km. These results are consistent with earlier work on the upper mantle in eastern Queensland.

Harrison Button, University of Queensland: *Linear inversion of seismic-refraction amplitudes for near-surface velocity control*

This thesis examines the linear inversion of seismic refraction amplitudes to constrain seismic velocities in the near-surface. Seismic refraction amplitude is related to the head-wave coefficient, which can, in theory, be parameterised as the product of a source term, a receiver term, and an offset term. Previous approaches have included convolutional stacking and non-linear inversion. Here we use a linear-inversion process to extract surface-consistent source and receiver terms from observed amplitudes. Linear inversion of model data produces similar results to non-linear inversion, with less computational effort. The final output from the inversion is a calibrated velocity-ratio profile across the survey. For model data we observe that for realistic velocity-ratios, the source term provides the bulk shape of the head-wave coefficient, whilst the receiver term provides the bulk amplitude. These model results, consistent with theory, suggest that the source term should be a more useful indicator of lateral variations in geology.

Linear inversion has been applied to a production Vibroseis data set that had previously been studied using a non-linear inversion method. We obtain similar results to the previous study. However, for both inversions, the source and receiver profiles are quite similar, in apparent conflict with theoretical modelling. This dilemma has prompted alternative parameterisations in the inversion process. Of the alternative parameterisations studied, it is found that simply taking the average of amplitudes at each source location, or receiver location, provides a solution that is similar to both the non-linear and linear inversion results. Further real-data trials are needed to clarify the applicability of this tool for near-surface velocity control.

Dale Harpley, University of Queensland: *Crustal structure under Concordia, Antarctica from teleseismic P and S phases*

P and S teleseismic data are analysed with the Receiver Function to estimate ice and crustal thickness at Concordia, Antarctica. Standard Receiver Function processing of P-wave data on ice sheets is contaminated by reverberations in the ice sheet, concealing the Ps Moho conversion. The S-wave Receiver Function (SRF) can show the Sp Moho conversion which arrives before the main S phase and ice reverberations. The strong reverberations in the P-wave Receiver Function (PRF) are used to measure ice-layer parameters via a Generalised Linear Inversion (GLI). The ice thickness is estimated to be ~3150m (within 4% of ice-core data). A spiking Wiener filter designed on the ice-model inversion is used to attenuate ice reverberations on stacked real-data PRFs. Lag-times are picked for Sp from stacked SRF data and Ps from ice-layer filtered PRF data. Lag times for both P and S are consistent with a crustal thickness of 43-44 km.

Callum Kowalski, University of Queensland: *Experiments in geophysical compressive sensing*

Compressive sensing is a relatively recent development in data acquisition which can improve the economics and logistics of geophysical surveys by relaxing traditional sampling constraints. This work provides simple examples of key compressive sensing concepts, aimed at improving understanding of the topic. Fourier-domain experiments on stationary time series demonstrate the key requirements for signal recovery from sub-Nyquist sampling, namely random sampling and transform-domain sparsity. Extension to non-stationary geophysical time series is more complex. Variations of the Fourier transform handle random sampling, and reduce transform domain noise. The wavelet transform is examined as an alternative to the Fourier transform to demonstrate that recovery is possible via various domains. The iterative Projection Onto Convex Sets (POCS) algorithm is shown to be a simple but effective method of optimising signal recovery. Fourier and wavelet-based implementations are demonstrated on time series. Fourier-based POCS implemented in the time-wavenumber domain allows efficient recovery from spatially-subsampled seismic shot records.

Introducing Marina Pervukhina – *Preview*'s new Associate Editor for Education

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It is with some degree of nervousness that I write this introductory piece. I have taken on the role of *Preview*'s Associate Editor for Education, and responsibility for the *Education Matters* column from *PV* 210, because I am passionate about education. I believe that it makes our lives more colourful, interesting and worth living beyond any perceived promise of better employment or higher income.

In this piece I set out some of my aspirations for future columns, however, some context is perhaps in order. I have been with CSIRO in Perth, WA since 2007 and currently work for their Energy Business Unit studying rock physics, petrophysics, and geophysics of seal shales, research that has a broad range of applications in the fields of energy security, carbon dioxide and hydrogen storage, water and mineral resources recovery to name a few. My path to Perth has meandered through New Zealand (study at the Christchurch Polytechnic Institute of Technology) and Japan (the Advanced Industrial Science and Technology National Agency, and a PhD at Kyoto University), but it started in Russia with physics and applied mathematics. My formal tertiary education has been completed in three different countries, involved three languages and taken over three decades. I have first-hand experience of the evolution of education from a traditional Russian system involving 14-academic hour days of lectures and seminars, to 2020 when the COVID-19 pandemic has perhaps dissolved the last boundaries between online and classroom teaching.

My main goal for *Education Matters* is to bring to the reader's attention to current and emerging trends in geophysical (and related) education. In so doing, I would like focus on particular topics such as machine learning and artificial intelligence, and how readers seeking to diversify their interests might access these topics, whether to leverage their current skill set or to strike out on a new path. Indeed, I am particularly excited about trends in self-directed learning (e.g. Coursera) and micro-credentialling. I believe such diversification is particularly important in uncertain times and could easily open new doors as others close. I would also like to bring the reader's attention to professional development opportunities being made available by the ASEG's sister societies (SEG, JSEG and KSEG).

Of course, I hope to continue the traditions established by Michael Asten. Reports from Australian universities regarding new and changing courses, and abstracts from recent theses are particularly useful to graduates and industry alike in a rapidly changing landscape.

In closing this introductory piece, I would like to thank Michael for establishing such a consistently high standard in exposition and reporting, as well as the ASEG for this wonderful opportunity. I would welcome the reader's input for future columns at Marina.Pervukhina@csiro.au.

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Environmental geophysics

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Inverting Loupe data

Welcome readers to this issue's column on geophysics applied to the environment. This month's column is about some interesting data collected in WA by Andrew Duncan and Greg Street / Loupe Geophysics. As background, a few months ago I wrote in this column that I would be interested in inverting other data sets using Aarhusinv/Workbench, and Greg kindly took me up on my offer. Coincidentally I was already interested in playing with data from that system, as the Loupe is very new and I think it has potential to become an important tool in the near-surface geophysical world.

First, a brief description of the Loupe system (Street *et al* 2018). The Loupe is a backpack-portable, two-person, time-domain electromagnetics (TEM) system that effectively uses the same configuration (basically a Slingram) as a number of airborne EM systems to allow data to be collected "continuously". The transmitter system (carried by one person on a backpack) is a 13-turn induction loop that is ~600 mm in diameter; the coil is mounted horizontally, so the signal is effectively a vertical dipole. It transmits a 20 amp, 50% duty-cycle current waveform at 75 Hz typically, from a height of about 1 m. The receiver system is carried by a second person. It comprises three orthogonal receiver coils with an effective area of 200 m^2 (after amplification); Hx, Hy and Hz are measured. The signals from the receiver coils are carried to the transmitter via an "umbilical" cable that also serves to maintain a set distance between the receiver and transmitting antennae; for this survey that distance was 7.5 m. Positions are recorded using a DGPS system attached to the transmitter. The receiver/transmitter pair are carried over a given survey area at walking speed. Data are sampled at ~500 kHz and stacked for two seconds for each reading. At a walking speed of 5 km/hr, data are collected at ~3 m intervals. Data are windowed into 22 approximately logarithmically-spaced window intervals. The first window is centred ~6 µsec after transmitter shutoff and is nominally 4 µsec wide. The last window is centred ~2.3 msec after transmitter shutoff and is nominally 1 msec wide. These data are processed by stacking and averaging the raw data and then correcting for system response in the same way that airborne EM data are treated. The results are output into the Amira TEM file format (which is pretty convenient, except it includes no information about data repeatability, which is useful in the inversion process – minor gripe from Mike). The data were inverted using Aarhusinv (the engine that drives Aarhus GeoSoftware's Workbench program) in a 12 layer smooth-model configuration. Aarhusinv and Workbench both incorporate depth of investigation (DOI) information estimates as described in Christiansen and Auken (2012). This information is included as black dashes on the two resistivity-depth sections shown later.

Onto the survey at hand. The field area is in Perth, along the Swan River, and is a site that was heavily polluted back into the 60s and 70s by local industry. According to Greg, there was a large fertiliser plant and a landfill both about a kilometre or so northwest of this study site (up-gradient for the groundwater in the area) and the groundwater was heavily affected by both. The area seemed to have been affected by multiple pollution sources: back in the '80s Greg sent some students to the area (wow you're that old Greg?) with a Geonics EM-31 and ended up digging up raw sulphur that had been dumped and buried in the area. The fertiliser plant and landfill were both cleaned up in the 90s, but Greg (and others) are interested in knowing whether things are as clean as hoped. Figure 1 shows the field area, with the Loupe data traverse highlighted in purple. All of those data were inverted, and two resistivity-depth sections were prepared from that as well; the location of Line 4 is shown in red, Line 5 is shown in yellow. Figure 2 shows the Line 4 inverted resistivity-depth section, while Figure 3 shows the Line 5 resistivity-depth section. Figure 4 is a resistivity-depth section cut at 10 m depth.

Figure 1. *Overview of survey area in Perth, WA. All survey lines are shown in purple; the location of Line 4 is highlighted in red, the location of Line 5 is in yellow. Distances along Lines 4 and 5 are shown in white.*

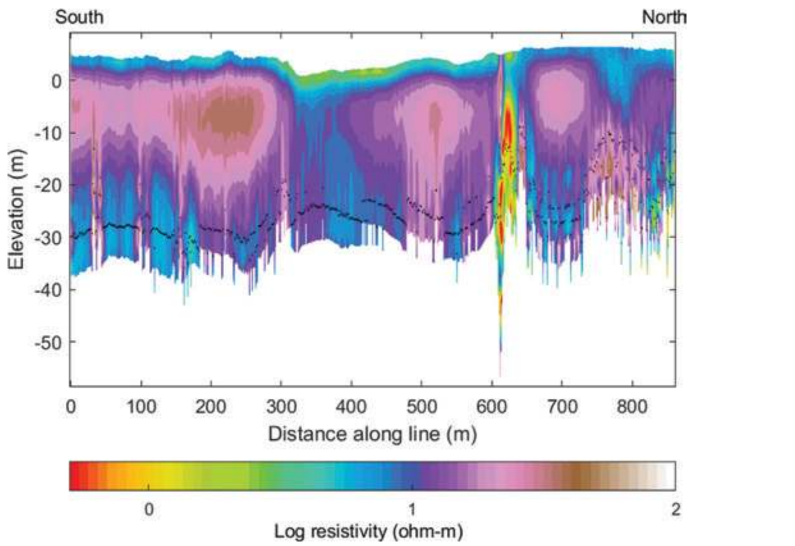

Figure 2. *Resistivity-depth section of Line 4 (highlighted in Figure 1 in red). Black dashes in the plot indicate the DOI as defined by Christiansen and Auken (2012). I don't know what the narrow conductive feature at ~620 m is. From the aerial photo it appears that the line crosses a path – perhaps there is a buried pipeline or power cable at that location.*

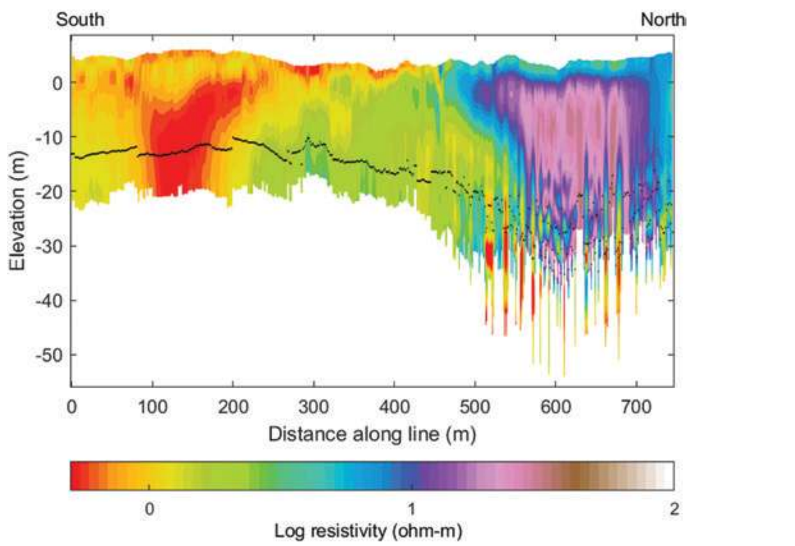

Figure 3. *Resistivity-depth section of Line 5 (highlighted in Figure 1 in yellow). Black dashes in the plot indicate the DOI as defined by Christiansen et al (2012).*

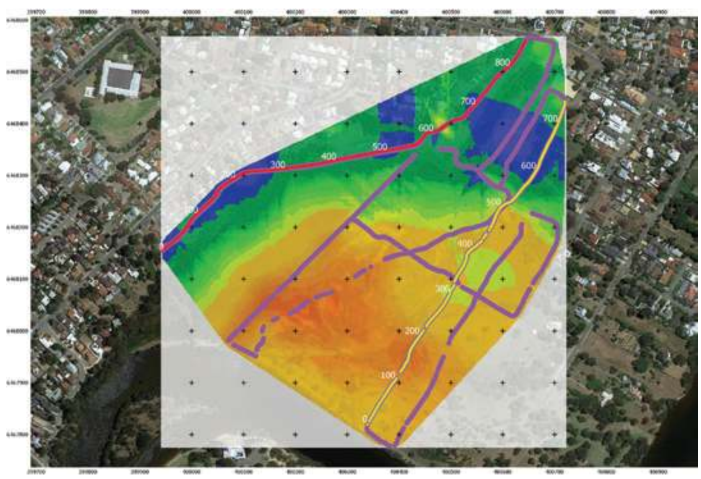

Figure 4. *Resistivity-depth slice at 10 m depth. Line colours are as described in Figure 1. Gridded data use the same colour stretch as shown in Figures 2 and 3.*

Greg and I agree that it doesn't look as if there is a sizeable conductive plume originating from the northwest in this data set (based on the expectation that there might still be something coming from the old plant and landfill sites). To me there is an intriguing resistivity low coming in at depth along Line 4 between stations 350 and 450. And there is a much stronger conductive unit showing up on Line 5 between station 150 and 250 (most likely natural salt accumulation over the years). Like any consultant worth their (not so) exorbitant fees, I recommend that more data be collected at tighter spacing, to provide higher resolution information so we can really see what's going on.

