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Australian Society of Exploration Geophysicists

PREVIEW

NEWS AND COMMENTARY

Vale Sydney Hall

Field technique factsheets

CAGE 2022

Student projects completed in 2022

FEATURES

Coping with ambiguity in geophysical data

The Do-It-Yourself geophysicist

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FRONT COVER

Elliott Barrington, who has recently completed his Honours thesis at Monash University, collecting downhole petrophysics on site in the Yarmana terrane. See *Education matters* in this issue for more information.

Preview is available online at
https://www.tandfonline.com/toc/texp20/current

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Editor's desk

I had the good fortune to see two of Ken Witherley's presentations to ASEG Branch meetings during his recent whirlwind tour of Australia. One presentation reflected on porphyry copper exploration models, the other on the future of exploration.

In both these presentations Ken made it clear that, in his view, whilst advances in geophysical techniques over the last 70 years have been astonishing, and the quantity and quality of geophysical data available from surface to considerable depths are almost overwhelming, the pay-off in terms of discoveries has not been realised because geologists have been reluctant to allow the data to challenge their cherished paradigms about the development of the earth and, in particular, about the development of orebodies. Ken used the history of exploration for porphyry copper deposits as an example, and suggested that while many geologists are still being constrained by the ruling paradigm for porphyry copper deposit formation, geologists in some of the larger mining and exploration companies are being more creative. Whilst these companies are not exactly being forthcoming with respect to the way in which geophysical data are changing their understanding of orebody formation, changes can be inferred from the evolution of company exploration programmes.

I share Ken's frustration about the failure of many geologists to allow geophysical data to challenge their presumptions. That frustration is even more acute because, as Ken has pointed out, the issue has been around for decades. In 1997, for example, in a CRC AMET workshop on *Future trends and directions in mineral exploration geophysics* (see *Preview* **66)** several contributors expressed the view that the rapid advances in geophysical techniques would not benefit exploration until geologists developed a better understanding of those techniques, and learnt how to work with the data being generated.

The ASEG is currently being proactive about bridging the gap between geologists and geophysicists. The inaugural Camp for Applied Geophysics Excellence (CAGE), which was held in Kapunda in South Australia in September this year, seeks to give geoscientists from industry, government and academia exposure to geophysics from the bottom up, which is to say, from data collection to interpretation. The camp was oversubscribed and by all accounts hugely successful. Kate Selway and Kate Brand report on the outcomes in this issue of *Preview* (*Education matters*).

Jim Hanneson has also come to the party with an article entitled "Coping with ambiguity in geophysical data". This article is written for both geologists and geophysicists and provides remarkable insight into problem solving in exploration geophysics.

Anton Kepic does his bit by encouraging budding geophysicists into their "sheds" with an article entitled "The DIY geophysicist". If you are into the nuts and bolts of geophysics, Anton is your new best friend!

As usual at this time of year we also feature summaries of student projects completed in geophysics in Australia in 2022 (*Education matters*). The number of postgraduate students in geophysics may be declining, but the work of the students who have stayed with the discipline is impressive. It is also clear that many of them are laudably blurring the boundaries between geology and geophysics.

In other news and commentary, David Denham (*Canberra observed*) reviews the first Labor budget and notes minor changes in the funding of scientific agencies. Mike Hatch (*Environmental geophysics*) delivers the last episode of Niels Christensen's adventures. Terry Harvey (*Mineral geophysics*) encourages exploration geophysicists to think outside the box. Mick Micenko (*Seismic window*) is prompted by serendipity to take another look at point source acquisition. Tim Keeping (*Data trends*) considers remanence mapping using tilt angles and MMTs, and Ian James (*Webwaves*) draws our attention to the proliferation of scams.

As this is the last issue of *Preview* for 2022, I would like to thank the *Preview* Editorial and Production teams for hanging in there during what was a remarkably difficult year. COVID savaged our ranks, not just in Australia, but also in the UK and in India.

On behalf of both teams, I would like to wish all of you a very happy *and* healthy festive season. We look forward to catching up with you at the AEGC in Brisbane in 2023!

Lisa Worrall
Preview Editor
previeweditor@aseg.org.au

The Editor in the Finke River Gorge in Central Australia – finding field evidence to back a pet theory and consequently having difficulty wiping the smile off her face!

President's piece

Emma Brand

Members and readers

Can you believe it! The end of the year is upon us! It truly feels like we have barrelled through 2022 at a million miles an hour, navigating all sorts of changes in the industry and the world around us. I hope that you have all managed to keep your heads above water and are able to survive the last remaining weeks of the year before getting a well-earned summer vacation break. I know that I will be looking forward to some down time with family and friends over the holiday period, resting and recharging for a 2023 that looks even bigger than 2022!

I've spent significant time over the past 18 months thinking about the future of geophysics in Australia and subsequently the future of the ASEG, and I was delighted to see Tim Dean contribute to that conversation in the last edition of *Preview*, outlining the context that we find ourselves in, along with some radical solutions to increase membership. As a profession, and as a society, we face incredible headwinds and navigating these to ensure our success for the next 50 years is critical. And we need to think outside the box to ensure that we navigate these challenges in front of us.

Our declining membership base is a bell weather for the health of our Society and reflects the declining number of geophysicists due to the contraction of tertiary geophysical education across Australia. In this context we can think of our membership numbers as the result of a decreasing market, which is one that we have little to no direct impact on nor, as a Society, do we have a mandate to address directly. However, as a member organisation of the Australian Geoscience Council we have avenues for influence into policy makers, and we leverage our position to do so.

What we do control is our "product", and in order to drive demand, one of the strategic approaches we have been focused on this year is creating, articulating and delivering exceptional Member value. Member value is pretty personal, however it is clear to me that Members first and foremost value the ASEG for access to technical and scientific contributions through *Exploration Geophysics*, *Preview*, monthly technical presentations and courses, including the CAGE geophysics field camp. These activities all align directly with our number one aim as a Society, which is to promote the science of geophysics, and specifically exploration geophysics, throughout Australia.

Exploration Geophysics is our core scientific publication, and therefore the quality and usefulness of this science is paramount. One of the measures of that is Impact Factor, which is equivalent to the average number of times documents published in a journal/conference in the past two years have been cited in the current year. We have seen some variability of the Impact Factor of *EG* over recent years, but it is fantastic to see that our current number is 1.1. The work that Mark Lackie as *EG* Editor, Steve Hearn as the Publications Chair and the Publications Committee do as a whole, is incredibly important for the health of the Society, and I'd really like to thank them for their tireless efforts.

My sense is that the next most important value proposition for Members is the network and community that is created through state branches, the AEGC conference and other events that bring our members together. This is also squarely aligned with our second aim as an organisation, which is to foster fellowship and co-operation between geophysicists. I'd like to recognise the important work that the State Branches do every day to develop and enhance this value for our members. For example, MAG22 is a phenomenal event developed and driven by the WA Branch, benefiting not only Western Australian Branch members, but all ASEG Members across the country and overseas. The vision and energy that the WA Branch is bringing to this event is truly creating value by bringing Members together through a compelling platform in which great science can be shared. And this happens every day through smaller events in every state across Australia, where our members connect and build a strong community of individuals dedicated to the enhancement of geophysical science.

There are other reasons why Members join the ASEG, these include; obtaining a hard copy of *Preview*, building career experience, volunteering, getting access to sister societies, getting access early bird rates for the AEGC2023 conference and, for the first time this year, an ASEG Member subscription to *Practical Geocommunication by Geologize* - an exciting **new addition for Members**. These benefits all enhance the value proposition of the ASEG and make a compelling case for membership,

Ultimately, as an engaged reader, it is likely that you have already renewed your ASEG membership for 2023. If you have not, I hope that I have made the case for your continued support and that you choose to allocate some of your hard earned salary to ASEG membership by renewing your membership here!

As always, I am open to your thoughts, feedback and suggestions, so please don't hesitate to connect.

Emma Brand
ASEG President
president@aseg.org.au

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. This brief reports on the monthly meetings that were held in October and November 2022. If there is anything you wish to know more about, please contact Leslie at secretary@aseg.org.au

Finances

The Society's financial position at the end of October 2022 was:

Year to date income: $281 284

Year to date expenditure: $327 512

Net assets: $1 042 486

Membership

As of 11 November 2022, the Society had 832 financial Members, compared to 844 at this time in 2021. The ASEG currently has ten Corporate Members, including two Corporate Plus Members. The Corporate Plus Members are: Velseis and Total Seismic. The Corporate Members are: Santos, Southern Geoscience Consultants, Transparent Earth Geophysics, DUG, GDD, HiSeis, SKYTEM and Planetary Geophysics.

Thank you once again to all our Corporate Members for your support during 2022. You can find the contact details for our Corporate Members on the contents page of *Preview*. Please support them as much as you can. Our state branches also have additional local sponsors, which are shown at all branch meetings and at the beginning of all webinars.

I hope you have all completed your membership renewal for 2023, taking advantage of the early-bird pricing.

Positions vacant

We still have vacancies for the position of Chair of our International Affairs and Education Committees. Our other standing committee chairs would also welcome any support that you can offer. If you would like to contribute to your Society, please consider volunteering for a position on one of these standing committees. You can contact Leslie at secretary@aseg.org.au if you have any queries.

Wine offer

If you have ordered wine from the SA/NT wine offer you will be notified shortly of the pick-up point in your local capital city. I hope you enjoy your selections as much as I know I will enjoy mine.

Events

There are still webinars through to the end of the year. Sessions are all recorded and available for viewing at the ASEG website or on our YouTube Channel. There are also plenty of end-of-year and Christmas events in the states to keep us all busy to the end of the year.

Social media

Stay up to date with all the happenings of your Society on social media. You can connect to us on in facebook for all the latest news and events.

Wishing you all a very Merry Christmas with family and friends, and here's to a fulfilling year in 2023.

Leslie Atkinson
ASEG Secretary
fedsec@aseg.org.au

Welcome to new Members

The ASEG extends a warm welcome to 14 new Members approved by the Federal Executive at its October and November meetings (see table).

First name	Last name	Organisation	State	Country	Membership type
Shabeer	Ahmed	Oil and Gas Development Company Limited	Islamabad	Pakistan	Active
Victoria	Berezowski	University of Newcastle	NSW	Australia	Student
Jon	Cocker	Beach Energy	SA	Australia	Active
Richard	Lewis	University of Adelaide	SA	Australia	Associate
Connor	Meagher	Newexco Exploration	WA	Australia	Graduate
Linus	Opat	The University of Melbourne	Vic	Australia	Student
Andrew	Prior	University of Melbourne	Vic	Australia	Student
Prabin	Shilpakar	Resource Potentials	WA	Australia	Active
Satyam	Singh	University of Sydney	NSW	Australia	Student
Stephen	Stark	WSP Golder	Qld	Australia	Active
Rachel	Szczepaniak	University of New South Wales	NSW	Australia	Student
Sheng Wang			Vic	Australia	Graduate
Matthew	Winefield	The University of Melbourne	Vic	Australia	Student
Albert	Willmott	University of Tasmania	Tas	Australia	Student

ASEG Research Foundation: Applications for 2023 grants now open!

The ASEG Research Foundation continues to back students in their degree studies. Through a competitive process, the Foundation makes annual grants to support the laboratory and fieldwork necessary to carry out the research projects that are essential for the completion of Honours, Masters or PhD degrees. The Foundation has existed now for 33 years and has spent over $1.5 M with the support of the ASEG and tax-deductible donations made by Members, supporting companies and others. In 2022 we were able to support four new projects, one BSc, one MSc and two PhDs. Thank you for the generous support of the ASEG ($45 000) and Members.

Applications for 2023 grants are now open and close on 3 March 2023. More information and the application form can be found at: https://www.aseg.org.au/foundation/how-to-apply

Doug Roberts
ASEG Research Foundation Secretary
research-foundation@aseg.org.au

ASEG Honours and Awards: Final call for nominations for 2023

The ASEG acknowledges the outstanding contributions of its individual Members, both to the profession of geophysics and to the ASEG, through the presentation of the Society's Honours and Awards across a range of categories. The next Awards are scheduled to be presented in conjunction with AEGC 2023, to be held in Brisbane between the 13 and 18 March 2023.

Nominations for these awards close on Monday 16 January 2023.

All ASEG Members as well as State and Federal executives are invited to nominate those they consider deserving of these awards. The available awards are:

ASEG Gold Medal - for exceptional and highly significant distinguished contributions to the science and practice of geophysics, resulting in wide recognition within the geoscientific community.

Honorary Membership - for distinguished contributions by a Member to the profession of exploration geophysics and to the ASEG over many years.

Grahame Sands Award - for innovation in applied geophysics through a significant practical development in the field of instrumentation, data acquisition, interpretation or theory.

Lindsay Ingall Memorial Award - for the promotion of geophysics to the wider community.

Early Achievement Award - for significant contributions to the profession by a Member under 36 years of age, by way of publications in *Exploration Geophysics* or similar reputable journals, or by overall contributions to geophysics, ASEG Branch activities, committees, or events.