I mentioned Amira format data files earlier – I have a suggestion. Perhaps we need two data files to satisfy my desire for error estimates. They would be the same in every way except that one contains the processed averaged stacked data (as it does now), while the second contains the error estimates calculated from the stacking and averaging process. I'm betting that I'm not the first to think of this, but it seems like a good idea to me.

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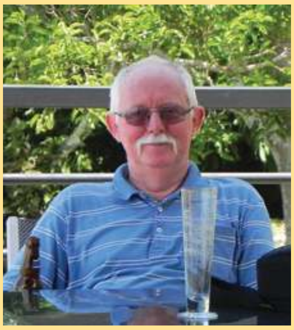
Minerals geophysics



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Drillhole geophysics

Drillhole based geophysics can be subdivided into two styles: logging and surveying. Logging seeks to measure the petrophysical properties of the rocks through which the drillhole passes. Surveying uses the extra access provided by the drillhole to extend and/or enhance the geophysical investigation of the surrounding terrain.

Drillhole logging was pioneered in the oil and gas industry, where the need to maximise the return from very deep and expensive drillholes is paramount. The oil and gas industry has developed and now routinely uses sophisticated geophysical logging tools to measure or derive a range of petrophysical properties for rock type characterisation, with particular emphasis on reservoir-critical properties such as porosity, permeability, fluid identification and quantification, etc.

In mineral exploration, geophysical drillhole logging is more likely to be directed at the petro-physical properties that our ground and airborne geophysical techniques are targeting: density, magnetic susceptibility, resistivity, IP effect, gamma ray radioactivity, etc. Such logging may be aimed at verifying that a geophysical target has been intersected and thus explained, or perhaps providing petrophysical property measurements for input into controlled inversion routines.

In mining operations, particularly if the mineralisation is well ordered, such as in some bedded evaporite, coal, base metal and iron ore deposits, geophysical logging of pattern drillholes can be used for detailed classification of rock properties and correlation of units. There will then be less need for an emphasis on physical sample recovery for geological logging, allowing a cheaper drilling technique to be used. Geophysical logging also has the advantage that petrophysical properties are measured *in situ*, reducing the risk of contamination from adjacent material, which is a concern in some drillhole sampling procedures. In the best case scenario, appropriate geophysical logging (with suitable calibration controls and checks of course!) may significantly reduce or even replace the need to sample and assay ahead of mining. Considerable investigative work on geophysical logging for mining was undertaken at the Century Zinc Mine in Northwest Queensland, for instance.

Drillhole-based surveying, where advantage is taken of sub-surface access provided by drillholes, is quite widely used in mineral exploration and to some extent in the mining industry. Drillhole-based surveying may involve either passive or, more commonly, active geophysical techniques.

In drillhole-based surveying with *passive* geophysical techniques, extra access afforded by drillholes is utilised to extend the range of sampling sites beneath the ground surface. In particular, magnetic or gravitational field measurements may be systematically recorded within the drillhole(s). This may provide critical input into inversion routines which would otherwise have to rely solely on above surface measurements. An often overlooked source of passive geophysical measurements is the drillhole orientation survey where total magnetic field intensity is recorded as part of the dip and azimuth measurement process.

In drillhole-based surveying with *active* geophysical techniques, drillhole access is utilised to position either transmitter or receiver sites (or both) beneath the ground surface to improve depth or precision of investigation. The most widely used example of this approach is electromagnetic (EM) drillhole surveying, where an in-hole receiver probe is used to systematically sample along the length of the drillhole the secondary EM fields generated by energisation from a transmitter loop laid on the ground surface. This can significantly extend the radius of investigation of the drillhole, and is an approach that has been used with great success to guide future drilling where the targeted mineralisation is electrically conductive.

In mineral exploration, drillhole-based surveying may have particular application where surface conditions are not favourable for the application of a particular geophysical technique. With IP-resistivity surveying, for example, where injection of electrical current through highly resistive surface material such as silcrete in Australia or desiccated thick gravels in the Atacama Desert in Chile can be problematic, placing electrodes in drillholes can by-pass these layers. Similarly, if conductive cover diverts most electric current away from the underlying resistive basement, strategically placed drill-hole based electrodes will ensure that a larger proportion of the transmitted current penetrates the basement and traverses the target zone. Sometimes these drillholes may not have been drilled for this purpose, as for example in systematic RAB/Aircore drilling programmes for basement geochemical sampling. However, with a bit of forward planning they may provide an opportunistic means of improving the effectiveness of your survey.

In mining operations, where multiple drillholes are available, hole-to-hole as well as hole-to-surface and hole-to-mining-void geophysical surveys can be used to investigate intervening hitherto untested regions. Specialised techniques include radio frequency imaging (RIM) and seismic tomography (which both utilise computational concepts originally developed for medical imaging) to map out target zones and structures in the region under investigation.

So, if you have the luxury of a drillhole or two in your exploration project area, and it is appropriate, why not take the opportunity to run drillhole geophysical logs to measure *in situ* petrophysical properties of the rock types making up the geological environment, or take advantage of improved access to undertake a drillhole-based geophysical survey to investigate wider, deeper and/or with more precision?

Seismic window

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Reflections….

In the June issue I made the comment "it is incredible how a seismic source that can be barely felt … can provide details of the geology 4 km or more below…" In the late 1970s - 80s a team of technical gurus questioned why the seismic reflection method worked at all. I don't recall the detail of their conclusion but by rights seismic reflection shouldn't work, certainly not as well as it does because the seismic source energy is rapidly dissipated and becomes overwhelmed by noise. Described below are three factors that affect the strength of the seismic wave as it propagates through the earth, but there are more.

Spherical divergence

The largest effect on seismic wave strength is the decrease associated with geometric spreading. As the seismic wavefront travels away from its source the energy per unit area across the wavefront must decrease as the area of the wavefront expands. In a homogeneous medium the wavefront will be spherical and its energy per unit area is inversely proportional to the square of the distance from the source (Figure 1). After travelling a kilometre the energy per unit surface area is one million times less than that at only 1m. Interestingly, surface waves are confined to a boundary and hence, being a 2D phenomenon their strength decreases linearly with distance travelled. So after 1km their energy per unit area is diminished to only 1000th. This partially explains why surface waves appear much stronger than reflected waves.

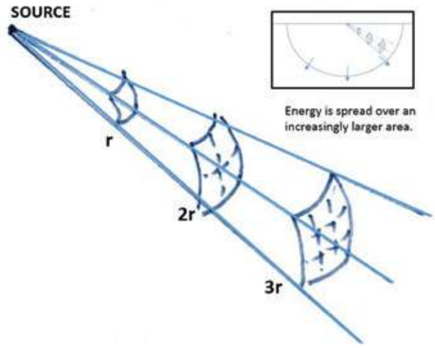

Figure 1. *Illustration of spherical divergence – as the wavefront expands the energy / unit area decreases proportionately with the square of distance travelled.*

Reflections and scattering

The downward propagating seismic energy is partially reflected each time a reflector (a change in acoustic impedance) is encountered. In the example of Figure 2 a significant boundary reflects 16% of the incident energy and 84% is transmitted. Suppose we have 10 similar reflectors every 100 ms two-way time. After travelling 1 second (TWT) the down going energy is $(0.84)^{10}$ of the original energy. A reflection from this 10^{th} layer has passed through 9 layers before being reflected and would be $(0.84)^9 \times 0.16 \times (0.84)^9$ or 0.0069 of the original strength when it is recorded at the surface. This example assumes vertical ray paths and flat planar reflectors. Of course if there is some rugosity on the reflector the reflection may be scattered and never return to the receiver array. And if the ray path is not vertical there will be mode changes at the interface as some energy is converted to shear waves at the expense of the p wave we are trying to record.

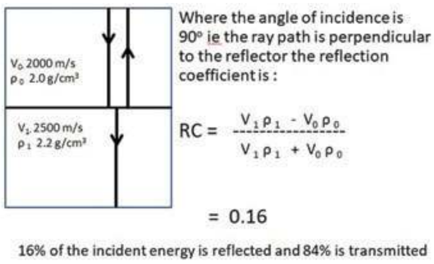

Figure 2. *The down-going ray loses energy at each interface as a certain amount is reflected. In this example 16% of the incident energy is reflected and 84% continues downward (up-going and down-going ray paths are drawn separated for clarity but for vertical rays and horizontal reflectors they are coincident.)*

After spherical divergence and a number of reflections the signal strength is close to one billionth of the input source energy yet despite this we can still produce an image of the subsurface. To illustrate this, if the source was a one kilogram charge at the surface it would be equivalent to a microgram of the same explosive at the reflection point. I'm trying to visualise a microgram of explosive – it's not very big, about $1/50^{th}$ of a grain of rice if my kitchen calculations are accurate.

Q

The quantity Q is a measure of the loss of energy caused by internal friction when one grain slides against another and creates heat. Some typical values (Table 1) show Q can vary between 20 and 100 for sandstones and shales while more consolidated limestones and quartzites can have a Q value up to 600. The inverse, 1/Q is the percentage of energy lost in each cycle and is independent of amplitude and frequency – the same percentage of energy is lost per cycle irrespective of frequency. Because high frequencies have more cycles than low frequencies in a given time there is preferential attenuation of high frequency information.

A sandstone with Q = 20 loses $1/20^{th}$ or 5% of its energy every cycle while a much more consolidated quartzite with a Q = 300 loses only 0.33 % per cycle because relative movement

Table 1. Some measured values of Q taken from "Reflection Seismology" by Kenneth H Waters, 1978

Rock sample	Q	1/Q (%)	No of cycles to reach 10% of original
Granite	311	0.32	700
Basalt	561	0.18	1300
Marble	547	0.18	1250
Quartzite	392	0.26	900
Limestone	203	0.49	950
Amherst sandstone	24	4.17	55
Old Red sandstone	93	1.08	210
Pierre shale	17	5.88	38
Sylvan shale	72.5	1.38	160

between adjacent grains is restricted by recrystallization.

With Q included we now have a reflection one ten-billionth of the source energy. However all is not lost, because we can apply corrections such as spherical divergence correction and q compensation to boost the amplitudes back to something like the amplitude near the source. But these corrections are also applied to noise which is ever present at low amplitudes – boosting noise is detrimental to the final product so there are also many ways to reduce noise (the most robust being stacking) in the seismic processing centre.

Some loose ends

Earlier this year readers were invited to enter a competition to win a bottle of wine. There were no entries so the bottle was opened at a poker evening and found to be the best red ever consumed by the attendees.

In June 2016 I wrote an article on the boom and bust nature of the oil industry and predicted things were looking up. Unfortunately the oil price has not recovered over the last 5 years and is still trading around $US 40.00/bbl. Like many of my colleagues, I am available.

ASEG Research Foundation

Attention: All geophysics students at honours level and above

- **You are invited to apply for ASEG RF grants for 2021.**
- Closing date: **1 March 2021**.
- Awards are made for:
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- Awards are made to project specific applications and reporting and reconciliation is the responsibility of the supervisor.
- Any field related to exploration geophysics considered, e.g. petroleum, mining, environmental, and engineering.
- The completed application forms should be emailed to Doug Roberts, Secretary of the ASEG Research Foundation: dcrgeo@tpg.com.au

ASEG Research Foundation

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

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

Management: The ASEG RF Committee comprises ASEG Members from mining, petroleum and academic backgrounds, who serve on an honorary basis, and who share the administrative costs to spare Research Foundation funds from operating charges.

The funds are used in support of the project, for example, for travel costs, rental of equipment, and similar purposes. Funds must be accounted for and, if not used, are returned to the ASEG Research Foundation.

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

Data trends

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Pseudo data, artefacts and recursion - it's all about the run up

Grids accumulate artefacts with every process as they migrate away from their original self. Merging grids inevitably involves combining data sets with different DC shifts, and false edge effects occur as surrounding cells ramp up or down in transition to a new "local" DC. Merging point data often imposes more irregularity onto already irregular spaced data and the grid develops pimples where unlevelled points overlap. Variable density gridding merges well but often, if set to retain original data values, can produce a pimply visual experience. Some methods retain original values by stamping them onto a finished grid that, formed without using those explicit values, can impose incongruities. A beneficial idea casually came from the always humble Clive Foss, who was on a quick visit to the GSSA. A simple sounding solution that shines with recursive beauty.

Start with wide spaced gridding of real data and include the data values generated (pseudo data/points/stations) to create a smaller spaced grid.

At its simplest (see Figure 1):

1. Grid points x distance apart (black circles) with 1/4 spacing
2. Observe three (pseudo) points generated between the original data points (the red and green circles)
3. Convert the grid into a data set
4. Delete the first and third pseudo data points (red circles)
5. You now have a data set with half the original spacing (x/2)
6. Set X = X/2 and repeat from step 1 until satisfied.

At step 5, you could replace the remaining middle pseudo data (green circle) with a nearby real data point. More cells between data points smooths out differences and your algorithm has enough run up to fit this real data without (at least less) incongruity.

You could recursively grid any image down to as small a cell size as possible. The hard part is sorting your point data into your spacing groups. Spacings (x) that are multiples of two are easiest to deal with, but don't let that stop you experimenting.

A description of this method's application to the 2016 South Australian Gravity Grid can be found here: https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/RB201700012.pdf

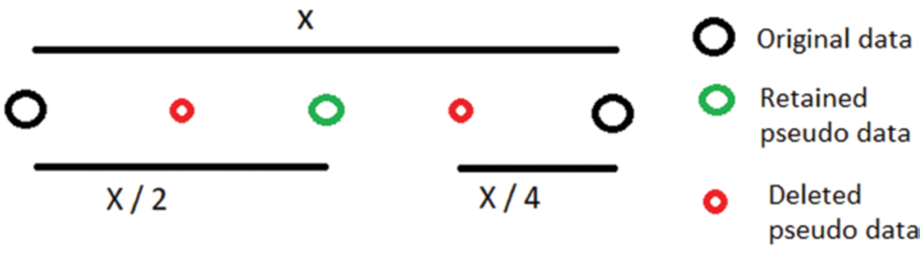

Figure 1. *Points used and created by a gridding process. Original data (black circle) spaced distance X apart. Generated pseudo data (green and red circles) are created X/4 distance apart. Green circle indicates point value used in the next iteration of gridding points at X/2 distance apart. This may be a pseudo data value or substituted with a real value.*

Webwaves

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Preview comes of age

The online publication of *Preview* 209 marks the second year of *Preview* being published on the ASEG website. The *Preview* pages continue to be very popular, with 5440 views from countries across the globe, as seen in Figure 1. Encouragingly, the average user spends 5 minutes 58 seconds on the page, indicating that people are reading *Preview*, either as our online Flipbook or by downloading the PDF copy. Each digital PDF copy of *Preview* is downloaded an average of 252 times. Views typically spike around release day, with a large percentage of users accessing the website directly from the email notification of a new *Preview* release. ASEG has also created a mailing list for non-members to get email alerts for *Preview* releases, broadening access to *Preview* in the wider community. Signup to this mailing list can be found on the publications and *Preview* pages of the ASEG website (https://www.aseg.org.au/publications/overview).

Having firmly established the process and readership for online publication of new *Preview* releases, we are now focussing our efforts on the back catalogue. The end goal is to have all ASEG publications in one location that all of our Members can access. I have been busy uploading and arranging the historical archives of *Preview* on the ASEG website. This *Preview* digital library can be viewed at the following link (https://www.aseg.org.au/publications/preview-digital-library).

All past issues have been laid out as a year per row, topped by our special gold issues for the 50th anniversary of ASEG in 2020. You can see that the current branding started in August 2014 with updated artwork, when Greg Street was President and Lisa Worrall became Editor. As you scroll through the years, you can see the annual colour themes. The colour themes started in January 2008 when David Denham, as Editor, introduced them starting with *Preview* 132. Going back another 16 years, you can see that the first colour issue of *Preview* was released in 1992 with Issue 41. Further back still, we lose resolution, with some glaring omissions in our *Preview* collection: Issue 2 in 1986 through to Issue 14 in 1988 are missing. If anyone has a copy of these, please get in touch so we can complete the *Preview* archive.

Work on the publications section of the ASEG website is ongoing, with plans to have all ASEG publications available to Members online and in one location. The next phase will be to create a Members-only page to host *Exploration Geophysics*, with the first tranche of uploads including all of the *Exploration Geophysics* releases published through Taylor and Francis. To view and access ASEG publications, go to the ASEG website here: https://www.aseg.org.au/publications/overview.

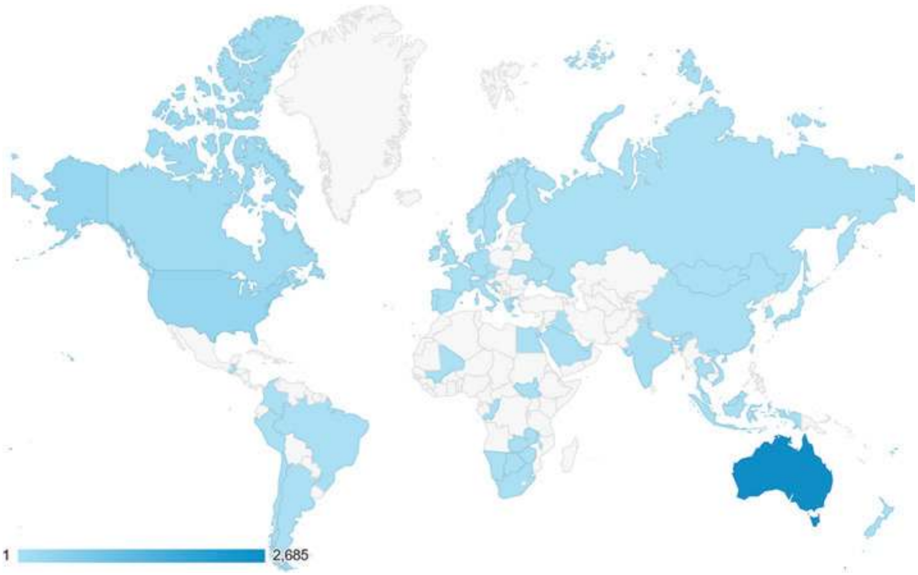

Figure 1. *Online Preview readership by country.*

Figure 2. *The Preview digital library highlighting the annual colour themes.*

Divination: A geophysicist's view, science or séance?

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Introduction

Near-surface geophysics was the subject of a timely and thoughtful article by Mike Hatch in these pages last year (*Preview* **198**). It prompted me to think about the performance of geophysics applied to the first few tens of metres of the subsurface in environmental, including metallics (buried drums and scrap), hydrogeological, unexploded ordnance (UXO), forensic, engineering, and mineral investigations by highly trained scientists and engineers. The near subsurface is a difficult medium, often having capricious lateral and vertical variability. This pertains to physical properties and boundaries of rock units and other materials. Is there an easier way of locating features in the subsurface? Our competitors would claim so. Perhaps they can teach us something. Welcome to the realm of the paranormal. The method is a particular type of divining. The operators are dowsers. Practitioners are seemingly serenely unconcerned with, or restrained by, the above considerations.

The geological sciences developed in the late 18th century, geophysics in the 20th. Divining emerged from the mists of antiquity and depends on the reaction of a simple device, often a forked piece of wood (Figure 1). It was, and still is, used by lay people and some professionals. Divining is charismatic and cheap; geophysics is workaday, and it costs. Divining is cloaked in mystery; geophysics is open and operates on established scientific principles and continually strives to develop and improve its instruments and data analysis. Divining is indifferent to error, and immune to derisive criticism from the educated and the elites. It is a background business, conducted with enviable confidence, and endorsed by many.

Divining has a fascinating history. This article, admittedly rambling, discursive and subjective, may be of interest to *Preview* readers, especially those intrigued by the unusual.

Early divination

In all cultures, from antiquity through Medieval to Renaissance times, divination involved inspired messages from deities or the supernatural, received by intuition, invoked by incantation and ritual, and revealed by interpretation. In ancient Rome there were three categories of practitioners: ceremonial priests (dealing with Sibylline Prophecies), haruspices, and augurs. The latter two observed and interpreted avian, animal, sacrificial, and celestial (astrological) signs. A strong body of opinion regarded it all as probably ridiculous and at best dubious, as reported by the orator Cicero (106-43 BC) in his

Figure 1. *a dowser at work in 18th century France.*

De Divinatione where he questioned how many predictions actually came true, and also noted that the severe, highly moral Cato the Censor (234-149 BC) had wondered how one diviner did not laugh on meeting another (to rejoice in human gullibility). Yet divination was taken seriously, by many, and woe betide the doubters.

One divining instrument was bird behaviour. Cooped sacred chickens were a field-tool used by the Romans on campaign. The omens were good if, after the cage doors were opened and feed provided, the chickens displayed poor table manners i.e. they ate greedily and dropped grain from their beaks – the spillage test. In 249 BC Publius Claudius Pulcher, an impatient Roman naval commander in a sea battle with the Carthaginians, frustrated that the sacred chickens would not feed, threw them into the sea shouting "Let them drink, since they don't want to eat." (Figure 2) Sadly, Publius Claudius was routed; the prescient birds drowned. Poor chooks.

Nowadays there are chickens galore – not to be selected and fed in obsolete ritual, but to be fed on, by the masses. Birds could still help in divinatory matters. After consuming a chicken roast dinner, the wishbone (fused clavicles) is easily retrieved and may function (gnawed clean) as a handy, pocket, mini divining tool. Its rough, stubby similarity to the popular forked twig should make it acceptable for a devotee to divine, at will, day or night. If it fails to reveal hidden delights, then one could always break it and make a wish instead.

Divination's survival

The eventual triumph of Christianity, in the Roman Empire during the reign of Constantine (AD 285-337), led to the suppression of pagan practices. They were deemed heretical. Divination suffered quite a shock. However, like the residual radiation from the Big Bang, the old beliefs survived, settled at large in the general population where social movements,

Figure 2 *An early form of divination. Sacred chickens were a Roman divinatory field-tool. Chooks with a good appetite for grain were a favourable omen. Before the 249 BC naval battle of Drepana, during the first Punic War, an impatient Roman fleet commander, Claudius Pulcher, much vexed by the birds' refusal to eat, ordered them to be thrown into the sea, to drink instead. After such a sacrilegious breach of divination protocol he was soundly defeated by the Carthaginians. (Perhaps his more prudent crew, sizing up their opponents, fed the chickens earlier in a futile attempt to avoid battle.)*

sects, fortune tellers, and quacks continued to operate. Nowadays some of these activities are esoteric, and some are mundane, such as astrology. It is peculiar, and relevant in the context of divining, that the para-science of astrology still survives, indeed thrives. Astrology embodies the Stoical belief in a universal "sympathy" coupling humans in the microcosm to nature in the macrocosm. Thus, the configuration of the heavens at one's date of birth decides one's lot and luck in life. Astrologers' cosmic reckonings are now daily available in the back of magazines and newspapers to titillate the believers and entertain the cynics. Who can resist a surreptitious glance at one's horoscope – a personal slice of the heavens? On the other hand, dowsing thrives as an esoteric activity, beguiling and mysterious, and readily carried out by the "gifted" using a pedestrian prop.

Divination is associated with the earth or earth materials in several ways including geomancy, scrying, and rhabdomancy. Geomancy is the divination of patterns of stones or sands on the ground or thrown on the ground. Scrying is practised by portentous seers who gaze fixedly into a rock crystal and describe and explain images seen therein. The rock crystal is quartz, either as a hexagonal prism or a smoothed ball manufactured from a large crystal. But rhabdomancy is our focus, it is the domain of the dowser.

Rhabdomancy

The ancient Greek word for a rod, stick, switch, stave, baton or wand is ἡ ῥάβδος, rhabdos. Over millennia, lengths of wood have been used by humans for foraging, fishing, spearing, walking, climbing, surveying, measuring, goading, enchantment, thrashing (preferred implement of chastisement in boys' high schools of yesteryear), and especially as symbols of authority e.g. the imperial sceptre, and the Roman *fasces* (bundle of rods carried by a magistrate's lictor). Rods have been used in medicine. In the late 19th century short metal "tractor" rods (*tractare*: to touch, massage, drag around) were applied by a Dr Perkins to his Connecticut patients for the relief of aches and pains due to "noxious electrical fluid". This procedure was deemed, by his peers, to be quackery. Rods are a device in popular contemporary fiction. Magic wands are Harry Potter's indispensable tools for wizardly activities in a series of well-known fantasy novels, and, for aficionados, a wide range of them are commercially available to suit every occasion.

An additional function for a rod is in rhabdomancy (ἡ μαντεία : divination). It is so used to produce, or seem to produce, magical, marvellous, mysterious, or miraculous results e.g. searching for and finding minerals, water (water witching) and other objects, in the near subsurface. The instrumentation is basic: a divining rod, held by a dowser.