ASEG Service Awards - for distinguished service by a Member over many years to ASEG Branch activities, Federal or State committees, publications, conferences, or other Society activities.

ASEG Members are eligible for all award categories. Non-members also are eligible for the Lindsay Ingall and Grahame Sands awards. Under exceptional circumstances, the other awards may be offered to a non-member of the ASEG who has given appropriate service to the ASEG or to the profession of geoscience, and who has been duly nominated by the Federal Executive.

Nomination Procedure

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

Nominations must be specific to a particular award and all aspects of the defined criteria should be addressed. Because these awards carry considerable prestige within the ASEG and the geoscience profession, appropriate documentation is required to support each nomination.

Further details of the award categories, lists of previous awardees and citations for recent awards, award criteria, nomination guidelines and nomination forms can be found on the ASEG website at: https://www.aseg.org.au/about-aseg/honours-awards

Further information can be obtained by emailing the Chair of the Honours and Awards Committee at awards@aseg.org.au.

Nominations including digital copies of all relevant supporting documentation are to be emailed to: awards@aseg.org.au. All correspondence and nominations will be treated confidentially.

Andrew Mutton
ASEG Honours and Awards Committee Chair
awards@aseg.org.au

Nominations close Monday 16 January 2023

ASEG Young Professionals Network: Update

The Western Australian joint industry mentoring programme is a collaboration between nine professional associations: Petroleum Exploration Society of Australia (PESA), Australian Society for Exploration Geophysicists (ASEG), Energy Club of WA (ECWA), Society of Petroleum Engineers (SPE), Engineers Australia (EA), Society for Underwater Technology (SUT) and Subsea Energy Australia (SEA), and Professional Petroleum Data Management Association (PPDM).

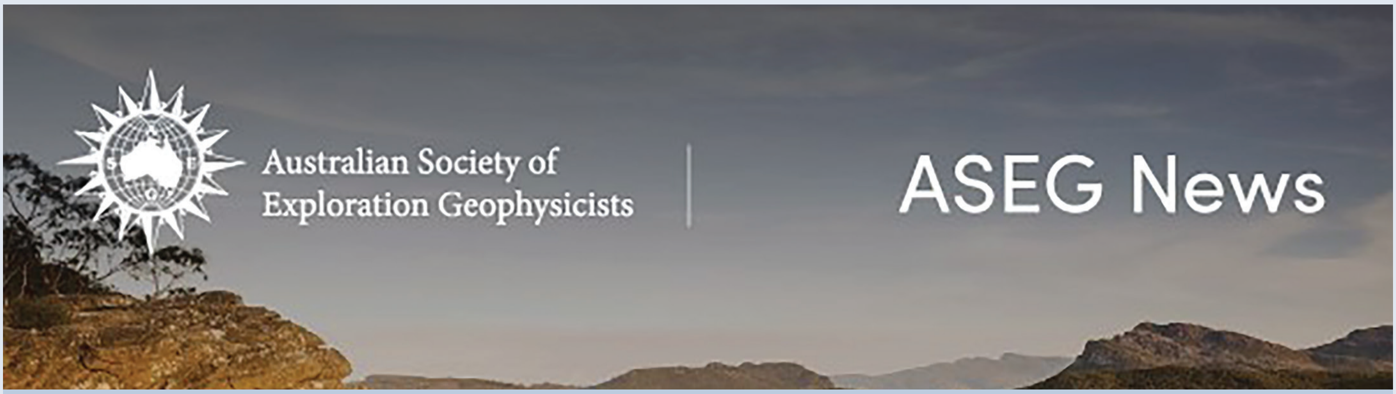
Members of the participating associations met in The Globe on Tuesday November 29 for 2023 wrap. The evening was an opportunity to make meaningful connections in a friendly environment and the sponsors are gratefully acknowledged.

J.J. Leong
j.leong@terraresources.com.au

The ASEG Young Professionals group in Queensland is sponsoring an Early Careers and University Student networking social on December 9 at Saccharomyces, Southbank. This event is run by the Brisbane Brews committee, which is tasked with bringing several geoscience societies in Brisbane together in a relaxed environment to enhance ties and foster networking.

Please go to https://www.eventbrite.com.au/e/465486130547 to register.

Nick Josephs
qldsecretary@aseg.org.au



Update on Members spotlighted in the ASEG newsletter

The first Member spotlighted in an ASEG newsletter was Marina Costelloe in May 2018. Over 40 geophysicists /geologists have now shared their experiences, views and interesting stories. You can find them at https://www.aseg.org.au/publications/newsletters. If you would like to subscribe to the ASEG Newsletter, nominate someone for the Member spotlight, or leave any suggestions, please email us at communications@aseg.org.au.

List of Members spotlighted in 2022

Nicholas Josephs
Bhavik Harish Lodhia
Gerrit Olivier
Natasha Hendrick
Lisa Vella
Eric Battig
Audrey Quealy
Chibuzo Chukwu
Desmond FitzGerald
Sasha Aivazpourporgou
Wei Xuen Heng

ASEG branch news

Western Australia

The Western Australian ASEG Branch hosted Dr **Mustafa Sari** from CSIRO at our September Tech Night. He presented a talk entitled; "Geomechanical and petrophysical properties of rock salt for waste disposal or energy/gas storage: Frome Rocks Salt Dome". Dr Sari introduced a topic that was new to most of the ASEG attendees – the use of salt domes for long-term storage of nuclear waste. It was a fascinating trip into the world of geomechanics, which generated a lot of questions from the geophysicists in attendance.

The WA Branch (represented by **Partha Pratim Mandal**) also recently hosted an online presentation. On 20 October Dr **Michinori Asaka** from INPEX presented a webinar from Tokyo, Japan to an eager group of international attendees, entitled; "A predictive anisotropic rock physics model of shale and its practical applications". Dr Asaka presented an anisotropic shale model and described its application to seismic forward modelling and wellbore stability analysis. The presentation is now available to watch on the ASEG YouTube channel.

We were able to change things up for our October technical event and take our Tech Night programme out into the 'field'. **Adam Kroll** from AirGeoX gave a live demonstration of drone magnetics acquisition at Herdsman Lake. In addition to taking the time to explain the intricacies of drone operations to Members, Adam also shouted drinks for the event - thanks AirGeoX!

The second annual MAG symposium was held on 9 November in Perth. A full write-up and photographs of the symposium will follow in the next edition of *Preview*.

Our Christmas party on 7 December marks our final event for the year - we will celebrate the end of 2022 with a relaxed evening of lawn bowls, we hope to see all WA Members there!

Darren Hunt
wapresident@aseg.org.au

Australian Capital Territory

The last couple of months has been quiet period for the ACT Branch. At the time of writing we are looking forward to **Sebastian Wong**'s talk on the creation of workflows to aid in interpreting the data acquired during the largest airborne electromagnetic survey conducted by Geoscience Australia. Our thoughts are also turning towards what ASEG wine or wines to get and other Christmas plans. And lastly, we need to find a way to commemorate all that has happened during the year.

Don't forget Geoscience Australia's Wednesday seminars (https://www.ga.gov.au/news-events/events/public-talks). These are a good source of geoscientific information that includes the use of geophysics.

Phillip Wynne
actpresident@aseg.org.au

New South Wales

The ASEG NSW Branch had the pleasure of hosting two events in recent months, both talks generating much discussion that had to be continued over drinks. An international flair was added to our September meeting, when **Berta Vilacis** (University of Munich) gave a presentation whilst in Sydney and being hosted by UNSW. Berta's presentation entitled, "Evidence for upper mantle flow in the Atlantic and Indo-Australian realms since the Upper Jurassic from hiatus maps and spreading rate changes", discussed how mantle convection is an essential driving force of plate tectonics whereby surface deflections driven by mantle convection create erosional environments, which induce hiatuses in the stratigraphic record. These hiatus surfaces were modelled and used as a proxy for mantle flow induced dynamic topography. This research demonstrates how studies of lithospheric vertical and horizontal motion can be used to track past mantle flow and provide powerful constraints for adjoint based geodynamic inverse models of past mantle convection.

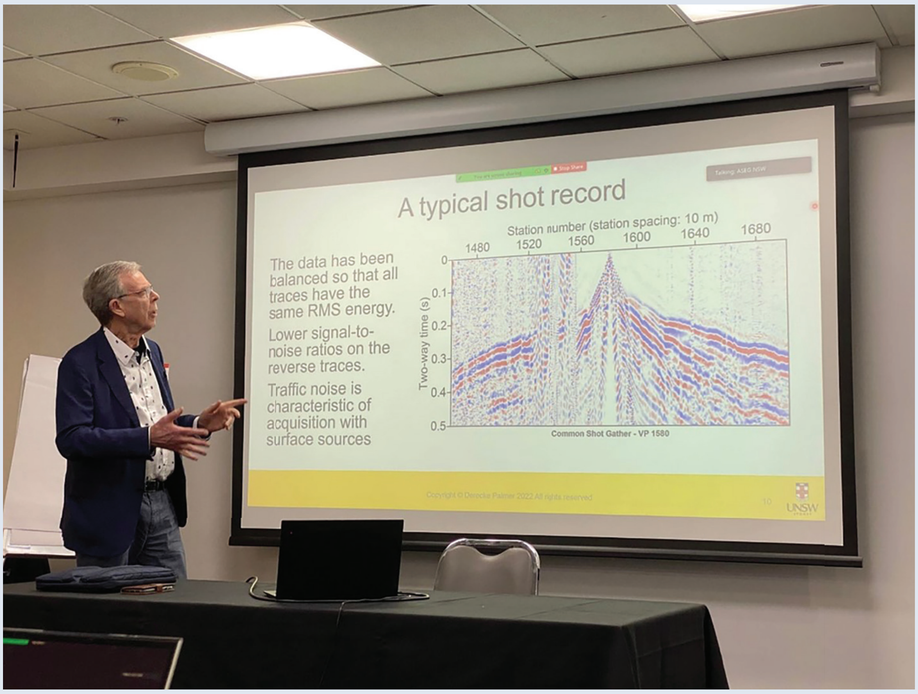
In October, **Derecke Palmer** (UNSW) presented his findings on "Is there a seismic refraction signature for sulphide mineralisation?". Derecke's talk examined three questions; a) Is there a seismic refraction signature for sulphide mineralisation at the base of the regolith, b) will full waveform elastic inversion rapidly replace travel time acoustic tomographic inversion and become routine with most geotechnical investigations, and, c) could a detailed analysis of the refraction component of selected regional reflection profiles recorded by GA be useful? This research was applied to an area close to the hearts of many geophysicists from New South Wales – Mt Bulga, a massive sulphide ore body. The presenter sought feedback from the knowledgeable audience on the theories of Mt Bulga's origins. The research demonstrated how an understanding of the regolith is needed to sustainably manage our natural resources.

*The UNSW crew after Berta's presentation, left to right: **Bhavik Lodhia** (Secretary of the ASEG NSW Branch), **Berta Vilacis** (University of Munich) and **Stuart Clark** (UNSW technical officer).*

An invitation to attend NSW Branch meetings is extended to all interstate and international visitors who happen to be in town at the time. Meetings are generally held on the third Wednesday of each month from 17:30 at Club York. News, meetings notices, addresses and relevant contact details can be found at the NSW Branch website.

The ASEG NSW committee takes this opportunity to wish you and your families a very Merry Christmas and Happy New Year!

Stephanie Kovach (President) and Josh Valencic (Social Media Officer)
nswpresident@aseg.org.au



Derecke Palmer presenting his thought-provoking research at the October NSW Branch meeting.

Queensland

The Queensland Branch had a relatively quiet October, with Members taking the opportunity to catch up for a few drinks along with other geoscientists at the Brisbane Brews event at Range Brewing, Newstead. Racing towards the end of the year, November and December are shaping up to be a busy couple of months.

On Tuesday 8 November, the Qld branch hosted Dr **Gerrit Olivier** from Fleet Space Technologies presenting a talk on "Using real-time seismic nodes to explore the Earth, Moon and Mars". Fleet have recently arrived on the exploration geophysics map, primarily with their Exosphere real-time Ambient Noise Tomography service, a passive seismic technique perhaps sitting in a sweet spot between the cost and effectiveness of HVSR-type 1D surveys and full active seismic. For many that had heard about Fleet's product it was great to see Dr Olivier delve deeper into the technical detail of the technique, attracting an in-person and online audience of over 40 people. It's not often that a completely new disruptor enters the exploration geophysics industry, and it will be exciting to see more examples of what Fleet can achieve, both through their own innovation and through partnerships with existing operators.

On the 15 November PESA-ASEG had a joint lunchtime talk presented by Dr **Claudio Strobbia** of Realtime Seismic and entitled "Challenging land seismic surveys". We were grateful to have Claudio present on his short tour of Australia and the audience much enjoyed his presentation.

On 21 November the Queensland Branch was extremely proud to be hosting another international geophysicist, Dr **Ken Witherly** from Condor Consulting, who flew in from the USA. We partnered with AIG to bring you his presentation on "EM techniques in uncovering Porphyry copper deposits".