Rods can have a variety of shapes including a straight, forked (Y), bent (L), and divergent (V). Rods can be rigid or flexible (bobbing). The Y rod is frequently used, it is picturesque, and the fork furnishes a handy grip. In the hands of a dowser, with the right knack, a rod of any configuration moves to indicate hidden treasure, or so it is claimed. The L rods are quite popular too. They achieved a recognition of sorts in Russell Crowe's 2014 movie The Water Diviner in which he surveys a rural paddock with a pair of L rods. The short parts of the rods (base of the L) were held in the hands, while the long parts of the rods, horizontally positioned leading the way, crossed over each other above an underground location deemed to contain water. This location was duly marked by pushing the long ends of the rods into the ground.

The Old Testament of the Christian Bible (Numbers, 20, 7-11; and Exodus, 17, 6) records the striking success of the 13th century BC prophet Moses in finding water under the Lord God's guidance. Perhaps this is the earliest report of dowsing. A rod was used by Moses to smite a rock and provide water for his people in the wilderness (Figure 3). This is quintessentially divinatory. It ticks all the boxes: the supernatural (the Lord), a select and gifted agent (Moses), a rod, geology (rock), the movement of the rod towards the sought substance, and the scientifically inexplicable bounty.

What are we to make of this, and the profusion of claims since then? Consider astrology; there is a vast corpus of astrological literature (documents, texts, charts, symbols, forecasts) explaining its methods and predictions. The same applies to geophysics. However, there is little available on dowsing except faith, word of mouth, commendations, anecdotes, and hearsay. Accordingly, an appreciation is difficult, but we will try.

Figure 3. *The prophet Moses scores a striking success as a water dowser.*

Empowered woods

Antiquity regarded some woods as magic materials. Fruit bearing trees such as the hazel (nuts) and the oak (acorns) were thought lucky. Actions performed with their branches passed on that luck. Tacitus (AD 56-117+) in his *Germania* reported that the German tribes cut slips from a branch, marked them, cast them onto a white cloth, and then interpreted three chosen slips for signs of approval or disapproval of a proposed activity (frequently of a lethal kind). At summer solstices, after sunset, Scandinavians laid slips of mistletoe to identify subsurface treasure which, if there, moved the slips. Cicero in his *De Officiis* wistfully invoked the *virgula divina* as a magic wand to supply every want and comfort. The *virgula divina* was the original divining rod but virtually nothing reliable was written about it in antiquity, the dark ages, and medieval times. However, it must have been in use for a long time before it appeared, fully functional, in Germany during the Renaissance. In 1518 it was denounced by Luther as a satanic violation of the first commandment. Later it was for the first time discussed by Agricola in his monumental mining text *De Re Metallica*. Figure 4 depicts a dowser wandering around the ground above a mine.

We shall now discuss Renaissance attitudes to divining. The views of three outstanding early modern scientists are worthy of attention: Georgius Agricola, Robert Boyle, and Althanasius Kircher. Agricola, an empiricist, was a brilliant and thorough synthesiser of mineralogical data and mining practice. Boyle was a gifted investigator, a great experimenter, and skilled in analysis. Kircher was a gadfly polymath, cerebral and imaginative, and very influential in his time (Figure 5).

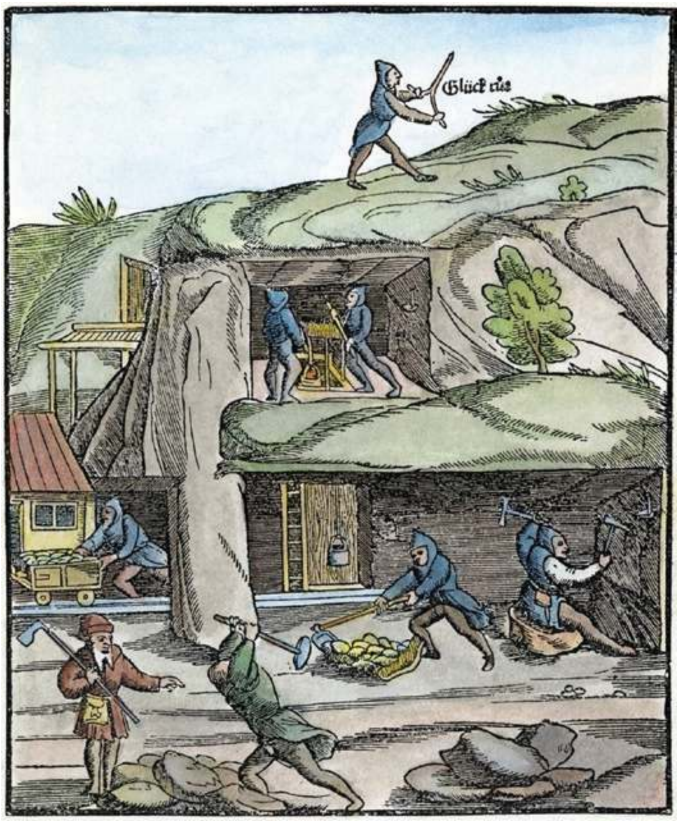


Figure 4. *A mining and prospecting scene in 16th century Saxony-Bohemia. This woodcut is from the 1580 edition of Agricola's De Re Metallica. Below, sweating miners hammer, tunnel, raise and truck ore. Above a dowser roams, forked twig erect, to conjure up more mineralisation.*

Figure 5. *Three very influential pioneers of early-modern science interested in divining: (left) Georgius Agricola German physician, (middle) Robert Boyle English Scientist, and (right) Athanasius Kircher German Jesuit polymath. Agricola published several landmark works on mining (notably* De Re Metallica*), economic mineralogy, and geology. Boyle founded modern chemistry and made advances in the field of early experimental physics. Kircher was an inventive and versatile scholar who contributed significantly to geological knowledge (Mundus Subterraneus). All had outstanding intellectual abilities. The three had direct experience of divining and were well aware of the divine. Their attitudes to divining differed (see text).*

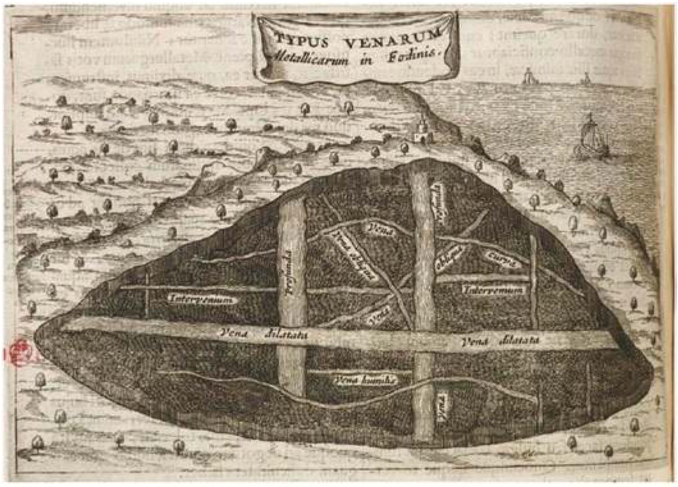
Prospecting in 16th century Saxony-Bohemia

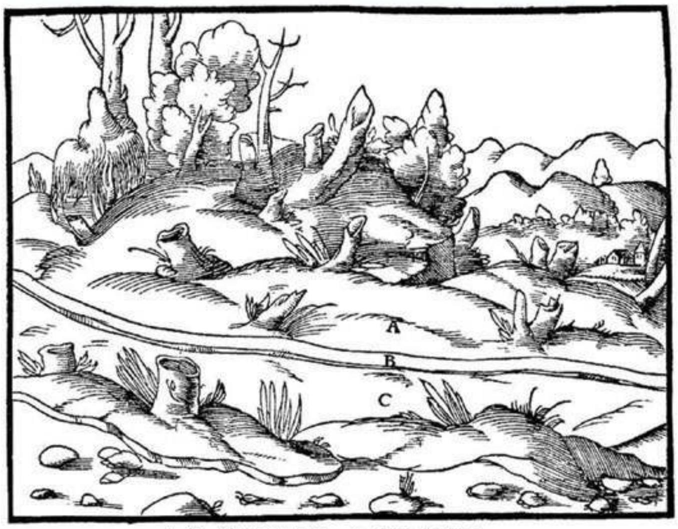
In a region of Europe, about 200 km south of Berlin and 100 km northwest of Prague, lie the Ore Mountains, the Erzgebirge, of old Saxony-Bohemia. In mines of this region, polymetallic sulphide and oxide mineralisation hosted by veins and veinletted stockworks, in and around granitoids, gneisses, and felsics, were extracted and processed, for centuries. Georg Bauer (1494-1555), a respected physician in a local town, studied the local mineralogy, exploration, and mine practice, documenting his findings in several books under his Latinised name Georgius Agricola. His *De Re Metallica,* with its wonderful woodcut illustrations, was published in 1556. As learning revived and emerged from the medieval mindset, Agricola was one of many able men and women who objectively and accurately documented matters in which they were interested, and which they personally and carefully investigated. Agricola carried out such a study on prospecting, including divining, in the Erzgebirge.

The town of Freiberg, on the northern flanks of the Ore Mountains, was mentioned by Agricola as having risen to prominence because of its silver-lead mines. Freiberg, later, through its Mining Academy, became the centre for European exploration and mining geology. The mineralisation here was typical of the prospecting targets in the 1500s, so is used as an example in the article. The Freiberg steeply inclined fissure vein system was discovered by chance around 1170 when a torrent of rain cleaned out wagon wheel ruts, exposing a mineralised vein.

The vein mineralogy included galena (PbS), pyrite (FeS_2), ruby (native) silver (Ag), argentite (Ag_2S), cassiterite (SnO_2), magnetite (Fe_3O_4), haematite (Fe_2O_3), other sulphides, and quartz, carbonates, and barite. The mineralisation was generally low grade but enriched at the intersection of fissure veins. The shallow oxidised ores were rich in native silver and argentite. The host rock was biotite gneiss.

Agricola called these steeply inclined fissure veins *vena profunda* (profunda: deep, Figure 6). Vein width ranged from 5 cm to over 1 m. Vein spacing was roughly of the order of tens to hundreds of metres. The more valuable argentiferous veins had a N-S to NW-SE strike. The veins can be conveniently grouped as silver-lead, quartz-lead, barite-lead, and barren, as shown in Figure 7. The ores probably lacked salient physical properties except perhaps for a high conductivity in pods of ruby silver – argentite





A. C.—The mountain. B—*Vena profunda.*

A—*Vena profunda.* B—*Intervenium.* C—Another *vena profunda.*

Figure 6. *Top: There were several types of Ore Mountain veins. These are depicted (from Book 10 of Kircher's Mundus Subterraneus 1678 edition: "types of metal veins and mine workings"). Vertical (profunda), inclined (obliqua), flat (dilatata), and deep (humilis) veins were encountered. Vertical or steeply inclined veins were common in the Freiberg field during Agricola's time. Agricola's depiction of outcropping steeply inclined veins vena profunda (profunda deep). Middle: a single vein on the side of a mountain. Bottom: two veins traversing steep topography. These deep, steep, veins ranged from 5cm to over 1.5m in width; the vein spacing ranged from 10s to 100s of metres. From De Re Metallica Book 3, 1556 edition.*

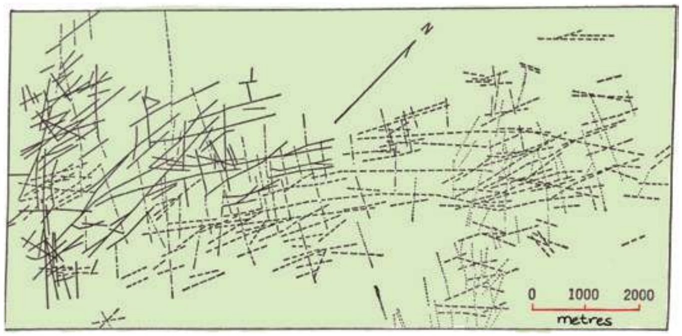


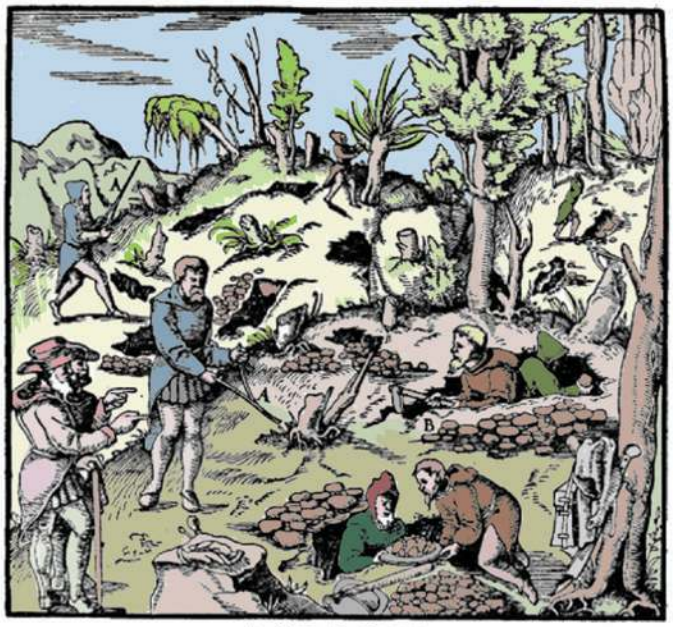
Figure 7. *The Freiberg vein system showing rich silver-lead veins trending N-S and NW-SE (black solid lines); lead-quartz veins (dashed); lead-barite veins (dotted); and barren veins (dots and dashes). After Figure 5.4-9 Economic Mineral Deposits by A.M. Bateman 1959. John Wiley & Sons.*

in the oxidised zone. Low to moderate erratic conductivity would be the best that the other sulphides could manifest as most of the sulphides were cubic, a habit which is not advantageous for high conductivity when aggregated (see my comments on pyrite in *Preview* **203** last year). However, the ores had a physical character suggesting that geophysics (magnetics, electromagnetics, resistivity / IP) could be usefully applied, at least indirectly, in exploring for Freiberg type mineralisation. In Agricola's time, however, there were three techniques: visual observation, costeaning (pitting, trenching), and divining, as outlined in Table 1.

Figure 8 is a delightfully informative woodcut from Book 2 of *De Re Metallica*. It depicts, on a hilly site, an interesting cast of characters engaged in prospecting. In the right foreground, two

Table 1 Summary of 16th Century Prospecting Techniques, Book 2 *De Re Metallica.* Ag-Pb Fissure Veins, Ore Mountains, Saxony-Bohemia

Eyeballing			
	Direct Recognition	→	Scree, alluvials, shed from veins
		→	Bushfire burn-off, exposed veins
		→	Torrential rain, exposed veins
	Indirect Recognition	→	Geobotanical signs: stunted tree growth, tree foliage over veins resists frost damage, particular herbs & fungi grow near & on veins
Digging			
	Surface Pits		To intersect veins → Samples
	Surface Costeans		
Divining			
	YRods-Forked Twigs: must be right size neither too large nor too small		
		→	Hazel for Ag min.
		→	Ash for Cu min.
		→	Pine for Pb/Sn min.
		→	Iron/steel for Au
Protocols		→	Correct grasp of sensing device, random wanderings – muttered incantations
Result		→	Gyration of twig/rod towards vein



A—Twig. B—Trench.

Figure 8. *Surface prospecting in 16th C Saxony-Bohemia showing supervisors, workmen in pits and costeans, and dowsers. From De Re Metallica Book 2, 1556 edition.*

prospectors seem to have discovered interesting ore in their surface pit, towards which one diviner's twig points, *after* the discovery. The ragged stump of a dead tree is nearby, perhaps its roots were poisoned by the mineralisation below. Behind them, another two prospectors continue with their costean. In the top right a prospector hacks into an outcrop in front of a blazing tree, set alight to get rid of it. In the left background a dowser wanders, twig erect, ready for a response. In the centre background another dowser is cutting a branch from a dead tree, and behind him are other dead trees. Eight stumps complete the scene of a site cleared for prospecting (even in the 16th century, forest clearance for mining was a contentious environmental issue, which Agricola acknowledged). There are four other abandoned prospecting pits, or gouges, with extracted rubble left on the surface. In the lower left a prosperous looking gent, replete with hat and walking stick, and gloves laid on a nearby tree stump, points to the workmen in the second pit. He could be an entrepreneur, the owner of the site, hoping for more productivity. The other hatted fellow could be the overseer. In the lower right next to the miner's kit a sword in a scabbard rests against a tree – possibly a symbol of the political and religious turmoil during the Lutheran Reformation in Europe. Agricola was a staunch Catholic living in a Protestant area but was respected by all for his professional work (medical and mineral), decency, and integrity.

According to Agricola, dowsers claimed that only they had the correct twig-skill (right size, right material, correct clench) and as true dowsers, devoid of "impeding peculiarities", they were assured of success in getting the twig to respond to the mineralisation 'vein power' as they wandered around, muttering incantations. Presumably 'vein-power' was believed to be a type of paranormal emanation to which a cognitively gifted dowser was attuned, using a forked twig or similar accoutrement such as a metal rod as a focus.

Veins were alleged to induce a gyrating twisting motion in the forked twig. Agricola did not doubt that the twig moved, but rejected the bona fides of the actual movement using the analogy of the magnet which does not turn iron, rather draws the iron directly to itself – so the twig should move itself only once in a semicircle directly towards the vein. Clearly, the gyration was part of the show, along with the verbals. Agricola regarded divining as a relic of heretical wizardry embraced by "'unsophisticated commoners". He regarded dowsers as "cunning manipulators" whose occasional success was due to chance. He believed the "good and serious" miner / prospector should have nothing to do with divining. I think Agricola's criticism of divining, four and a half centuries ago, is telling, and still quite relevant.

As is evident in Figure 7, there were numerous veins in the Freiberg system. There would have been a lot of local lore about them: known strikes, long strike lengths, many intersections with enrichment zones, and frequent cross-strike outcrop or sub-outcrop occurrence. Hardly the random plum target buried in a big pudding. A shrewd observer would have been aware of this and would have tried to use it to advantage. But to no avail. Conventional prospecting revealed the Freiberg mineralisation, not divination. Costeaning, pitting, trenching is very hard work. If there was a reliable method of finding ore, it would have been eagerly adopted. Dowsing is a lot easier, but it was not found to be useful in finding shallow ores.

Mining was a serious business in Agricola's time. He lived in the reign of the Saxon Elector Augustus 1 (1526-1586) and in his preface to *De Re Metallica* he declared himself a "dear and faithful subject" of the exalted ruler. Augustus believed in economic development and surveyed his lands for mineral deposits. Silver was especially sought after as it was virtually a form of currency, serving as an essential financial instrument in the exercise of Augustus' power. Mining improvements were encouraged, and miners held in high esteem; princes sometimes attended feasts dressed in miner's garb. If dowsers with divining rods had facilitated the discovery of silver and the establishment of mines there would have been a record of any discoveries and of Augustus' enthusiasm for the technique. There is no such documentation because, as Agricola indicated, it did not work.

Seventeenth century opinion

The 17th century saw the flowering of very able scientific intellects in many fields as the influence of the pseudoscience of astrology waned. In England, William Harvey published his treatise on the circulation of the blood in 1628. The Royal Society was established in London by 1660. The renowned Sir Isaac Newton developed the differential calculus and gravitational theory in the 1665-1684 period.

The impressive Irish physicist and chemist Robert Boyle (1627-1691) established modern chemistry with his *Sceptical Chemist* in which he defined the chemical element as the ultimate limit of chemical analysis. He also researched specific gravity and (Boyles Law) showed that the pressure and volume of a gas are inversely proportional. An indefatigable character, he had the New Testament translated at his own expense, and circulated, in Arabic, to Muslim countries of the East; its reception can be imagined. He was very curious about divining and was no fool. He observed metal dowsers at work in the Somerset lead region in England where mineralisation occurred. He accepted the movement of the rod but was puzzled by its cause. He was not convinced that it really worked as advertised. Presumably, he did not endorse the belief of tin miners (to the southwest in Cornwall) that fairy power turned the rod i.e. pixies, the guardians of mineral treasure, guided the rod to ore. It was a loss to early science that he could not devote more time to the problem. Boyle was a busy person involved in numerous projects.

The theories of mineral formation were many and varied in Renaissance times. The views of a supreme alchemist of the time, Johann Joachim Becker (1635-1682), typified the emergence of modern theories. He did not believe the astrological claims of the planetary procreation of a mineral, with each metallic having an astrologically decipherable signature configured on its planet's surface. He called them out, saying that they did not see a metal's symbol reflected in the features of a planet, rather they saw donkeys, because such quadrupeds were their own (i.e. astrologers') reflections. He believed in an immense fire vault at the earth's centre. Conveniently, this doubled as the Hell of pious theologians who contemplated with relish the tortures of those damned therein. This intense heat was deemed to vaporise water and metallic "seeds" which, when exhaled on or near the surface, would condense in basins, voids, and cracks forming oceans, springs, and metal deposits too such as gold veins distilled from auriferous vapours. Such underground "sweated" deposits were believed to continue to emit their essence as finely textured corpuscles to the surface.

Theories of this type were influential in the time of the extraordinary Jesuit Athanasius Kircher (1601/2-1680). Based in Rome, he wrote a pre-modern geology and mineralogy textbook, which included sections on mineral exploration. In his *Mundus Subterraneus* [10, 17], in sometimes opaque Latin, Kircher wrote about divining. I translated this as no one else appears to have done so, but I will spare the reader the slabs of his Latin text and provide a summary instead. Kircher discussed

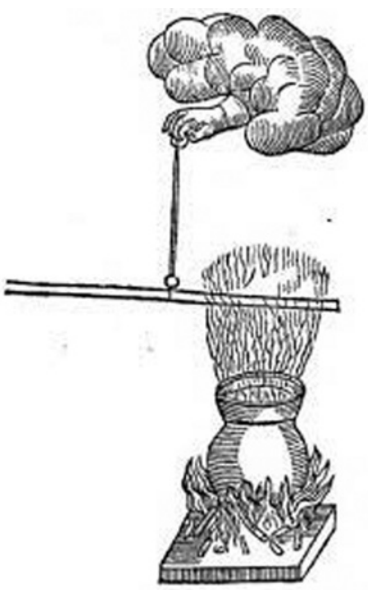


Figure 9. *Kircher's idea of how a divining rod could work is depicted in one of his experiments. A composite wood – rock salt rod is suspended as shown above a pot of boiling brine. Kircher thought that sympathetic interaction between the rod salt and the pot salt had made the rod end absorb salt from the vapour and thus cause it to incline. He regarded this result from a special, material specific, type of rod as verifying the divination method, but only for a sympathetic couple e.g. a gilded rod for location of a gold deposit. Unfortunately, the vapour here is water, not a salty steam, and the rod's rock salt, being hygroscopic, simply absorbs water vapour condensed on it. This and a couple of other experiments run by Kircher appear to be the only published laboratory attempts to justify divination. Kircher did not seem to have field tested his ideas.*

the problems of believing in the efficacy of divining with any arbitrarily chosen forked twig. Superstition was rife e.g. the credulous thought that Satan was involved. Various tests with rings suspended by a cord indicated that finger/hand tremor, the twist of the thread, or muscular action could make the ring rotate and result in rings pointing in particular directions e.g. an iron ring would indicate north. The argument here is that hand spasms could also move a divining rod. He ridiculed the idea that any old twig could find anything, beyond chance. He then proceeded to outline his ideas and some experiments, because, as he stated, no credible explanation had yet been given for the divining rod's movement in the hands of a dowser (beyond muscular spasm). He believed, it seems, in emanations of the Becker type, and also in the vague ancient Greek theory of συμπάθεια – sympathy between materials e.g. ink and water combining readily, magnetic attraction, the sun absorbing water. Magnetic attraction, the *magnetismo* quality, furnished him with a suitable analogy for his belief in a like-to-like attractive mechanism.

In his laboratory Kircher fashioned a composite rod of wood and NaCl (rock salt) and suspended it over a pot of boiling brine (Figure 9) with one half of the rod over the exhaled vapour. He thought the salt in the brine was sympathetically attracted to the salt on the rod and was extracted from the vapour to be absorbed by the rod end, thus causing it to incline. In this way divining could work because, he thought, by analogy, kindred subsurface metal sources and rods should interact e.g. gold ↔ gold. Unfortunately, this reasoning was flawed. The vapours are not some type of salty plasma but steam i.e. water (why else do we have evaporation pans for residual salt production), and NaCl, even as rock salt, is quite hygroscopic, absorbing water condensing on it. This was the reason for the inclination for the rod, not sympathetic attraction. Kircher rejected ordinary divining but believed tailor-made rods should work for specific targets. Kircher never published any field test results for his apparatus.

So we see that: Agricola refuted the divining rod and the dowser, empirically; Boyle was sceptical; and Kircher, while seeming to reject the practice if it used arbitrary forked twigs, actually believed in sympathetic coupling between a rod and a kindred subsurface substance, but never field tested his ideas with his tailored rods. So the debate continued.

Dowsing down the centuries

Any divining procedure that bypasses the tedious constraints and complexities of geology, physics, and hydrology, and offers simple subsurface enlightenment, is bound to attract attention and controversy, and indeed it has, from around Agricola's time to the present.

Water search, or "water witching", also succumbed to the diviner's embrace in the 16th century. Doubtless inspired by Moses and the rod, St Teresa of Spain in 1568 sought the services of a friar for a convent water supply. Twig in hand, the good friar moved, stopped, seemed to make the sign of the cross, and indicated by movement of the twig where to dig. An abundant supply of good water was found. Such an exercise in applied holiness led to some to doubt the Devil's involvement in the dowser's art. Be that as it may, there is no doubt that water witching, or hydroscopy, remains to this day an accepted method by many in rural areas around the world. It gets popular attention and publicity, whereas scientific methods do not.