The Combined Oil and Gas Christmas drinks celebration was held on 24 November. Originally aimed at those in O&G industry, was truly for everyone and the Port Office Hotel was a great place for a Christmas party.

Finally, on 9 December, the ASEG Young Professionals Group will be sponsoring the final Brisbane Brews for the year, encouraging those soon to be graduated or new to our industry to get together in a relaxed environment. Please share with anyone who you think would be interested in attending.

2022 has been another busy year for everyone in the exploration geophysics community and on behalf of the ASEG's Queensland Committee we would like to offer all *Preview* readers our best wishes for good health and an excellent Christmas and New Year break. We look forward to welcoming as many of you as possible to the AEGC conference in Brisbane in March 2023!

James Alderman
qldpresident@aseg.org.au

Gerrit Olivier presenting to the Qld Branch.

South Australia and Northern Territory

The SA-NT Branch of the ASEG held our annual Melbourne Cup Luncheon on Tuesday, 1 November. The event was attended by 43 of our Members, friends and colleagues resulting in a great day catching up with old friends and some new ones.

As usual, **Neil Gibbins** from Vintage Energy MC'ed the event, and brought a wealth of knowledge and enthusiasm

ASEG news

MC Neil Gibbins and punters at the ASEG SA-NT Branch Melbourne Cup Luncheon.

to the job. He ensured that everything ran smoothly, and the Calcutta Sweep was completed before the race began. I would also like to say a big thank you to the Cumby for providing the venue and excellent food and service.

Lastly, we couldn't host any of our fantastic events without the valued support of our sponsors. The SA-NT Branch is currently sponsored by **Beach Energy**, **Borehole Wireline**, **Oz Minerals**, **Vintage Energy**, **Minotaur Exploration**, the **Department for Energy and Mining**, **Zonge**, **Santos and Heathgate**.

Our final event of the year will be our Christmas party on 15 December, I encourage all of our state Branch Members to attend what will surely be a fantastic way to finish off the year. The SA-NT committee wish you all a safe and relaxing Christmas break, and we look forward to seeing you at ASEG events in 2023.

Paul Soeffky
sa-ntpresident@aseg.org.au

Tasmania

Meeting notices, details about venues and relevant contact details can be found on the Tasmanian Branch page on the ASEG website. As always, we encourage Members to 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.

Gerrit Olivier
taspresident@aseg.org.au

Victoria

As we near completion of another lap around the sun, I am feeling unusually dejected. There are only so many sleeps left until Christmas, but for some gloomy reason, it doesn't feel like Christmas this year to me. I mean, this is the happiest time of the year for many people, but I freely admit I am struggling to get into the 'spirit' of Christmas. Am I being a killjoy here? Does anyone else also feel like skipping Christmas this year? For most people, Christmas is a celebration and a time for giving, where families come together for the holiday season. The spirit of Christmas lends itself to this 'togetherness'. Sadly, this Christmas just feels like any other day at the office – you do a silly amount of work and some fat guy in a suit gets all the credit 🤣

Who am I kidding? I love this time of the year because I can see the finish line… my annual journey's end…this year's last stop. This is the one time of the year where I can utterly surrender my inhibitions and indulge in perilous acts of debauchery in celebration of another year gone by. Yes, I will be consuming obscene amounts of alcohol (disclaimer: I do not own shares in Carlton United or Lion Breweries). I can't ever recall having a bad Christmas (alcoholism has affected my long-term memory), only bad Christmas jokes. Here's one. What's the difference between snowmen and snowwomen? Snowballs, what else?

Ok, so I might have actually started my period of indulgence a little early this year. The delirium has certainly kicked in so before I fall off my chair writing this, I will provide a modest recap of recent branch events.

On Tuesday October 25, Victorian Members were treated to a talk by **Tom McNamara** (post-graduate student, Melbourne University), with support from his co-author, Dr **James Parsons** (geophysicist & software engineers, QIntegral Pty Ltd), entitled "Quiacito™ Multiphysics: A case study in seismic and potential fields integration" at the Kelvin Club. Dr **Jarrod Dunne**, the third co-author of the talk and your Victoria Branch treasurer was unable to attend at the last minute. While Tom did not present any work related to his current post-graduate studies, what he and James did present was a masterclass on the methodology and power behind Quiacito, a seismic-based interpretation and modelling software that is capable of allowing an interpretation to be quickly modified, converted and tested against forward models of potential fields data - all in real-time. Potential fields data is often under-utilised or overlooked in the oil and gas industry. With the Quiacito approach, areas of a basin where there is a lack of velocity control or an absence of petrophysical rock properties from wells, the integration of potential fields data, in particular gravity, can help provide the additional constraints to improve our interpretations. Well done to Tom and James for covering Jarrod's *derrière* on the night.

By the time you read this, the Victorian Branch would have hosted its last technical meeting for the year. World renowned geophysicist **Ken Witherly** (Condor Consulting, Canada) will have already delivered his talk "Future Imperfect - Where should exploration be headed in the next 25 years?" to a gathering of Victorian Members on 22 November at The Kelvin Club.

Tom McNamara presenting to the Victorian Branch.

Lastly, the annual joint ASEG-PESA-SPE Christmas luncheon will be on again. No final date has been locked in, but **Errol Johnstone** (chief geoscientist, Melbana Energy) will be the guest speaker at the event. Please keep an eye out for notifications.

Before the year is out, I want to thank my fellow Victorian Branch committee members for their tremendous help this year, and to all Victorian Members for putting up with my facetious approach to running this Branch. Without your unwavering and enthusiastic support, I would be as mundane a president as a mystery flight to Canberra. Lastly, why did the snowman want a divorce? Because his wife was a total flake 😊

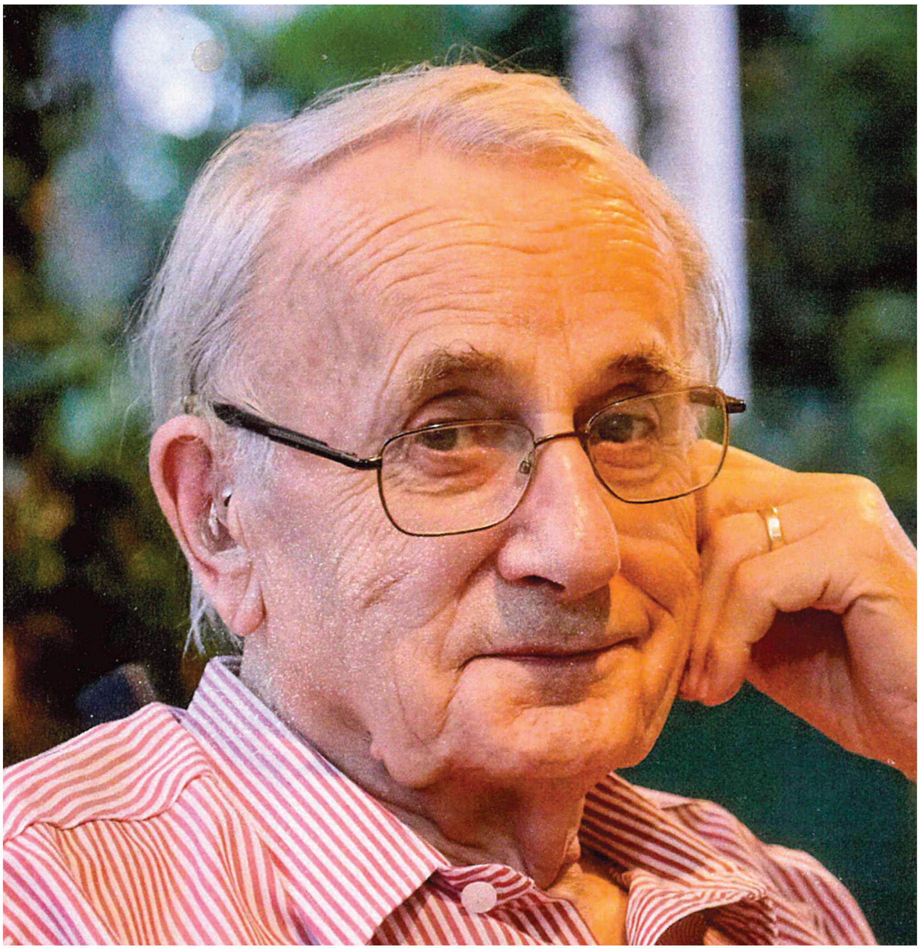
Stay safe out there, boys and girls. Have a safe and exciting festive season. See you in new year.

Thong Huynh
vicpresident@aseg.org.au

ASEG national calendar

Date	Branch	Event	Presenter	Time	Venue
ASEG Branch face-to-face meetings have been disrupted in many states due to COVID outbreaks. Some branches are 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/2ZNgIaZ). Please monitor the Events page on the ASEG website for the latest information about upcoming webinars and other on-line events.					
30 Nov	WA	2022 AGM	TBA	1730	Shoe Bar, Perth
07 Dec	NSW	Annual dinner	TBA	1800	TBA
07 Dec	WA	Christmas party	TBA	1700	Leederville Sporting Club, 78 Cambridge Street, West Leederville
09 Dec	Qld	YPN Brisbane Brews	TBA	1700	Saccharomyces, South Brisbane
15 Dec	SA-NT	Christmas Party	TBA	TBA	TBA
Dec	Vic	Christmas Party	Errol Johnstone	TBA	TBA

Vale: Sydney Hall (1923-2022)



Sydney Hall

The end of a geophysical era has come with the recent death of Sydney Hall at the age of 99. Amongst a range of geophysical achievements, Sydney will be remembered by numerous alumni from University of Queensland from the late 60s, 70s and 80s, who were trained and influenced by Sydney and his longtime colleague, the late John (Jack) Webb.

Sydney was born in Wellington NZ in 1923 and developed his interest in the natural world by participating in the Boy Scouts and other outdoor activities. In 1942 he started a Science degree at Victoria University, emphasising maths, physics and geology. He graduated in 1947 and proceeded to obtain a Master's degree in physics.

Sydney worked for a few years in NZ's Department of Scientific and Industrial Research, before moving to the UK where he started a PhD at the School of Mines, Imperial College London. The topic of his PhD was seismic scale modelling. He received his PhD in 1954, returned to NZ briefly, and then rejoined Imperial College as a lecturer. His research into the Earth's magnetic field took him to Scandinavia, and also gave him a taste for Australia, with research at the Woomera test site.

In 1968, Sydney's contribution to Australian geophysics began in earnest when he took a position as Senior Lecturer in the Department of Geology and Mineralogy at University of Queensland. Thus began two decades during which he taught and mentored numerous geophysical students at UQ. Along with Jack Webb, Sydney drove the introduction of the BScApp (Geophysics) degree, which became the flagship for education in applied geophysics at UQ. It included strong theoretical components (including those taught by Sydney), but always with an eye to the demands of the geophysical profession, with practical components from applied maths, to programming, to field geophysics. This degree and its successors have provided a steady stream of highly capable geophysical graduates, who as a group have contributed significantly to the profession.

Sydney retired from UQ in 1988. Up until very recently he participated in regular so-called "AGMs" with former students, where over leisurely refreshments, the topics of conversations ranged across the spectrum of all the geophysical techniques and beyond, into politics and music. Sydney possessed a refined sense of humour and participated enthusiastically in endless amusing anecdotes ranging from the character-forming qualities of spherical-harmonics to field-trip misadventures.

Sydney was perhaps, at heart, a mathematician, which helps explain why his technical capabilities and knowledge were so diverse. At DSIR he was a gravity specialist. His PhD was in seismic modelling. His subsequent work at Imperial College concentrated on geomagnetics. At UQ he worked initially on potential field methods, before moving on to electromagnetics, perhaps drawn to the mathematical challenge. His very recent work, done within the past few years, was on EM modelling - analytical of course. His level of theoretical understanding is evident in a preprint describing this recent research (https://zenodo.org/record/7349429#.Y32OO3VfgzN).

Sydney actively encouraged students to join ASEG. He was involved in technical committees for ASEG Conferences in 1992 (Gold Coast) and 2001 (Brisbane) and served on the Editorial Panel of *Exploration Geophysics* from 2000 to 2008.

Sydney's much-loved wife Noeline died last year. He was immensely proud of his children Philippa and Nicholas, and his grand-children Catrin, Sarah, Madeleine and Oliver.

Sydney Hall, directly and through his students, had a major impact on Australian geophysics.

Vale Sydney.

Steve Hearn
steveh@velseis.com

Geoscience Australia: News

Recent highlights of Geoscience Australia's geophysical programmes, as conducted under the Australian Government's Exploration for the Future programme and in collaboration with our State and Territory survey partners, are outlined below. A summary of all current and recently completed programmes and survey locations can be found in Figure 1 and the tables that follow this section.

Exploring for the Future – 2022 Western and Eastern Resources Corridor AEM Surveys

This year's airborne EM programmes through the Western Resources Corridor (see Figure 1, orange shaded areas straddling the SA/WA/NT borders) and through the Eastern Resources Corridor (see Figure 1, orange shaded areas through NSW and Vic) have all been fully acquired. Survey datasets, including inversions with GA's own deterministic products, are on track for publishing early next year.