An elegant, thorough and entertaining discussion of the divining rod and dowsing was presented over 100 years ago by Arthur Ellis in a Water Supply paper of the US Geological Survey. He cited 570 publications on the subject in the French, German, and English literature from 1532 to 1917. These vividly attest to the continuing interest and curiosity of practitioners, promoters, believers, scientists and sceptics in such matters, unabated to this day. An internet search now readily reveals over 50 references to commentaries, field tests, denunciations, and justifications of the method since Ellis' summaries. Noteworthy among these is the Australian Skeptics' series of tests carried out in Perth (WA) and Gosford (NSW), arranged by James Randi and Dick Smith during 1980. No diviner was able to claim a $40 000 prize for the better-than-chance locating of buried targets: water in a piped water grid, a box of brass, and an ingot of gold.

No report to date has convincingly demonstrated that divining is a reliable technique nor that the dowser's success rate is any better than random chance outcome. One can discount the apparent triumphs of water witching in extensively alluviated farming areas, where information on water tables and aquifers is usually known, or if not commonly known, is available on enquiry in the files of local and state government rural departments. However, it is acknowledged that divining rods or twigs do move in the hands of some practitioners, and the relevant question for us is how do these movements occur? What is divining's secret? What makes a dowser? To this end some simple field tests were carried out, and the basic physics considered.

Field experiments with Y rods

Eight divining rods were made for field testing. These are shown in Figure 10. The test site, 70 km NW of Sydney NSW, was previously documented in the Environmental Issue of *Exploration Geophysics* (**23**, 4). This 1992 field work entailed magnetic, transient electromagnetic, and resistivity responses in traverses directly over and near shallowly buried 50 L and 200 L steel drums in Areas A and B of a test site in Hawksbury Sandstone terrain. These targets were located readily by magnetics, with anomalies of the order of 10's of nT. Transient EM also gave clear indications; resistivity less so. The point of this exercise is that it permits comparison of rod responses with geophysical data from known subsurface metallic sources. The drums are in high, dry, barren, sandy gravel and still in good condition (magnet check), so it is assumed that similar geophysical responses would be obtained if the surveys were repeated now. Traversing with the divining rods (Figure 11) gave no indications whatsoever i.e. no dipping, twisting, or other movement over or near drums. All eight rods were used, in turn, each held 1 m above ground.

A leaking fresh water dam north of the test paddock had previously been investigated by me with spontaneous potential field equipment. A positive SP anomaly of 25 mV was found around the seepage outlet. The Y rods did not move here either.

I did notice one effect that has been reported by others, but not widely appreciated. If the forks of resilient wood or metal Y rods are held tightly and squeezed firmly, any relaxation of the clench, through fatigue or whatever, will cause the pointer part to drop, irrespective of the surroundings. Elastic or springy Y rods can be relied on to give the occasional indication, however meaningless.

Figure 10. *Divining rods constructed for field experiments. Top (left to right): no.1 steel, very high magnetic susceptibility (~130 SI), 165 gm mass; no.2 fencing wire, high magnetic susceptibility, 47 gm; no.3 stainless steel, non-magnetic, 176 gm; Middle (right to left) no.4 grey gum, 115 gm; no.5 yellow bloodwood 18 gm; no.6 jacaranda, 26 gm; Bottom orthogonal rods, no.7 stainless steel, non-magnetic, 287 gm; no.8 copper non-magnetic, 420 gm and 57 cm length. Scale 30 cm on each panel. Rods no.1, no.2 responsive to magnets, rods nos.1, 2, 3, 7, 8 highly conductive (ohmmeter test), rods nos.4, 5, 6 non-magnetic and resistive.*

So, these simple tests failed completely. For the drum traverses the steel divining rod did not exhibit sympathetic interaction with the subsurface steel. However, some may say that the rods

Figure 11. *Don the Dowser with steel rod no.1 (Figure 10) fruitlessly searches for 50 L steel drums buried at shallow depth in area B previously geophysically and successfully surveyed with magnetics, TEM, and resistivity. This method of divination failed to locate the drums. The forked steel rod neither twitched nor dipped (except by clench-fatigue).*

are fine, but that deficiencies in my qualities are responsible, in that I do not have the "gift". I could only concur with this. Doubtless I would have failed in the type of trial depicted by the English artist Heath Robinson in his 1924 cartoon on testing candidates for the position of water diviner on the Metropolitan Water Board (Figure 12).

Physics

Can the divining rod respond to potential fields? Is gravity the force to which a rod is sensitive? It would seem highly unlikely if not impossible that a rod could be calibrated to register absolute gravity (even in pendulum divining instruments, not discussed here). What about relative gravity? Geophysics procedures require instrumental drift, earth tide, elevation, latitude, Bouguer, and, sometimes, terrain corrections. Anomalous gravity affects are acceleration differences and are expressed in gravity units (g.u. μms^{-2}, 0.1 milligal) which are tiny accelerations about 10^{-7} that of normal gravity. Most anomalies range from a few to a few hundred g.u. Gravity studies require highly sensitive instruments and rigorous field procedures. This is really not a descriptor of divining where a rod is carried at inconstant height by a quivering human frame.

Does gravity yank a rod down or sideways? Consider a 100 g rod very near the earth's surface and 1 t of compact junk just below the earth's surface and 1m away on a transverse line. We acknowledge the earth's gravity which acts on both (assuming them to be quasi spherical with mass concentrated at the centre) pursuant to the Newton's inverse square law:

$$F = G\frac{Mm}{r^2}$$

$G = 6.67 \times 10^{-11}$ newton m^2kg^{-2}, gravitational constant

M = mass of earth, 5.98×10^{24} kg

m = mass of surface object

r = radius of earth, 6.38×10^6 m

for the divining rod (m = 0.1 kg) the earth's force is about 1 Newton (similar to the force of a falling apple), and for the junk (m = 1000 kg) the force is about 10 000 Newtons (alternatively weights, w, could be computed from w = mg where w is in Newtons and g is the acceleration of gravity 9.8 ms^{-2}).

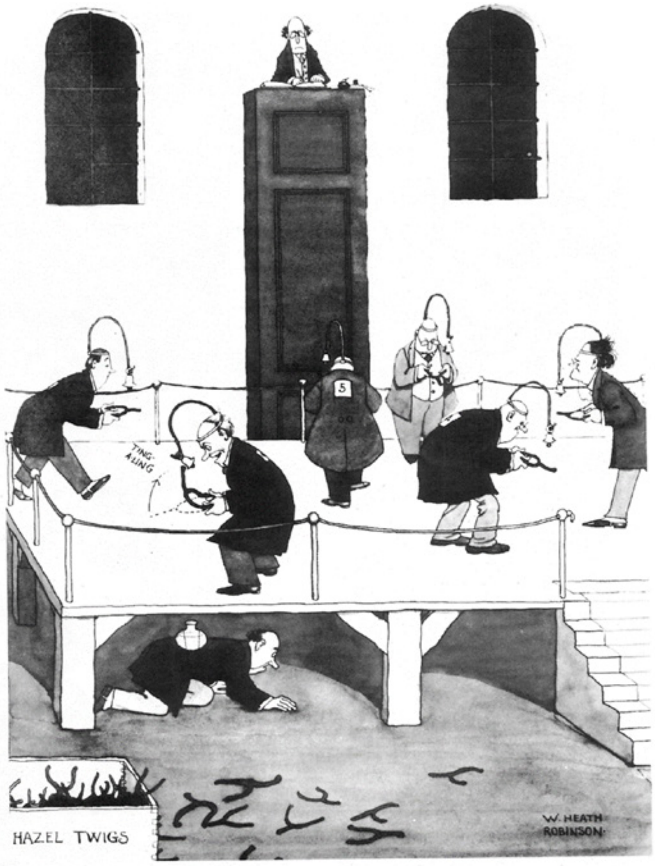


Figure 12. *"Testing of candidates for the position of water diviner on the Metropolitan Water Board": a 1924 cartoon by the comic visionary Heath Robinson (1872-1944) who excelled in portraying gentle eccentricities, makeshift contraptions, and the debunking of officials and individuals who took themselves too seriously. His hazel twigs, presumably possessing a peculiar polarity, move up to strike a bell detector to indicate a successful detection of water underneath. Public domain / https://commons.wikimedia.org/wiki/File:William_Heath_Robinson_Inventions_-_Page_055.png. From the book William Heath Robinson Inventions.*

Now the force between the rod (m_1) and the junk (m_2) is obtained from:

$$F = G\frac{m_1m_2}{r^2}$$

And F in this case is 6.67 x 10^{-9} N. A force of the order of nanonewtons is insignificant compared to the previous forces, and quite unable to cause the rod to move.

If gravity cannot explain the physics of the divining rod can magnetics do so if the necessary changes are made to the inverse power-of-distance equation? Considerations would be limited to only two of the rods, the magnetically responsive no. 1 and no. 2. However, assuming some sort of magnetised target, the situation is worse than gravity given the approximate $\frac{1}{r^3}$ fall off of the magnetic field from the target body.

For the conductive rods (nos. 1, 2, 3, 7, 8) there is another aspect of magnetics that can be considered. This does not involve rod twisting, but rod charging which the dowser may sense. A conductive rod in motion in a magnetic field will undergo electrical polarisation as shown in Figure 13. The voltage difference between the ends is the product of the field magnitude, the rod length, and the rod velocity i.e. Blv. Imagine a dowser traversing with a horizontally held copper

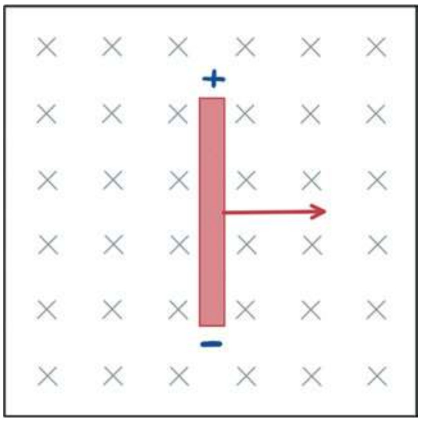


Figure 13. *Induced electromotive force charge separation in a conductive rod (length l) moving with velocity (v) to the right in a magnetic field (**B**) is as shown. The magnetic field is directed orthogonally into the plane of the diagram (X). The potential difference between the rod ends in Blv (volts) [think of the right-hand rule].*

rod no. 8 ($l = 0.57$ m) in an area with a 50 000 nT magnetic field ($B = 5 \times 10^{-5}$ T, inclination -90°) and maintaining a leisurely pace of about one footstep per second ($v \approx 1$ m/s). The voltage potential difference between the ends of the rod will be ~ 3×10^{-5} V i.e. 30 µV. Could the dowser sense this tiny difference, with clenched hands presenting a contact resistance of a few megohm between hand and copper? The answer is no, neither quantitatively nor qualitatively, for normal human bodies. If the magnetic field changes to, say, 100 000 nT owing to a subsurface feature further along the traverse then the potential difference would be ~ 60 µV. Neither this nor the difference between the two zones (indicating some sort of contact anomaly) would be detectable by a person without sophisticated instrumentation.

So one cannot really believe that a dowser with any sort of divining device would be sensitive to magnetic anomalies. Unless, of course, pigeon-like, there are, arrayed in the dowser's brain, magnetic particles that somehow communicate the magnetic ambience to the gifted person's mental apparatus, irrespective of the rod used.

We could go on through all the conceivable physical methods – radiometrics [radioactive bodies actually do emanate a part of their essence]; - acoustics [could the dowser's diaphragm act as source and receiver of infrasound, via the rod, and by which the subsurface is assessed?]; - electromagnetics [could the dowser's chest, arms, hands, linked to the rod, form a type of flesh-wood coil somehow to be electrically energised to generate a primary magnetic field to probe the subsurface and then somehow to receive a secondary (phase and amplitude shifted) magnetic field to be interpreted by the brain?]; - and so on… Space does not permit a detailed speculative analysis. However, there is one other phenomenon of interest that will be discussed: streaming potentials. Reports of UK water authorities using divining, to locate leaks, indicate that the water dowser's claim to be able to locate underground streams is still taken seriously. Rushing underground streams of popular imagination do not exist except in water mains leaks, and in caverns in karst or tubed volcanic terrain after rain. Groundwater, in confined or unconfined aquifers, under natural hydraulic gradients, moves usually very slowly with water velocities of the order of a few m/day, if that. However, locally, as geophysicists know, water seeping downhill, or leaking from dams, will generate streaming potentials positive in the flow direction. In studies of dams, self potential (SP) surveys show anomalies of the order of tens of millivolts associated with water movement, typically positive at outflows. It eludes me as to how a divining rod, either wood or metal, could be substituted for a voltmeter and non-polarizing electrodes set in-ground to register the small anomalous electrical field. Possibly the diviner has sensitive feet, even with shoes on, and as the operator paces up or down across the equipotential lines, with gradients of a few mV/m, the subtle difference in potential is registered between the feet, passed through the trunk of the body (containing sensitive anatomical parts) thence to the brain for subconscious interpretation?