Exploring for the Future – 2022 Upper Darling Floodplain AEM Survey

Geoscience Australia in collaboration with the New South Wales Department of Planning and Environment (NSW DPE) are pleased to release the Upper Darling Floodplain Airborne Electromagnetic survey data during this *Preview* period. Running northeast through Wilcannia in the south through to Bourke in the north, acquisition of the 25 000 line km programme occurred between March-July 2022 on 250 to 5000 m line-spacings (see Figure 2). The data reveals unprecedented detail of the top 300 m of ground across the floodplain, and will be invaluable for groundwater investigations and irrigation considerations. The data can be found at: https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/147267.

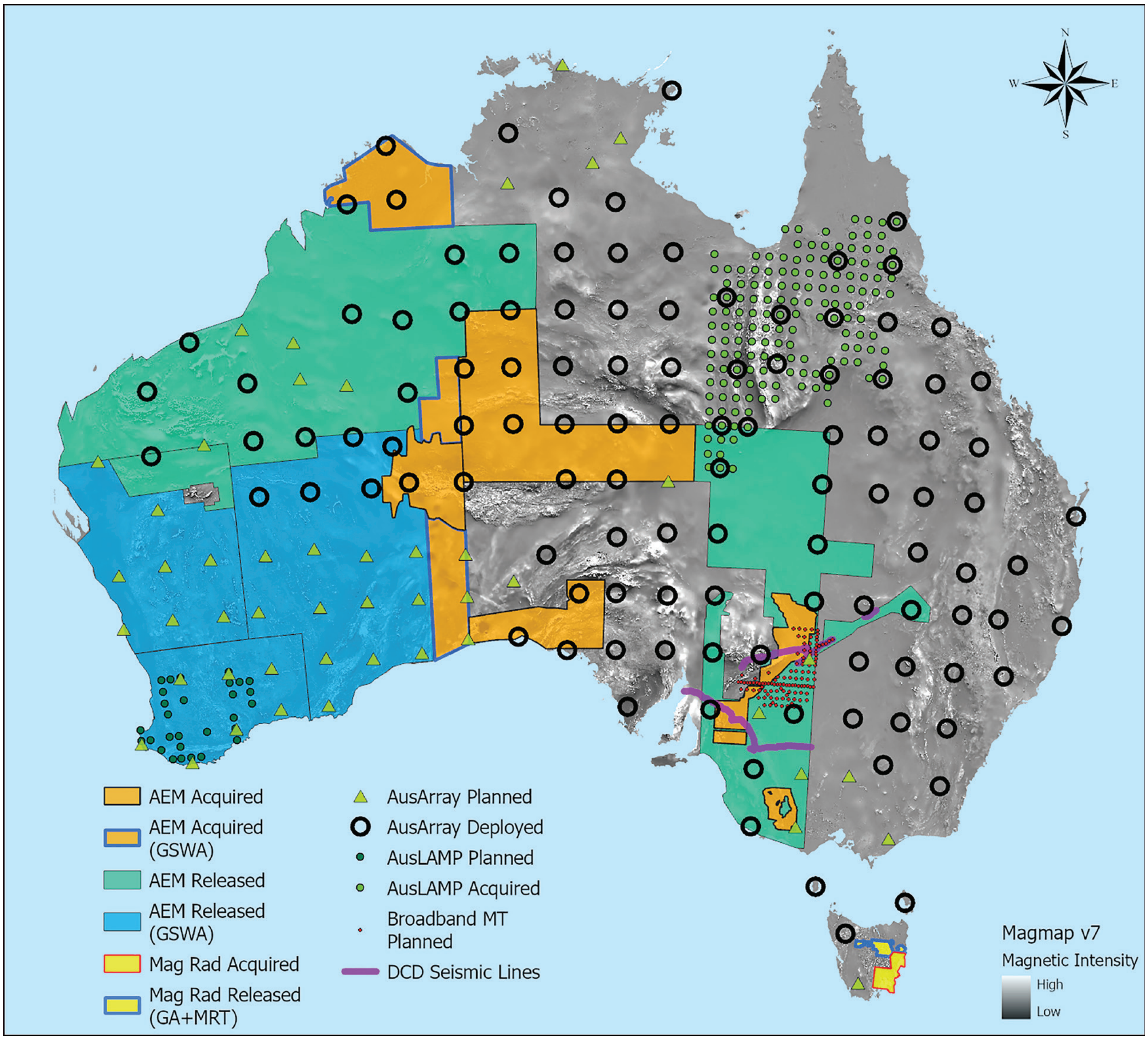


Figure 1. *2021–2022 geophysical surveys – in progress, released or for release by Geoscience Australia as part of the Exploring for the Future (EFTF) programme and in collaboration with State and Territory agencies. Note too that the completion of the Western Resources Corridor programme this year, brings regional AEM coverage across Western Australia to 100% (previous regional work shown in green as 'released'). Projects that are substantially or wholly funded by state government agencies are identified by the bracketed contributors. Background image of national TMI compilation, Geoscience Australia, 2019 (see http://pid.geoscience.gov.au/dataset/ga/144725).*

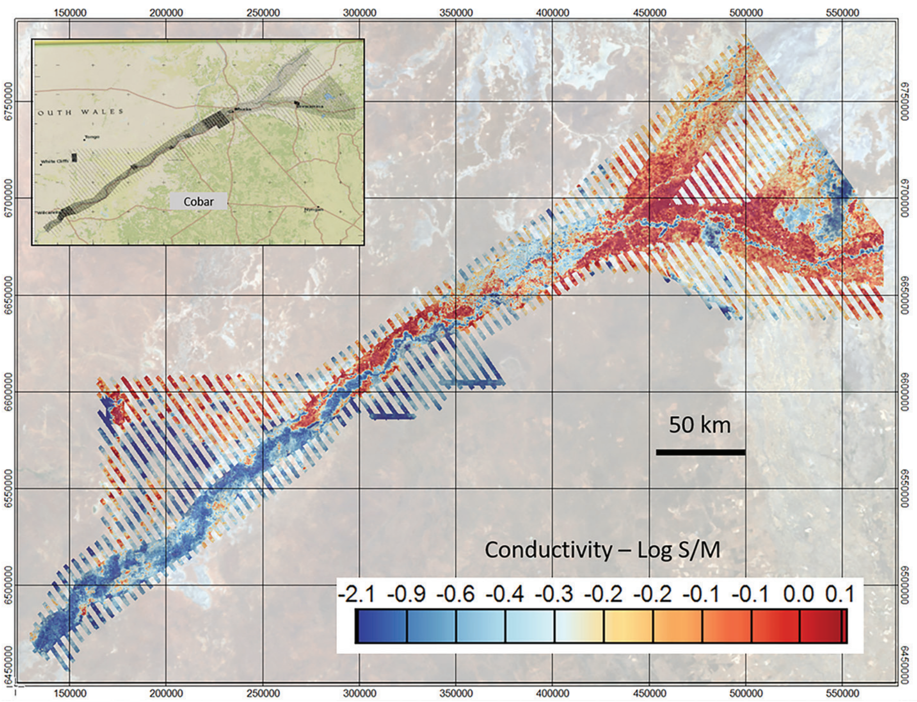


Figure 2. *Ground conductivities from the 2022 Upper Darling Floodplain AEM data. Shown here is the layer 9 slice from the inversion, or approximately 16 m below ground surface.*

Exploring for the Future – Field technique factsheets

Geoscience Australia has developed a series of simple factsheets (see Figure 3 for an example) that describe the various field surveys that Geoscience Australia conducts. They are intended to assist communication with communities impacted by our data acquisition activities. Factsheets on geophysical methods such as AEM, MT, passive seismic, reflection seismic and SMR are included in the collection. The factsheets are available via http://pid.geoscience.gov.au/dataset/ga/147248.

Mike Barlow
Geoscience Australia
Mike.Barlow@ga.gov.au

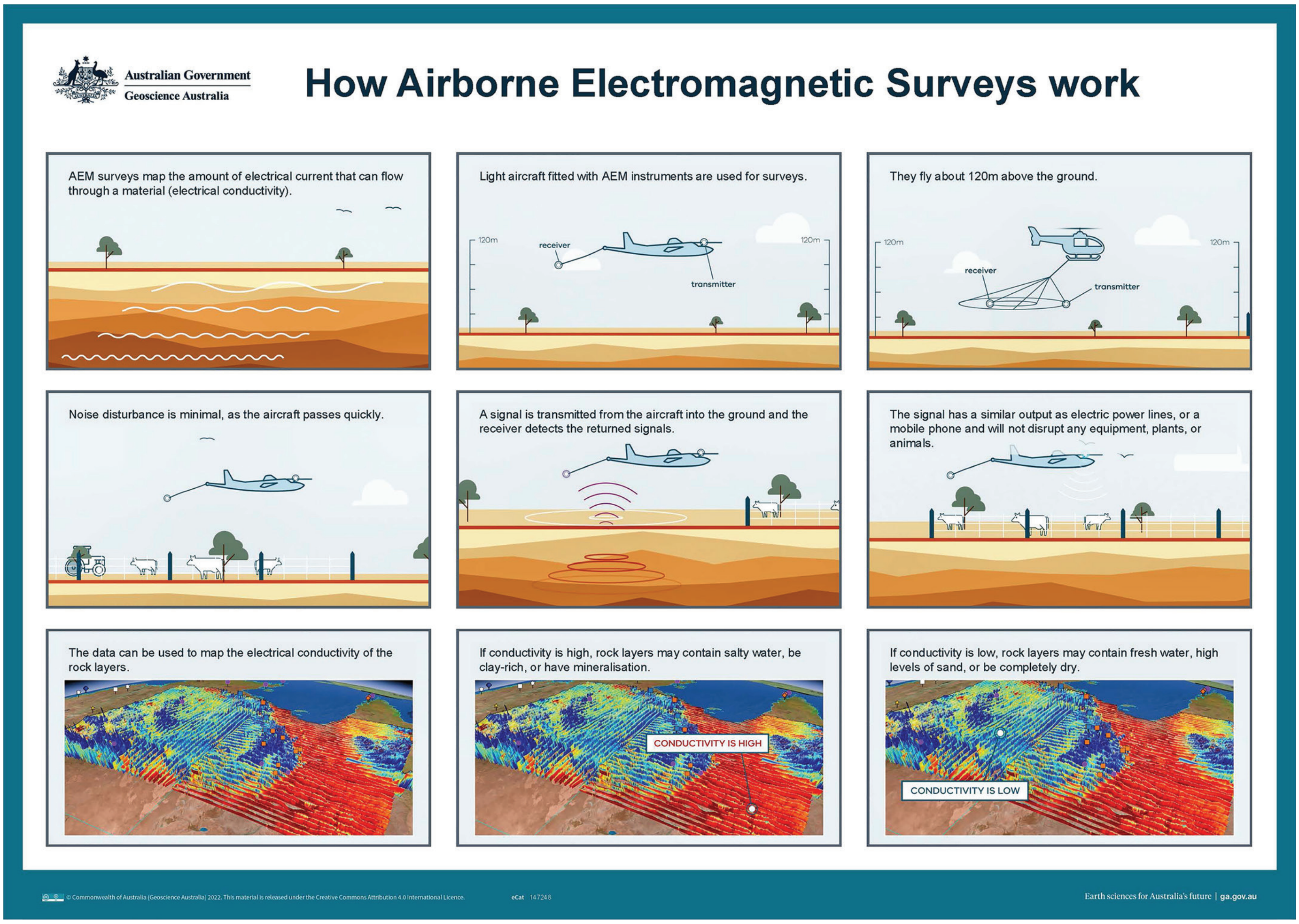


Figure 3. *Field technique factsheet: AEM fixed wing (http://pid.geoscience.gov.au/dataset/ga/147248).*

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 22 November 2022)

The survey details are provided for information only, and on the understanding that the Australian Government is not providing advice. Further information about these surveys is available from Mike Barlow Mike.Barlow@ga.gov.au (02) 6249 9275 or Donna Cathro Donna.Cathro@ga.gov.au (02) 6249 9800 at Geoscience Australia.

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Line spacing Terrain clearance Line direction	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Eastern Tasmania	MRT	GA	MAGSPEC	Mar 2022	57 000	200 m	11 600	Jun 2022	Sep 2022	See Figure 1 in previous section (GA News)	Set for Dec 2022

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 (km²)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Canobie	GSQ	GA	Xcalibur Multiphysics	Nov 2021	~5000	1–2 km	5300	Dec 2021	Mar 2022	See Figure 1 in previous section (GA news)	Released by GSQ and GA, Apr 2022
Brunette Downs Ground Gravity	NTGS	GA	Atlas Geophysics	Oct 2021	~ 12 000	2 x 2 km grid	55 000	Apr 2022	May 2022	See Figure 1 in previous section (GA news)	Released by NTGS and GA in Jun 2022
Melbourne, Eastern Victoria, South Australia	AusScope GSV DEL WP	GA	Sander Geophysics	Apr 2022	137 000	0.5–5 km	146 000	TBA	TBA	See Figure 1 in previous section (GA news)	TBA
Kidson Sub-basin	GSWA	GA	Xcalibur Multiphysics	14 Jul 2017	72 933	2500 m	155 000	3 May 2018	15 Oct 2018	See Figure 1 in previous section (GA news)	Set for release Dec 2022
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	Released this month as https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/147066
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	Released this month as https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/147066
Warburton-Great Victoria Desert	GSWA	GA	Sander Geophysics	Warb: 14 Jul 2018 GVD: 22 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	Released this month as https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/147066
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)	Released this month as https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/147265
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 the national database in 2022

TBA, to be advised

Table 3. Airborne electromagnetic surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km^2)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Western Resources Corridor	GA/ GSWA	GA	Xcalibur Multiphysics	Mar 2022	~ 38 000	20 km	760 000	Oct 2022	Dec 2022	See Figure 1 in previous section (GA News)	TBA
Musgraves	GA	GA	Xcalibur Multiphysics	Jun 2022	~ 22 000	1 – 5 km	~ 100 000	Aug 2022	Dec 2022	See Figure 1 in previous section (GA News)	TBA
Upper Darling River	GA	GA	SkyTEM	Mar 2022	25 000	.25 – 5 km		Jun 2022	Oct 2022	See Figure 1 in previous section (GA News)	https://dx.doi.org/10.26186/147267
Darling-Curnamona-Delamerian	GA	GA	SkyTEM	Jun 2022	14 500	1 – 10 km		Oct 2022	Dec 2022	See Figure 1 in previous section (GA News)	TBA
Eastern Resources Corridor	GA	GA	Xcalibur Multiphysics	Apr 2021	32 000	20 km	640 000	Jul 2021	Oct 2021	See Figure 1 in previous section	Oct 2021 http://pid.geoscience.gov.au/dataset/ga/145744
AusAEM20	GSWA	GA	Xcalibur Multiphysics & SkyTEM	Aug 2020	62 000	20 km	1 240 000	Nov 21	Dec 2021	See Figure 1 in previous section (GA News)	Mar 2022 see http://pid.geoscience.gov.au/dataset/ga/146345

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 2016–19 156 stations deployed in 2021–22	50 km	Long period MT	The survey covers areas of NT and Qld. Data package: http://pid.geoscience.gov.au/dataset/ga/134997 Model: http://pid.geoscience.gov.au/dataset/ga/145233 News article: http://www.ga.gov.au/news-events/news/latest-news/exploring-for-the-future-takes-a-deeper-look-at-northern-australia Acquisition of 32 new sites in SW Qld completed mid-2021, data to be released late 2022 together with additional data planned to be acquired under Exploring for the Future during 2022.
AusLAMP NSW	GSNSW/ GA	NSW	AusLAMP NSW	~300 stations deployed 2016-21	50 km	Long period MT	Covering the state of NSW. Acquisition is essentially complete with fewer than 10 sites remaining to be acquired or reacquired. Phase 1 data release: http://pid.geoscience.gov.au/dataset/ga/132148.
Curnamona Province-Delamerian Orogen	GA/GSNSW/ GSSA/ University of Adelaide	NSW/ SA	Exploring for the Future - Curnamona Cube Extension	~100 stations planned 2023	25-12.5 km	Audio and broadband MT	This survey will extend the University of Adelaide-AuScope Curnamona Cube MT survey from the Curnamona Province into the Delamerian Orogen.

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
Perdirka Basin Phase 2	GA	SA/ NT	Shallow legacy data	~1800	Varies	Varies	3-6 sec	2D shallow legacy data, explosive, vibroseis	GA commissioned additional reprocessing of selected legacy 2D seismic data in the Pedirka Basin, SA and NT, as part of the Exploring for the Future programme. The objective was to produce a modern industry standard 2D land seismic reflection dataset to assist in imaging the subsurface. Reprocessing of these data by Geofizika is complete. The data package is available on request via http://pid.geoscience.gov.au/dataset/ga/146309.
Central Darling Basin	Coal Innovation NSW (CINSW)	NSW	Central Darling seismic survey	~208	10 m	10 m	6-16 sec	2D high resolution and deep crustal seismic	GA and CINSW signed an MoU to acquire and process 2D high resolution and deep crustal seismic data in the Central Darling Basin. New seismic data will be acquired, processed and interpreted to assist in proving up a geological resource in NSW for the safe and permanent storage of CO_2. Data acquisition was completed in May 2021. CINSW contracted Velseis to process the data and GA is QCing the process. The data package is available on request via http://pid.geoscience.gov.au/dataset/ga/146666
2019 Camooweal 2D Seismic Survey Archiving Project	GSQ	Qld	Camooweal seismic survey	~300	30 m	10 m	20 s	2D deep crustal seismic	Under a MOU with GSQ, GA is preparing a Data Processing Package for the 300 line km 2019 Camooweal 2D Seismic Survey. This data package will support an interpretation project being undertaken by GSQ to produce new precompetitive geoscience information to assist industry in better targeting areas likely to contain significant gas and sedimentary-hosted mineral deposits. The data package is available from http://pid.geoscience.gov.au/dataset/ga/146301 (GA) or https://geoscience.data.qld.gov.au/seismic/ss095590 (GSQ)
Darling – Curnamona – Delamerian deep crustal reflection survey	GA	SA, NSW, VIC	Darling – Curnamona – Delamerian deep crustal reflection survey	~1275	10	10/40	20	2D Deep Crustal/ high resolution vibroseis seismic survey.	This survey will create an image of important crustal boundaries including the structure of the Delamerian margin, which runs through NSW, SA and Vic, separating older rocks of the Gawler Craton and Curnamona Province from younger rocks of the Lachlan Fold Belt (Tasmanides). Acquisition commenced in Jun 2022 and concluded in Aug. Data are currently being processed.

Table 6. Passive seismic surveys

Location	Client	State	Survey name	Total number of stations deployed	Spacing	Technique	Comments
Australia	GA	Various	AusArray	About 180 temporal seismic stations	~200 km spacing	Broad-band ~18 months of observations	The survey will cover all of Australia to establish continental-scale model of lithospheric structure and serve as a background framework for more dense (~50 km) movable seismic arrays. Deployment of this national array commenced with an initial 11 seismic stations deployed in the NT in 2021. Deployments in SA and NSW commenced in Apr 2022 and will progress through other states during 2022.
Northern Australia	GA	Qld/NT	AusArray	About 265 broad-band seismic stations	50 km	Broad-band 1 year observations	The survey covers the area between Tanami, Tennant Creek, Uluru and the WA border. The first public data release of the transportable array was in 2020, with further data and model releases expected by Dec 2022. 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: · AusArray overview: http://pid.geoscience.gov.au/dataset/ga/135284 · Body wave tomography: http://pid.geoscience.gov.au/dataset/ga/134501 · Ambient noise tomography (including an updated, higher resolution model for the Tennant Creek to Mount Isa region): http://pid.geoscience.gov.au/dataset/ga/135130 · Northern Australia Moho: http://pid.geoscience.gov.au/dataset/ga/135179
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

Geological Survey of South Australia: Goodbye cookie-cut, hello variety

The GSSA will discontinue using the software that allows users to cookie-cut geophysical data from our state wide repository of government and company geophysical datasets. The decision was made due to a combination of factors, but the primary issue is a forthcoming change in the infrastructure housing the SARIG environment. The current Jetstream software isn't incompatible with the new servers, and the GSSA have explored numerous options moving forward.

All geophysical data will still be accessible for free download, but the "clip and ship" mechanism won't be available. Users can still use the spatial search option on SARIG to search an area and create a list of surveys in the area. The geophysical surveys can then be downloaded as data packages via the hyperlinks. Each data package consists of both original data and processed data.

What we are calling the "original data" are all the survey files and reports that have been delivered to the SA Government. These are usually part of mandatory annual reporting as part of an Exploration Licence, or in the case of government surveys they are what we have received from the contractor. In the case of older surveys (prior to mandatory reporting or early government surveys), original data are comprised of whatever information we can find. In the case of some historic surveys this may be nothing more than a pdf showing a scan of (say) a contour map. Most commonly and more recently we receive data as Geosoft GDB or ASEG-GDF2 format ASCII columns.

Processed data consists of the files created by GSSA geophysicists from the original data. There are Intrepid datasets, ER Mapper grids, and ESRI shapefiles. These are the data formats that were delivered via our instance of Jetstream. The Jetstream software had the functionality to reproject, resample, and export to ASCII columns via SARIG.

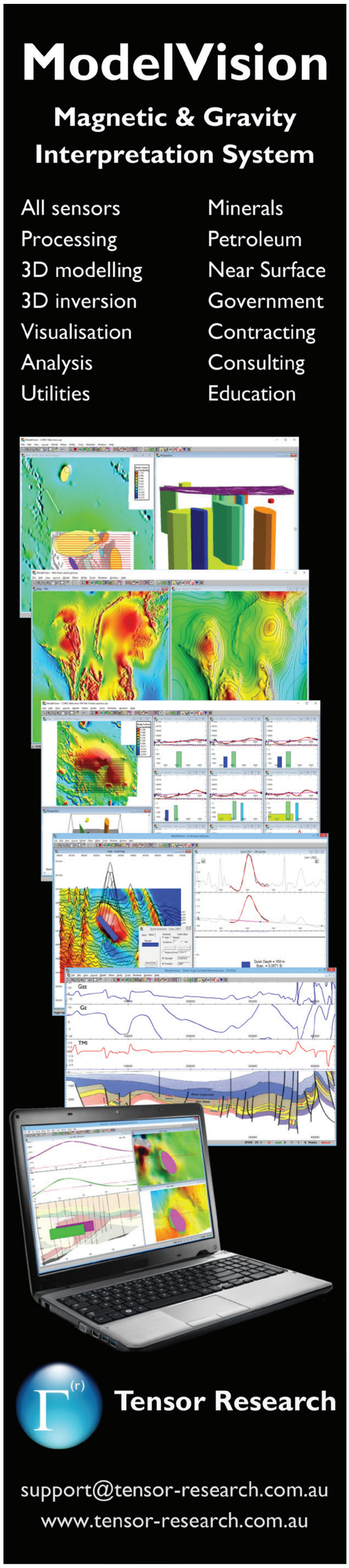
But, now that we're moving away from Jetstream, we need to ensure our datasets are accessible to everyone. The GSSA has committed to creating Geosoft databases and ASEG-GDF2 formatted ASCII files to sit alongside the Intrepid datasets. While this will significantly increase the size of the data repository, it will mean there's more chance that users will have access to data that they can use. A solution that doesn't require data double-up would be ideal and we are also exploring options in this space, but for the immediate future we are converting the datasets and updating each survey folder.

Revisiting the data packages also allows us to reproject data into other datums and projections (notably GDA2020). We will also include finely processed grids that were used as part of state grids, and we're exploring the options to add a new field to each dataset: a levelled signal field, corresponding to values in the state grid products.

It's uncertain when the revised data packages will be ready for public consumption, but our intention is to roll them out in 2023.

As always, if you need any help accessing geophysical data in South Australia, please contact customer resources at +61 8 8463 3000 or DEM.CustomerServices@sa.gov.au

Philip Heath
Philip.Heath@sa.gov.au



Mineral Resources Tasmania: Databases available for first time

Mineral Resources Tasmania is for the first time making its Samples/Observations and Drilling databases available for download as single packages, as part of a bulk data report. Of particular interest to *Preview* readers, physical property attributes are also presented as a single consolidated file in conjunction with the corresponding subset of Samples and Observations records. While some property data points are only identified by x-y location coordinates, many have also been attributed with lithostratigraphic unit, lithology and other relevant information such as presence of notable minerals and originating reference.

The data have been compiled over time from a range of sources, mainly company exploration reporting, academic research and MRT itself. Of 36 237 open file petrophysical samples extracted and made available in November 2022, 34 520 are from drill core with the balance generally originating from outcrops or mine workings. The majority (26 561) are magnetic susceptibility measurements, with density being the next most common (12 561). However, a significant number have multiple parameter determinations, with any or all of P-wave velocity, S-wave velocity, resistivity, chargeability, gamma radioactivity and thermal properties obtained in addition to density and/or magnetic susceptibility. Most Tasmanian geological units are represented in this more comprehensive subset. Also of note is the presence of 673 remanent magnetic intensity determinations, 451 of which also have inclination and declination NRM data.