The Ideomotor Response – IMR

How then can we explain the continual use of a puzzling technique with a dubious record? Suggestion can be a powerful influence. For 200 years some scientists (e.g. the famous Michael Faraday 1791-1867), medicos, and psychologists have believed that ideas can cause a reflex action in a body, analogous to a body acting automatically to pain. They postulate that thoughts and beliefs give rise to reflex muscular movements of often small, but significant amplitude. This is the subconscious ideomotor response, IMR. [ἴδιος one's own, *motus* movement]. Thus is explained automatic writing, table turning, Ouija boards, and divining with rod or twig. In such phenomena the activity is posited as due to mental states, not to esoteric energies, spirit/sprite involvement, or the paranormal continuum. Quite reasonable persons can exhibit muscular actions or spasms in line with their expectations.

Concluding remarks

What is the basis for the use of divining and the activities of dowsers? It seems to me to involve the centuries old belief that a sought substance's intrinsic vigour releases essential vapours carrying corpuscles of the substance that rise to the surface there to be intercepted by the artful dowser with a divining rod. The emanations are absorbed by a porous wood rod, or adsorbed onto a metal rod, which is consequently caused to dip down towards the source. Such vapours have yet to be observed and documented by conventional scientific means. The effects are claimed to be enhanced by the undefined qualities gifted to the dowser, and by a "sympathy" or affinity between a particular wood or metal and the sought substance. These are extraordinary claims; they require extraordinary evidence to secure validity. After thousands of years this evidence is yet to be provided, despite widespread interest.

In terms of physics I cannot fathom the principles, if any, of divining nor the peculiar personal power, if any, ascribed to dowsers. Perhaps it all has to do with the supernatural and with faith, a strong emotion, being a feeling rather than a cognition. The faith of the able, intelligent fathers of the early Christian church seemed irrational to pagans. But the clergy have always had a vested interest in the supernatural, their jobs depended on it. *Credo quia absurdum*: I believe because it is unreasonable, and *certum est quia impossibile*: it's certain because it is impossible, are only a couple of expressions they used to defiantly defend their faith when questioned on the mysteries of miracles, transubstantiation, the Trinity etc. They saw no real need for understanding. Such lines of thought continue to be widespread to this day in the minds of decent, otherwise reasonable, people. It is certainly manifest in divining and the dowser. This is an observation, not a criticism, as such people were and are entitled to their viewpoint, especially in our own daffy days of liberated cultural relativism where objective reality can be blithely rejected, and where beliefs trump facts. I note too that divining thrives on degree of difficulty. It is the instrument of last resort when all else has failed e.g. when geophysics with ground probing radar encounters conductive terrain; or seismic refraction is attempted over a sedimentary column with velocity inversion, or magnetics is applied in areas devoid of Fe, Mn minerals. Nothing, not even drilling, seems to work, so why not give divining a go?

I conclude by predicting that the divining rod will endure. Confident dowsers will continue to be called on to apply their art. I am reminded of the persistent amateur concert singer Florence Foster Jenkins (1868-1944) famed for her indifference to the fetters of music notation. Her execrable warbling provided giggling concert attendees with a bizarrely enjoyable, but less than highly aesthetic, experience. Florence Foster Jenkins generated much uncomplimentary comment, but she was a well-meaning woman who held her audience. In my opinion she had the last word, reportedly observing that "people say I cannot sing, but no one could say that I did not sing".

It seems to me that, as with Florence Foster Jenkins, divining aims to achieve success without the wherewithal to do so. The honest efforts of dowsers in harmless applications such as water witching are tolerated, or encouraged, or even admired, by some. However, I doubt that an easy-going attitude can be adopted towards divination applied to dangerous situations such as UXO location, or to forensic work with legal implications. In such fields, divination, as for any other technique such as geophysics, needs its strengths, if any, and its limitations established by empirical investigation and published analysis. It would appear that this is yet to happen, and until it does divination has more in common with the séance than with science.

Acknowledgements

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Don Emerson is a geophysical consultant specialising in the physics of minerals and rocks, he also has an interest in ancient and medieval geoscience.

Mark Lackie's best of *Exploration Geophysics*

Mark Lackie
Exploration Geophysics Editor in Chief (2009 - present)
mark.lackie@mq.edu.au

When I got an email from Ted Tyne asking me to select my best paper from *Exploration Geophysics* I first noticed the part about the 50 Year Anniversary and thought wow has *Exploration Geophysics* been going 50 years. Then the horror dawned on me, I had been alive for the whole of those 50 years, which could mean that I had glanced at all of the issues and that choosing a "best of" might be difficult. So, as a true geophysicist, I went off to have a few "reds" to reflect on the problem.

I quite like review articles as they put all the knowledge about a subject in an easy to read article and actually aid me in understanding a topic. Thus, review papers by Dave Clark on aspects of remanence, and Ted Lilley on understanding MT spring to mind. As an educator I like case histories about ore deposits as they show students about the power of geophysics and the value of team work. There are many fine articles in this category that could be nominated. More reds needed to be consumed, this is a big problem.

After consuming a very nice Victorian red it finally dawned on me ... what was the first paper I thought of after I read Ted's email - that should be my "best of" paper. My best of *Exploration Geophysics* paper comes from the monkey issue (so who knows what I mean by that?!!), and is the paper by Don Emerson, Dave Clark and Steve Saul entitled "Magnetic Exploration Models Incorporating Remanence, Demagnetisation and Anisotropy: HP 41C Handheld Computer Algorithms" that was published in Volume 16 in 1985.

The paper by Emerson, Clark and Saul is 122 pages long, so I cannot say I have read all of it in great detail. The paper goes through various magnetic models and incorporates features such as remanence, demagnetisation and anisotropy. The models cover a wide range of "types", including standard ones I could find in any given textbook and interesting ones such as the ellipsoid of revolution. The paper has lots of code for running the models with a HP 41C calculator (hmm… those were the days), which I must admit I have never used. However, when I undertook my PhD this paper gave me the background theory and, importantly, the mathematics in a very organised manner such that I could understand and code up the responses to simple models that include such strange beasts as anisotropy and demagnetisation, which interest me greatly. Recently I referred to the paper to code up a simple model using excel (my apologies to all the "true" coders with that statement) for a workshop organised by Mike Smith.

So, my "best of" paper for *Exploration Geophysics* is the paper that I most often refer to when I want to understand the magnetic response of a simple body that has complicating magnetic factors. The paper is clear and concise, and has the information I need laid out in a manner that is easy-to-follow (perfect for me!).

Best Paper

Emerson, D.W., Clark, D.A. and S. J. Saul, 1985. Magnetic Exploration Models Incorporating Remanence, Demagnetisation and Anisotropy: HP 41C Handheld Computer Algorithms, *Exploration Geophysics*, **16** (1), 1-122, DOI: 10.1071/EG985001

Editor's note: Only the first two pages of this paper are reproduced here as the paper is 122 pages long. Readers with an interest in this topic are encouraged to read the full paper, which can be accessed via DOI: 10.1071/EG985001

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Magnetic Exploration Models incorporating Remanence, Demagnetisation and Anisotropy: HP 41C Handheld Computer Algorithms

D. W. Emerson[1], D. A. Clark[2] and S. J. Saul[3]

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Contents

Page

Abstract

Handheld computer (HP 41C) algorithms are presented for basic and advanced magnetic exploration models along principal profiles. The thirteen models are: monopole, 2D line of poles, sheet of poles, dipole, 2D line of dipoles, 2D horizontal sheet of dipoles, 2D dipping thin sheet, 2D dipping thick sheet, 2D sloping step, 2D body with polygonal cross section, prolate and oblate ellipsoids of revolution, 2D elliptic cylinder, vertical rectangular prism. Key diagrams, program useage instructions, worked numerical example, program listing and register contents are given for each model. Induction, remanence, demagnetisation and susceptibility anisotropy effects are calculated. The vertical circular and annular cylinders are treated for the cases of induction and remanence.

Preface

This is a presentation of magnetic computational techniques for modelling residual or regional anomalies (but not for separating them). It does not include a detailed theoretical development. Its purpose is as a working compendium of techniques primarily designed to teach and to impart some understanding of the magnetic response of basic models – mostly simple but geologically very important.

Magnetics has a vital place in all exploration, but often data analysis comprises crude eyeballing or overinterpretation with geologically and petrophysically unrealistic sophisticated computer models. There is much to be said for a simple analytic approach with remanence and other factors considered. These programs endeavour to provide such an approach.

The total magnetic intensity (ΔB_T) and vertical magnetic intensity anomaly (ΔB_z) anomalies are computed. A considerable amount of B_z data still exists even though total field data acquisition is now virtually the norm. A diagram depicting the nature of measured (ΔB_m), theoretical total (ΔB_T), and vertical (ΔB_z) anomalies has been included as these concepts appear to be very poorly understood.

For units, the authors have a perverse preference for the cgs emu system as it is based on magnetostatic concepts ideally suited to the problems arising in magnetic interpretation. If SI units are used, factors of 4π crop up in the equations and it is best to avoid this complication. However, all calculations can be done in SI providing the correct conversion factors are used. In the magnetic formulae distances can be in any units provided they are consistent e.g. all in metres. The flux densities (magnetic field strengths) ΔB and F must be in the same units: gammas (10^{-5} gauss, cgs) or nanoteslas (SI). The gamma and nanotesla are numerically equivalent. The magnetic volume susceptibility *k* is a dimensionless ratio. It is the magnetic moment generated per unit applied field divided by the volume. The emu susceptibility must be inserted into the equations presented herein. Accordingly SI susceptibilities must be divided by 4π. Self demagnetisation factors N are also dimensionless, but the emu demagnetizing factor is 4π times the SI value. Then $0 < N_{emu} < 4\pi$ and $0 < N_{SI} < l$. Pole strengths are calculated in 'pole units' which arc hybrid units involving gammas and metres – their SI and emu relationship is not important because they are simply part of an internal computation. The magnitude or intensity of natural remanent magnetisation is expressed in 'gammas' (γ), so as to be consistent with the induced magnetisation. NRM intensities are usually quoted in the literature in microgauss (emu) or milliamp/metre (SI) which are numerically equivalent. One 'gamma' is equal to 10 microgauss. Southern hemisphere magnetic field inclinations are negative (upward pointing).

As an example of the units consider MAGMOO I with a monopole 20 m radius depth 100 m and resultant magnetisation vertically up:

Magnetization $\lvert J_R \rvert$	Pole Strength $P = (J_R . n) S$, $S = \pi r^2$	ΔB_T Anomaly calculated from formula at $x = 0$
5000×10^{-6}	$5000 \times 10^{-6} \times \pi \times 20^2$ $= 6.28 \times 10^{-6}$ G m²	5.9×10^{-4} G
5000 μG	6,283,185 μG m²	590.4 μG
500×10^{-5} G $= 500\ \gamma$	628,319 γ m²	59.04 γ $= 59.04 \times 10^{-5}$ G
1μG (cgs) $= 10^{-1}\gamma$ (cgs) = 1 mA/m (SI)		1 γ = nT (SI)

The body oriented co-ordinate system used is the Cartesian right-hand convention with the *z* axis positive downwards. Principal profile *x* axis analysis is presented. A principal profile is a traverse over the centre of a 3D body or a traverse normal to the strike of a 2D body.

It should be understood quite clearly that for MAGMOOS I, II, III the models give correct results only for vertical resultant magnetizations. For inclination (of resultant magnetizations): $90° > |I_R| > 60°$, the results may be acceptable but only approximate owing to the presence of poles on the sides of the bodies.

The exposition for each model includes: formulae, program instruction, key diagram, worked numerical example, and a listing of the program.

The instrument requirements are: HP 41C calculator, card reader, and thermal printer. If there is no printer, users can modify programs up to the LBL E step by inserting SF21 at the beginning of the program and substituting AVIEW everywhere for PRA. When division by zero occurs the program substitutes a very small number, but depth *h* cannot be set equal to zero metres at any body vertex- instead a small finite number is required. The plotting routine may be useful in some circumstances, but it is more of an ornament with limited application. When using the plotting subroutine $|x|$ cannot exceed 999. This problem can be avoided simply by changing the distance units (e.g. using kilometres instead of metres). The HP 41C is not meant to give detailed plots which may be rigorously interpreted; the plots are simple visual aids. The resolution is limited because the plot field consists of either 119 or 126 'columns', therefore the anomaly value is rounded to one of 119 or 126 values (inclusive) between nominated min. and max. values. If B_{MIN}, B_{MAX} are too large an error in the printout arises caused by the finite size of alpha register. If *x* values are 'too large', then plots appear on two lines causing an apparent origin shift- 'too large' varies for different models as different plot fields are used.

Some of the programs will require extra memory (modules) for the basic HP 41C calculator.

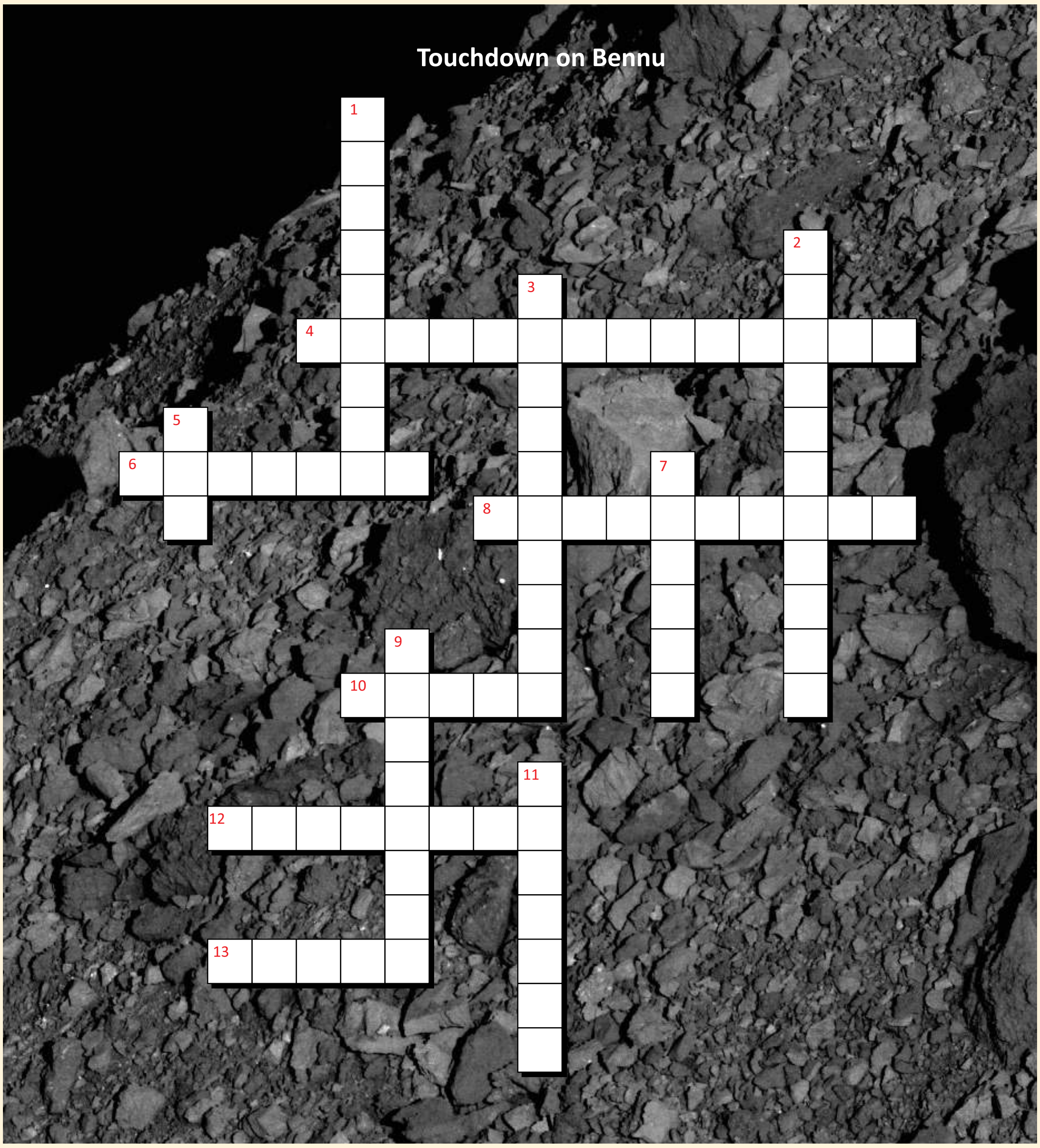
For further reading and background theory it may be worthwhile to consult:

(i) the classic paper (the basis for a lot of this work) by D. H. Hall, Directions of polarization determined from magnetic anomalies, *J. Geophys. Res.* **64**, 1945-1959, 1959;
(ii) The ASEG Short Course Notes on 'Pole and Dipole Models in Magnetic Exploration' by D. W. Emerson and D. A. Clark, unpub. 1982, 1983;
(iii) the book: *Magnetic Models in Geophysical Exploration* by D. A. Clark and D. W. Emerson (in prep.);
(iv) The Applied Magnetic Interpretation Symposium Proceedings ed. D. W. Emerson, *Bull. Aust. Soc. Explor. Geophys.* **10**, 1-139, 1979;
(v) the paper: by D. A. Clark, Comments on magnetic petrophysics, *Bull. Aust. Soc. Explor. Geophys*., **14**, 49-62, 1983.

It is a pleasure to acknowledge the indispensable assistance of: Mr Len Hay (Sydney University) in drafting the MAGMOD example Figures and for providing the cover design which accurately portrays the feeling of many an interpreter; Mrs D. Garbler (Sydney University) for cheerfully typing many drafts; Mrs Pat Godden (CSIRO), who drafted several Figures; and Miss Diana Bridgewater (CSIRO), who transferred pages of handwritten formulae into camera-ready copy.

Finally, a reminder to users that they are on their own with these programs. Any user accepts and uses any, some, or all of these programs at the user's own risk and responsibility entirely.

Preview crossword #11



Across

3. The Forest in Leicestershire, England, where the first fossilised Pre-Cambrian specimen was found and recognised as such.
4. Sedimentary facies term used to describe a succession of redeposited, deep-sea, clastic material of synorogenic character.
6. Line joining the lowest points of successive cross-sections either along a river channel or along the valley that it occupies.
8. In seismic processing, a common midpoint stack with only preliminary static corrections and preliminary normal-moveout corrections.
10. The largest object in the main asteroid belt between the orbit of Mars and Jupiter and the only dwarf planet inside Neptune's orbit.
12. The time of most northerly or southerly declination of the sun from the equator.
13. An Afrikaans word for a small hill in a generally flat area.

Down

1. A one-limbed flexure on either side of which the strata are horizontal or dip uniformly at low angles.
2. The process in which clay and other fine soil particles adhere to form larger aggregates.
3. The most common type of stony meteorites, accounting for roughly 86% of all meteorite falls.
5. A unit of electrical conductance that is the reciprocal of ohm.
7. Collective term applied to all pyroclastic particles or fragments ejected from a volcano, irrespective of size, shape, or composition.
9. In nuclear logging, the amount of time required for the system to be ready to count the next pulse.
11. A body of rock characterised by a lack of continuous bedding and the inclusion of fragments of rock of all sizes, contained in a fine-grained deformed matrix.

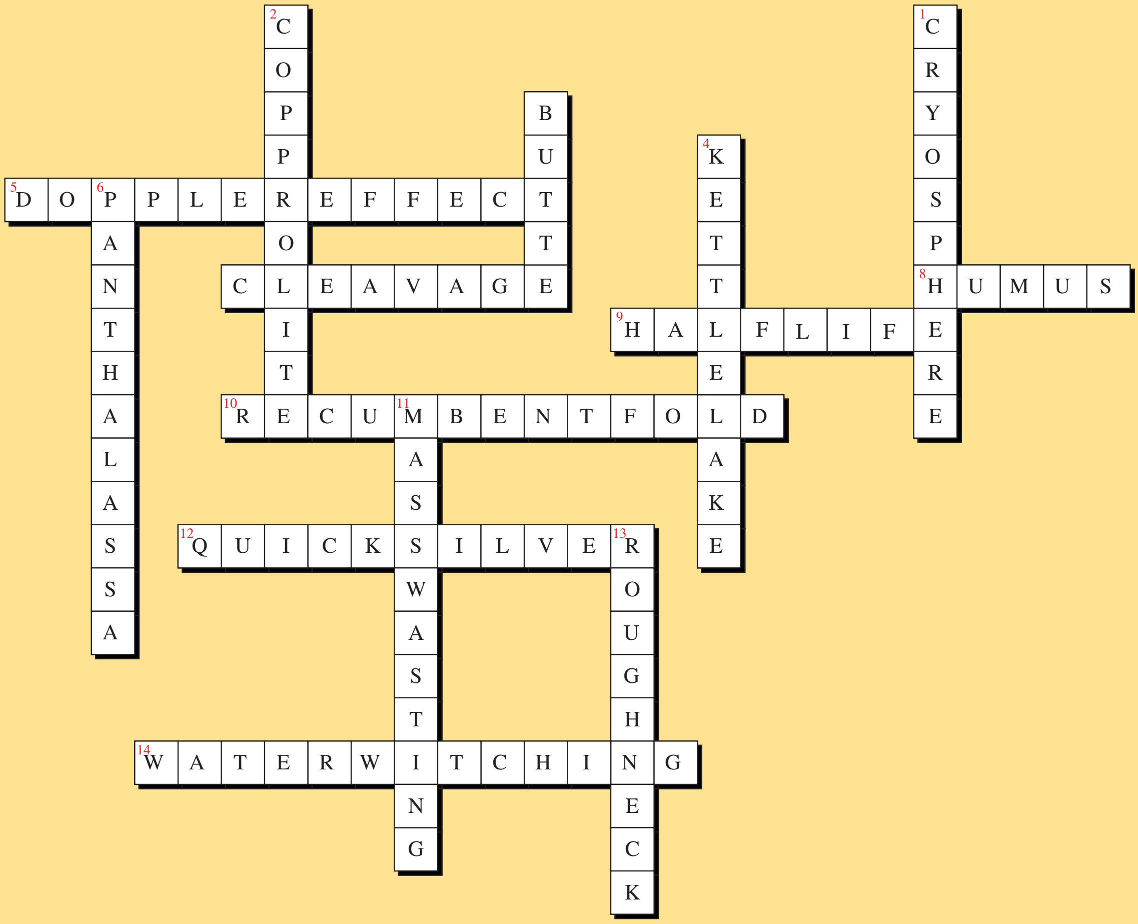
Play to win!!

Send your answers to *previeweditor@aseg.org.au*. The first correct entry received from an ASEG Member will win two Hoyts E- CINEGIFT passes – which can be used after cinemas re-open. The answers will be published in the next edition of *Preview*.

Good luck!

Preview crossword #10 solution

Singles social bubble



Business directory

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3. Attach the appropriate dues and submit the two pages of your application to the Secretariat at the address shown on the top of this page, retaining a copy of this page for your own records. If payment is to be made by credit card, the application may be sent by fax.

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❑ Associate — Please complete all sections
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Seconder			

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AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS
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Given Names

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State Post Code

E-mail

Phone (W) Phone (H) Fax (W)

Mobile

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Institution

Department

Major Subject Expected Year for completion of studies

Supervisor/Lecturer Supervisor Signature

Section 3 Membership Grade
(This document will be an Australian Tax Invoice when you have made payment)

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❑ Student (Group I & II Countries)	FREE

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Yes / No (please circle)

Section 5 Declaration

I, ____ (name), agree for the Australian Society of Exploration Geophysicists to make all necessary enquiries concerning my application and suitability to become a Member. By lodging this Application and upon being accepted in my membership, I agree to be bound by the Constitution of the Australian Society of Exploration Geophysicists, including its ethical and professional standards.

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December	**2020**		
2	Advances in Marine Seismic Data Acquisition Workshop https://seg.org/Events/Advances-in-Marine-Seismic-Data-Acquisition-Workshop	Singapore	Singapore
2–4	SEG Virtual Workshop: Exploring in Presence of Complex Overburden https://seg.org/Events/Exploring-in-Presence-of-Complex-Overburden		*Virtual event*
7–11	AGU Fall Meeting https://www.agu.org/Fall-Meeting	San Francisco	USA
8–11	EAGE 2020 Annual Conference Online https://eage.eventsair.com/annual-conference-online/		*Virtual event*
17–18	EAGE/SEG Research Workshop on Geophysical Aspects of Smart Cities		*Virtual event*
February	**2020**		
8–10	SEG/AGU Advances in Distributed Sensing for Geophysics https://seg.org/Events/Distributed-Sensing-for-Geophysics		*Virtual event*
9–12	Australian Earth Sciences Convention 2021 https://www.aesconvention.com.au/		*Virtual event*
22–23	2021 Energy in Data Conference https://energyindata.org/		*Virtual event*
March	**2021**		
14–18	SAGEEP 2021 https://www.sageep.org/		*Virtual event*
22–26	proEXPLO 2021 https://www.proexplo.com.pe/en		*Virtual event*
April	**2021**		
25–30	European Geosciences Union https://www.egu2021.eu/	Vienna	Austria
May	**2021**		
4–6	5th Myanmar Oil & Gas Conference https://eage.eventsair.com/fifth-aapg-eage-myanmar-conference/	Yagoon	Myanmar
June	**2021**		
14–17	82nd EAGE Annual Conference and Exhibition https://eage.eventsair.com/eageannual2021/	Amsterdam	The Netherlands
August	**2021**		
16–21	36th International Geological Congress https://www.36igc.org/	Delhi	India
23–27	Advanced Earth Observation Forum 2020 https://earthobsforum.org/	Brisbane	Australia
September	**2021**		
8–10	Mines and Wines 2021 Discoveries in the Tasmanides https://minesandwines.com.au/	Orange	Australia
15–20	Australasian Exploration Geoscience Conference (AEGC 2021) 2021.aegc.com.au	Brisbane	Australia
27–1 Oct	Australian and New Zealand Geomorphology Group Conference https://www.anzgg.org/conferences	Alice Springs	Australia
October	**2021**		
10–14	11th Balkan Geophysical Congress https://appliedgeophysics.ro/events/bgs2021/	Bucharest	Romania
December	**2021**		
13–17	AGU Fall Meeting	New Orleans	USA
August	**2022**		
15–19	12th International Kimberlite Conference https://12ikc.ca/	Yellowknife	Canada

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