Importantly, the petrophysical data are linked through unique sample ID numbers to the Drilling and broader Samples & Observations databases,

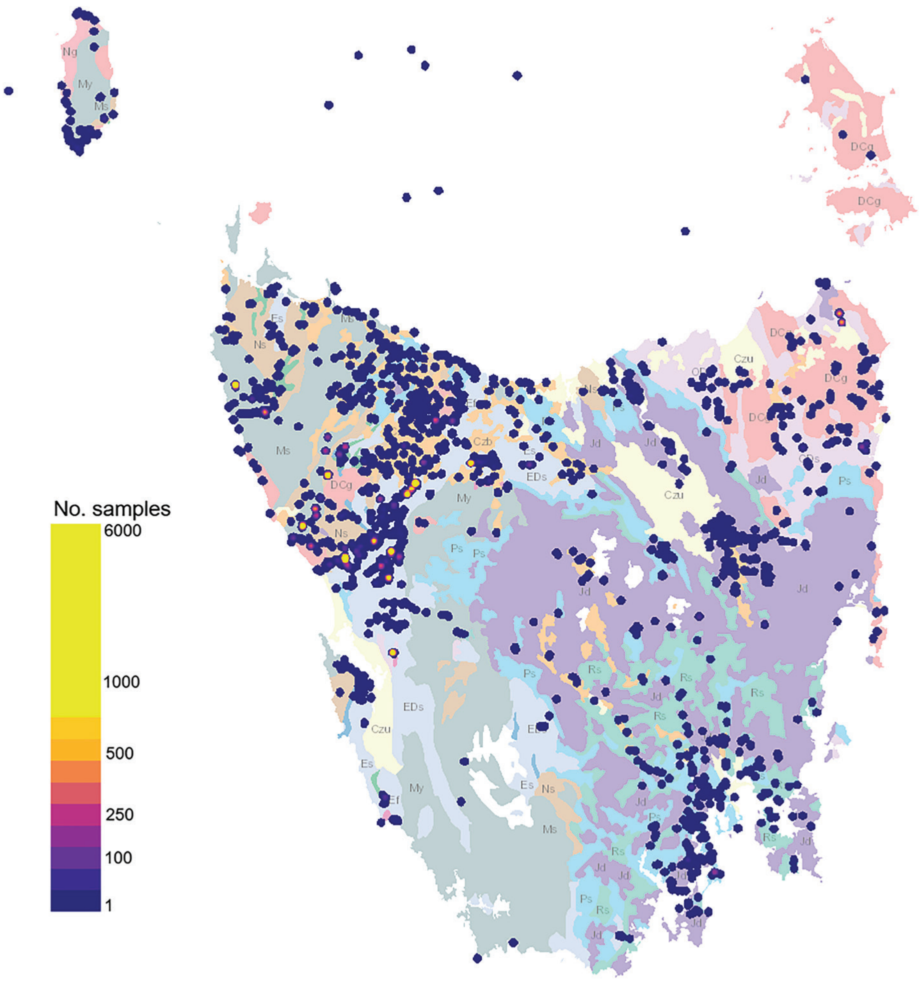


Figure 1. *Heat map of Mineral Resources Tasmania petrophysical sample distribution, overlaid on Geoscience Australia's 1 : 2.5 million geology.*

enabling examination of relationships to the geochemical and other data included in the package. It can all be downloaded from the MRT website: go to https://www.mrt.tas.gov.au/products/database_searches/documents_and_reports and search for Report Number BDR2022_01 under More Search Options, or from the home page https://www.mrt.tas.gov.au/home scroll down to Quick links, SEARCH data and documents then Documents and Reports.

Contact Mark Duffett mark.duffett@stategrowth.tas.gov.au with any queries about the petrophysical data, or info@mrt.tas.gov.au with any questions regarding the broader bulk data report.

Mark Duffett
Mineral Resources Tasmania
mark.duffett@stategrowth.tas.gov.au

Geological Survey of Victoria: Presence at IMARC 2022

The Geological Survey of Victoria (GSV) delivered presentations, hosted a booth display, and showcased 3-D geological models at the International Mining and Resources Conference (IMARC) held in Sydney in November 2022.

A key drawcard at the booth was a map (Figure 1) highlighting the breadth of collaborative geoscience programmes recently undertaken and currently in progress across Victoria. The comprehensive data acquisition programme will enhance the pre-competitive geoscience knowledge base across the State.

Exploration interest in Victoria is at an all-time high, with approximately 54% of available land currently under an exploration permit or application. GSV staff had many conversations at IMARC about gold mineralisation and emerging critical minerals prospects.

Visit www.earthresources.vic.gov.au for more information and contact Kate Bassano, Manager Exploration and Development, Geological Survey of Victoria at Kate.Bassano@ecodev.vic.gov.au to discuss Victorian earth resource exploration opportunities.

Suzanne Haydon
Geological Survey of Victoria
Suzanne.Haydon@ecodev.vic.gov.au

The GSV booth at IMARC 2022

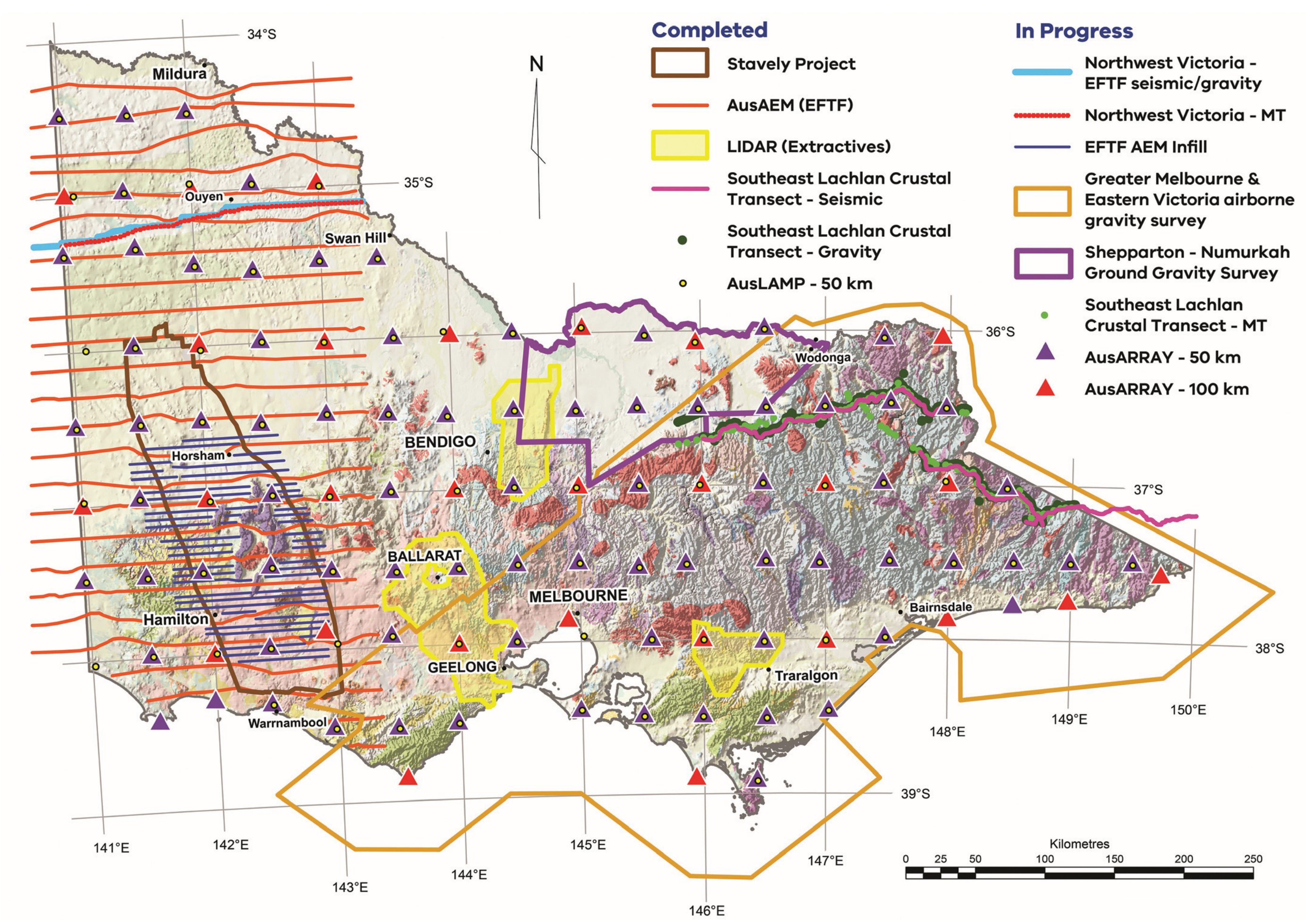


Figure 1. *Regional data acquisition programmes across Victoria.*

Geological Survey of Queensland: Current GSQ geophysics programmes and future work

It has been a busy year for the geophysics group at the Geological Survey of Queensland. We have been rolling out data and reports from the New Economy Minerals Initiative (NEMI) geophysics programmes. In July, the Queensland Government announced an additional $37.5 million in support of critical minerals exploration in Queensland as part of the Queensland Resources Industry Development Plan. This funding package includes an expansion and continuation of the Collaborative Exploration Initiative and $10 million for an expanded geophysical programme over the next few years. Geophysical project planning for these additional funds is well underway with programmes to be progressively announced over the next 12 months. Applications for the next round of the Collaborative Exploration Initiative will be open from 1 December 2022 until 11 January 2023.

We have been hard at work on interpretation and modelling projects to value add to existing datasets. Following the release of the 2021 Kamilaroi airborne magnetic and radiometric survey a new merged set of magnetic and radiometric grids was generated in the Mount Isa region. This new dataset, the Mount Isa Region Airborne Data Merge 2022 was produced from the five recently flown high-resolution GSQ geophysical airborne magnetic and radiometric survey and data from seventeen surrounding open-file exploration surveys. The final set of merged grids covers an area of approximately 44 000 km^2 of the highly prospective North West Mineral Province with a cell size of 10 m (Figure 1).

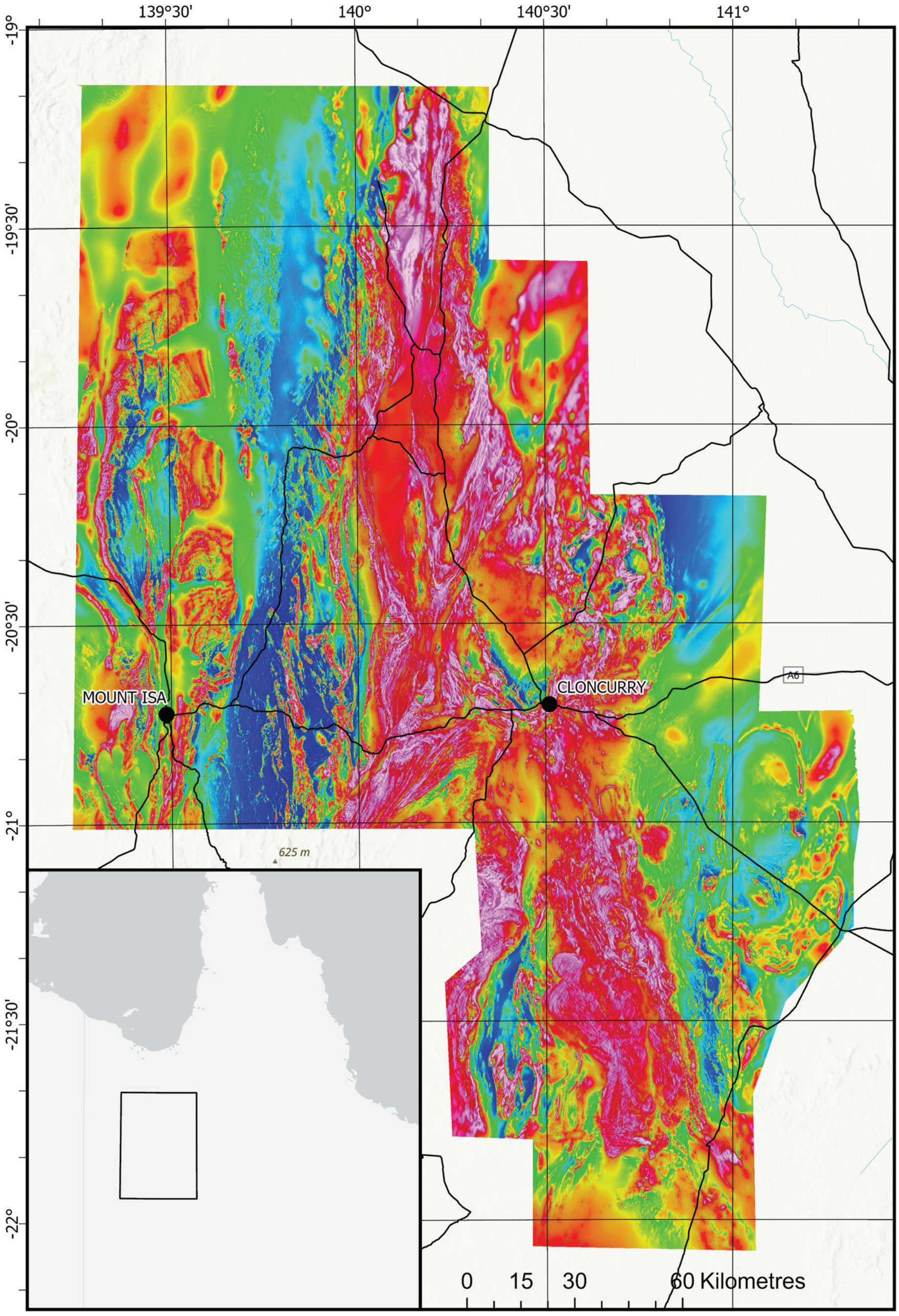


Figure 1. *Reduced the Pole magnetic grid (with semi- transparent first vertical derivative of RTP greyscale for texture) of final merged data from the Mount Isa Region Airborne Data Merge 2022 dataset.*

A large-scale reinterpretation of existing deep crustal seismic has been an ongoing focus for the Regional Compilations team in the GSQ. Together with researchers from the Sustainable Minerals Institute, the project integrated seismic, gravity, magnetotelluric and geochronology data to produce a new interpretation across the Mount Isa Province. Results from the first phase of the project were released in late 2021. The second phase of the project is now complete, expanding the interpretation into the Camooweal and Lawn Hill region. The report is in final editing phase and expected to be released soon (Figure 2).

Three-dimensional inversion modelling of the entire Cloncurry MT dataset comprising nearly 1000 sites is now complete. A technical note has been released with full results and interpretation. A suite of 16 different models were tested and are available in a model package in a variety of formats. The modelling work shows a number of conductive anomalies that are worth further investigation to the north of Cloncurry.

In the acquisition space, this year we completed the Canobie AGG survey in western Queensland and kicked off the CCA magnetotelluric survey. The Canobie survey consists of 4700 line km of new airborne gravity gradiometry data at 1 km line spacing, which was released

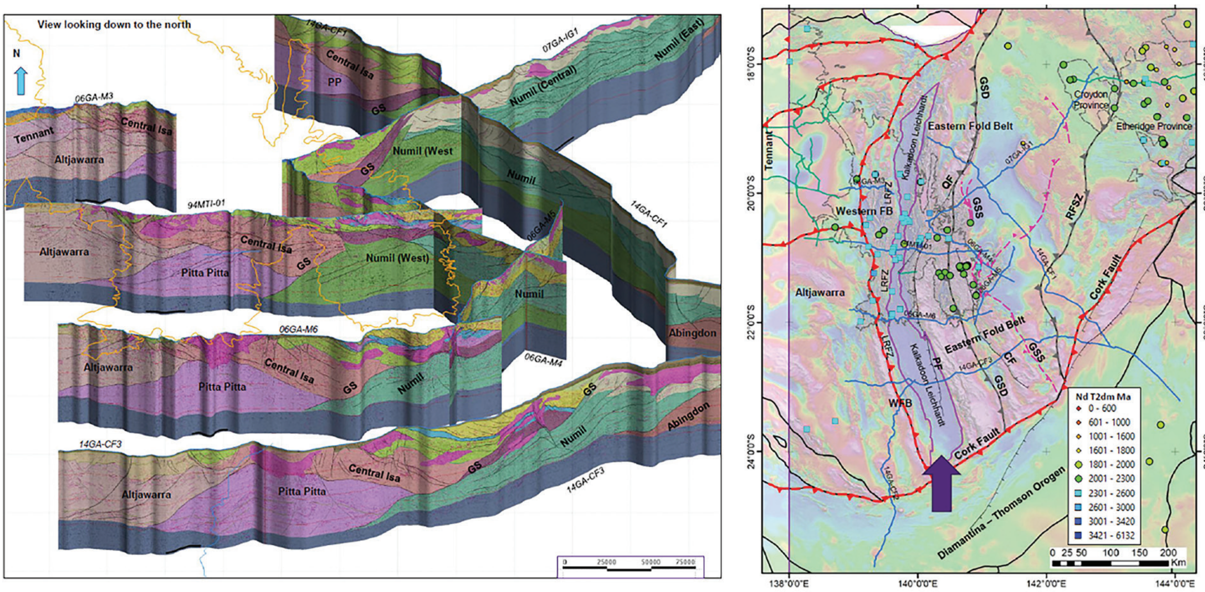


Figure 2. *3D views of the interpreted seismic lines from the deep crustal seismic re-interpretation project.*

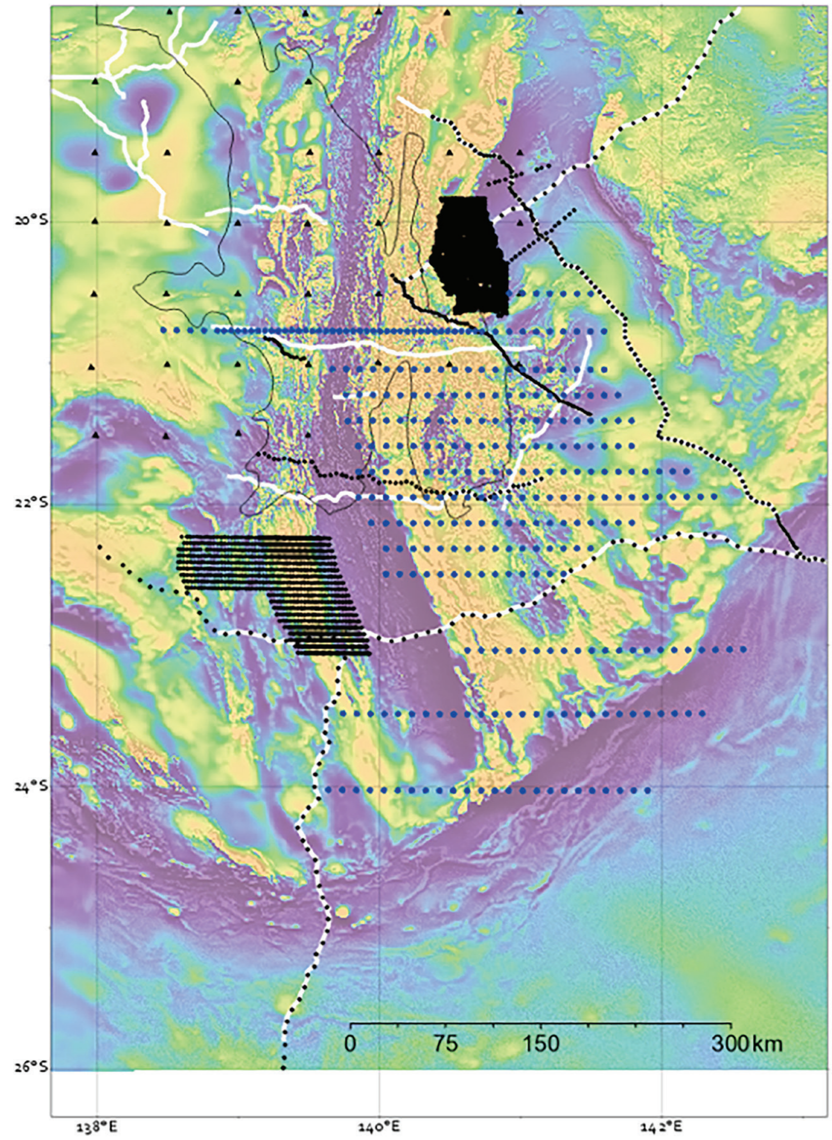


Figure 3. *Planned location of the CCAMT sites in blue. Historic sites are in black and deep crustal seismic transect locations in white.*

in May, with a technical note on the processing forthcoming.

Engagement and clearances for the CCA magnetotelluric survey have started in western Queensland (Figure 3). The survey will add more than 300 new MT sites to the Eastern Succession of Mount Isa in a wide-spaced grid. We are aiming to characterise the mid crustal conductivity structure across the eastern part of the province – tracking the location of the Carpentaria Conductivity Anomaly south of its known location in the Cloncurry area. Survey acquisition will commence after the wet season, with data release anticipated in Q3 in 2023, and modelling to follow.

Finally, the GSQ will have a booth at the Australasian Exploration Geoscience Conference (AEGC) in Brisbane in March 2023. We hope to see lots of familiar faces and meet many new ones. Wishing everyone a safe break over the Christmas and New Year period.

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CSIRO: Mapping the mineral carbonation potential of Australia

Utilising mineral carbonation as a solution for permanently locking CO_2 on geologic timescales requires knowledge of the spatial extent and favourability of the target rock in regions across Australia. Defining the spatial extent via geophysical mapping of mafic/ultramafic rock will assist in quantifying potential rock volumes available for *in-situ* mineral carbonation. However, mafic/ ultramafic favourability for CO_2 uptake and storage is also a function of whether the mineralogy of a rock is chemically amenable to reaction with CO_2 to form carbonates, and whether that rock has the necessary porosity and permeability to accommodate such reactions.

A new collaboration between The Carbon Lock Future Science Platform, CSIRO Mineral Resources and CSIRO Energy will explore whether geophysical methods including gravity, magnetics, EM and seismic, constrained by petrophysical data, can be used to map and differentiate favourable and un-favourable mafic/ultramafic rocks. The study will collate existing data (see Figure 1) and collect new samples from key locations around Australia. Petrophysics and automated mineralogy will be used to translate geological processes (e.g., alteration reactions) into geophysical properties. Rock property knowledge (e.g., magnetic, density, conductivity, acoustic properties) will be used to constrain geophysical models of host rocks. The project will map where potential mineral carbonation host lithologies occur, quantify their mineralogy, porosity and permeability, and model their 3-D architectures to determine likely reactive volumes.

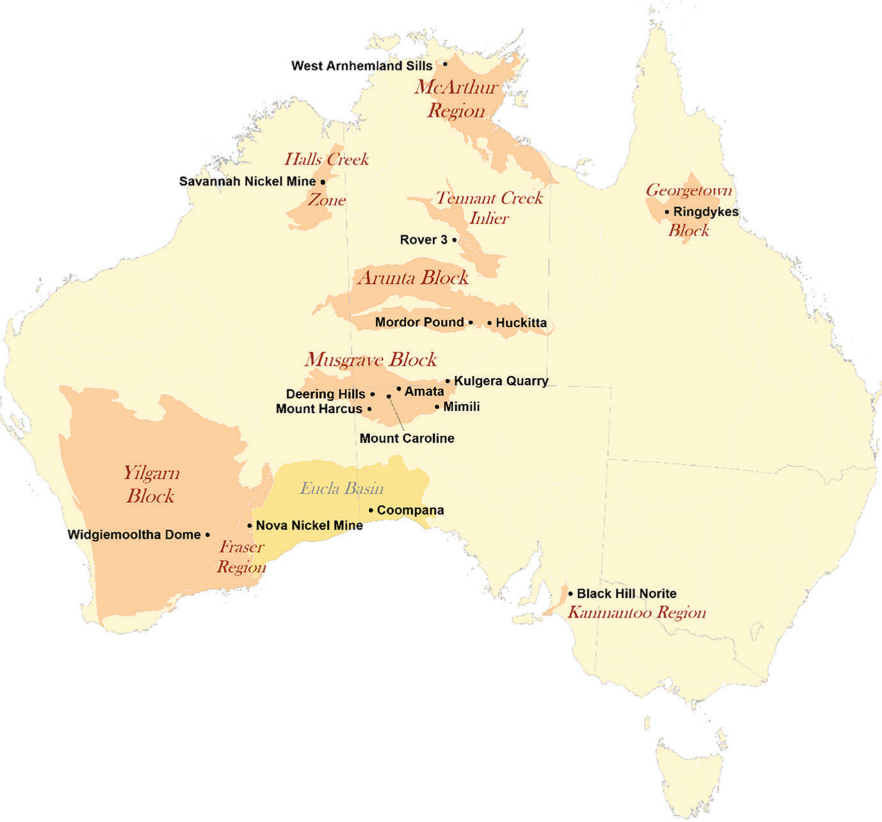

Figure 1. *Location of existing petrophysical samples of mafic/ultramafic rocks that may be favourable for CO_2 uptake and storage.*

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Canberra observed

David Denham AM
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Labor's October budget - dull but risk averse

Jim Chalmers, the Treasurer, had no room to change direction in his October budget. On the one hand, there is galloping global inflation triggered by Mr Putin, who caused the prices of food and energy to skyrocket by attacking Ukraine. In Australia, the annual inflation rate for 2022 is expected to be between 7 and 8%, depending on how it is measured. On the other hand, there is the debt blowout, mainly caused by the Government's support measures during the COVID pandemic. This is projected to reach $767 billion by 2025/6, up from $572 billion in 2022/3.

The Reserve Bank's attempt to reduce inflation by increasing interest rates is not working. In fact, it is adding to the inflation rate by increasing the costs of borrowing. But then, economists are not always right.

Consequently, the new big-ticket items in the budget were limited to election promises and ALP's high priorities.

In summary these are:

- Health - NDIS ($167 billion over four years), vaccines ($2.6 billion), cheaper prescriptions and urgent-care clinics),
- Defence - now more that 2% of GDP, and includes $1.4 billion aid funding,
- Families - $4.7 billion over for four years to make childcare cheaper for over one million families, and a National Housing Accord between governments, investors and industry to build 1 million affordable dwellings over five years from 2024 (no price tag but a $350 million down payment).
- Infrastructure - just $8 billion over several years on road and rail projects,
- Education – 480 000 fee-free places at TAFEs, starting in January 2023 with 180 000 available. Universities will have 20 000 more places for health, education and engineering courses, and there will be 10 000 places for apprentices working in the energy sector. Total cost of about $2 billion over several years.

As you can see most of the big spending is not scheduled to start until 2024, when the tax cuts for the higher income earners are scheduled to start - just a coincidence?

Mitigating climate change is still a problem for the Government. On the one hand, Labor has committed billions to accelerate renewable energy. On the other, it appears to have broken an election commitment on no new fossil fuel subsidies. They have allocated $1.9 billion for a new gas subsidy and committed to funding a $30 million Coalition-designed plan to frack the Beetaloo Basin in the NT. Climate change was never easy for governments!

Only small changes in agency funding

Budget Paper 4 is an easy-to-use document listing the funding for all the agencies for which the Australian Government has responsibility. Table 1 shows how the agencies are faring. The numbers speak for themselves but notice that CSIRO, with an allocation of $991 million, has an average staff level of 5449, whereas the NHMRC, with a similar budget, has only 195 staff. Obviously CSIRO must have to earn it's keep from cost recovery.

The "visual identity" project causes chaos in the BOM

When times are hard and the efficiency dividend is biting, would any leader want to spend $220 000 on a "visual identity" rebranding project? That's just what the Chief Executive of the Bureau of Meteorology, Dr Andrew Johnson, did, at a time when floods were rampant throughout New South Wales.

Can you imagine what effect that had on the meteorologists at the BOM?

According to the *Saturday Paper's* issues 422 and 423 (October/November 2022) "the planned name-change" and new corporate presence began more than three years ago and cost far more than has been reported. It is estimated that over $300 000 was spent on re-branding and communications consultants.

As well as the re-branding project, the regional forecasting centres in every state and territory have been shuttered. State managers have been replaced by a 'national desk', and all this was done when Lismore was being flooded.

Two of the outcomes from this re-organisation are the reduction in the launches of weather balloons, which affects Australia's commitments to the World Meteorological Organisation, and a change in the weather grids for Victoria and Tasmania from 3 km, which is what the new fire-danger rating requires, to 6 km. In other words, in two States the

Agency	**Government appropriation in $M and average staff numbers where available (in brackets) ***					
Financial year	**2017/18**	**2018/19**	**2019/20**	**2020/21**	**2021/22**	**2022/23**
AIMS	42 (223)	47	44	45	46 (253)	63 (300)
ANSTO	198 (1303)	214 (1275)	235 (1356)	220	280 (1333)	289 (1364)
ARC	789 (136)	793 (133)	818 (136)	833	804 (127)	832 (140)
Bureau of Meteorology	250 (1565)	296	315	294	358 (1599)	408 (1627)
Antarctic Division	176 (378)	188 (384)	185 (392)	225	270	270
Geoscience Australia	208 (600)	238	232	226	265 (592)	340 (603)
CSIRO	794 (5063)	834	839	834	949 (5001)	991 (5449)
NHMRC	938 (177)	946	926	943	927 (183)	939 (195)
ABS	431 (2486)	401	413	187	592 (3364)	369 (2678)

**AIMS (Australian Institute of Marine Science), ANSTO (Australian Nuclear Science and Technology Organisation), ARC (Australian Research Council), NHMRC (National Health and Medical Research Council), ABS (Australian Bureau of Statistics). Source: https://budget.gov.au/2022-23-october/content/bp4/index.html* capability of weather forecasting has been reduced.

At a Senate Estimates committee on 28 October 2022, Dr Johnson apologised for what happened:

"With the benefit of hindsight clearly the way we went about giving effect to our intent … there will be some significant learnings for us and I've apologised in my opening statement to this committee and the community if that's caused any uncertainty and angst, and that's a sincere apology,"

The message here is that, in a science-based organisation, it is vital that the science is emphasised as the core business. Without good science the centre of the agency is hollow.

Net Zero emissions - how to get there

A successful transition is one in which the cost and reliability of energy supply are maintained at socially and economically acceptable levels. Drew Clarke, the Chair of the Australian Energy Market Operator, indicated how Australia might get there in the 2022 Solar Oration at the ANU on 7 November 2022.

He identified five critical factors for success in the electricity transition: technology, markets, infrastructure, governance and social license. Although difficult to achieve, he at least showed one way of getting there. The Figure 1 indicates how it could be done. It will be interesting to see how well reality follows the charts.

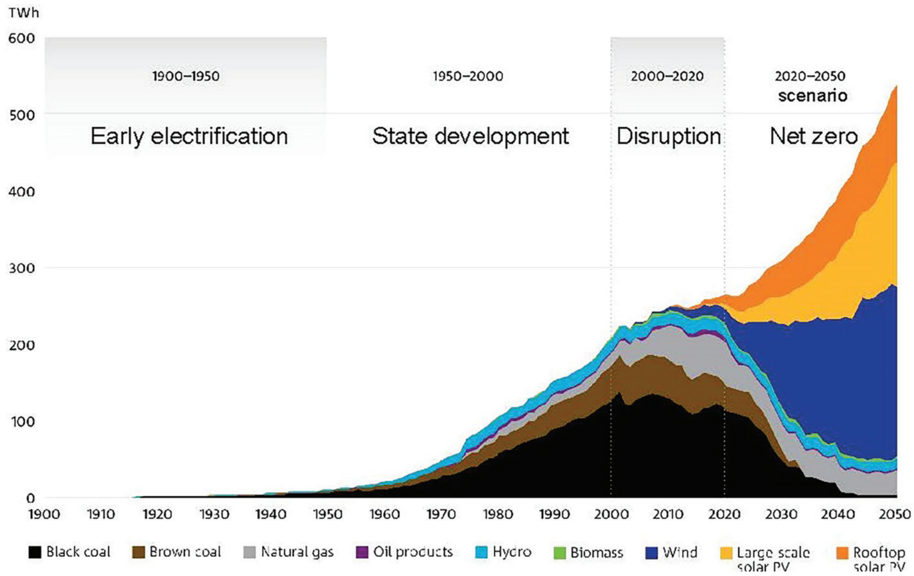

Figure 1. *Australian electricity transitions 1900 – 2050. Source: Drew Clarke, ANU Solar Oration 2022.*

Inaugural Camp for Applied Geophysics Excellence (CAGE)

The inaugural Camp for Applied Geophysics Excellence (CAGE) was run in late September this year, and would not have been possible without tremendous drive and support from the ASEG. Thanks to CAGE, 22 student and early career geophysicists have now received intensive training in the acquisition, processing and modelling of geophysical data, and have built a fantastic network amongst both their peers and industry leaders.

The motivation for CAGE was the recent decline in geophysics training opportunities at Australian universities, with opportunities for field training becoming particularly scarce. Industry has also moved to hiring geophysicists through contracting and consultancy companies, so there is a risk of having a team of geoscientists working with geophysical data without a comprehensive understanding of data collection techniques, and processing and modelling strategies. The ASEG is uniquely placed to help bring together industry, government and university geophysicists to provide training that will help fill this gap in understanding.

CAGE aims to give geoscientists exposure to the entire process of geophysics, from data collection to interpretation, whilst making lifelong networks to kickstart careers.

From the start, CAGE has received incredible support from the entire geophysics community, highlighting the need for more extensive field training. Financial support for CAGE came from ASEG, AuScope, NExUS, and BHP (platinum level) and GA (bronze level). In-kind support in the form of staff time, venue access and loaned geophysical equipment came from Southern Geoscience Consultants, MinEx CRC, The University of Adelaide, GHD, EnviroCopper, Flinders University, Zonge, Geological Survey of South Australia, GA, University of Queensland Sustainable Minerals Institute, University of Tasmania and Newcrest Mining. Software licences were donated by Mira Geoscience, Seequent and Geometrics.

The attendees were so engaged, enthusiastic and hard-working that they not only managed to develop good geophysical models, they also produced some great integrated interpretations with the known geology and hydrogeology of the field region.

As well as support for CAGE, there was also considerable demand for the Camp, with more than 70 applications received for the 25 available places. The selection and promotion committee selected the attendees on the basis of

The CAGE 22 cohort. Photo taken by Kate Brand. Photos in the photo composite were taken by Richard Lilly, Kate Brand and Kate Selway.

having a strong interest in geophysics but limited opportunity for field training, while seeking an even distribution in terms of geography, gender, background and career stage. The result, after some last-minute COVID withdrawals, was 22 attendees coming to CAGE from across Australia from a variety of backgrounds, from geophysics PhD students with strong theoretical knowledge to early-career geologists with little training in geophysics. One of the best things about the Camp was seeing how the attendees pooled their understanding of field practice, geophysical theory, software, geology and petrophysics. They worked together as really integrated teams in a way that we hope they will continue to do in throughout their careers, producing better results than they could do individually.

We set the attendees a challenging goal: to collect, process, model, and interpret four different types of geophysical data within a week. The field area was Kapunda, South Australia, where EnviroCopper, the University of Adelaide and CSIRO are conducting research into *in-situ* copper recovery, affording us land access, an interesting field area and some great existing geophysical datasets. Over the course of two days the attendees collected magnetic, nanoTEM, resistivity and hammer seismic data, before spending another two days learning how to process and model each dataset using industry standard software. The topic coordinators for each technique were: Dr Teagan Blaikie (magnetics, SGC), Dr Mike Hatch (nanoTEM, University of Adelaide), Ian James (seismics, SGC) and Wei Heng (resistivity, GHD). They are to be commended for their incredible work wrangling instruments and software and guiding all the attendees to a place where they felt comfortable and confident in each of the techniques.

CAGE was rounded out by guest lectures from Anne Tomlinson (SGC), Leon Faulkner (EnviroCopper), Eric Battig (Newcrest), and Dr Mike Barlow (GA) on geophysical survey planning, careers, interpretation and national datasets, as well as a careers night and a networking night with Dr Richard Lilly (NExUS). Because too much geophysics is never enough, they also got to see demonstrations of GPR (Andrew Frost, Flinders University) and MT (Dr Kate Selway, MinEx CRC and Dr Sasha Aivazpourporgou, UQ). On the final day of the camp the attendees used Geoscience Analyst to develop interpretations of their new integrated geophysical dataset, taking into consideration the rock properties they were imaging and the geology.

Feedback from the attendees has been extremely positive. 100% of respondents said that they would recommend the programme to their peers, and 75% gave CAGE the highest possible rating for enhancing their understanding of geophysics. Other feedback we got from the attendees included:

"The event was definitely 10 out of 10. Without exaggeration it is one of the best events I attended for a long time."

"Coming from a developing country like India, during my Master's, getting hands-on experience in acquiring, processing, and interpreting geophysical data is not possible at my university due to budget constraints. This experience made me confident to say that I am now a geophysicist."

"This was a great camp- I feel like I learned a semester's worth of geophysics skills in a week, and I had a lot of fun and made good connections with my peers in the process."

"Although it was full on, it was definitely worth the effort. It was so inspiring to hear all the speakers and made me excited for all the things geophysics can be applied to."

Thank you to the many people and organisations who helped make CAGE 22 a success. We hope to build on the success of the inaugural Camp for Applied Geophysics Excellence by running CAGE for many years to come. Please contact the authors to register your interest in helping out with CAGE 23.

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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 Mosayeb K. Zahedi 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/

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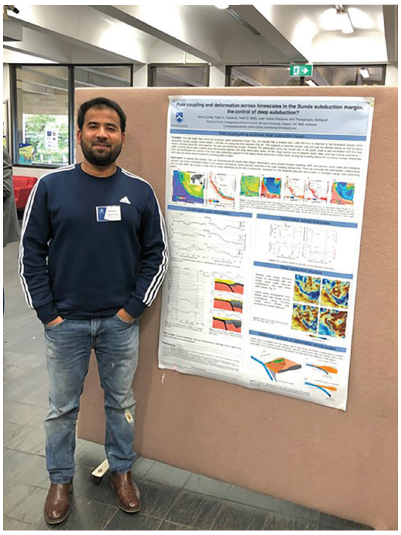
Theses in geophysics completed in 2022

PhD theses

Mohd Zuhair, Monash University: *Sunda convergent margin deformation across timescales*



Major earthquakes occur along the interface between the down going and upper plates, known as megathrust. Previous studies highlighted the role of several subduction parameters in controlling such seismicity. Most of these studies tested the subduction parameters in a two-dimensional framework. Such approaches fail to reconcile the megathrust seismicity with the deformation observed along subduction margins, invoking the role of large-scale, three-dimensional subduction dynamics in understanding seismotectonics of the subduction margins. This thesis aims to provide a new 3D seismotectonic model for the Sunda subduction margin, reconciling the link between the large-scale subduction dynamics, interplate coupling and margin deformation across timescales, and speculating on the inferences of the megathrust seismicity.

We study the Sunda subduction margin by incorporating geophysical observables, numerical modelling results, and earthquake catalogues. The oceanic Indo-Australian plate subducts beneath the Sunda upper plate, causing margin deformation across timescales and major earthquakes. We show consistency in slab geometry and upper plate deformation since Cenozoic by integrating gravity modelling, global strain rate and crustal thicknesses model analysis, and tomography driven subduction history with plate reconstruction. The study uncovers an inverse correlation between the subducting slab depth and the upper plate shortening and thickening in the Sumatra subduction zone. In contrast with the NW nearby Andaman domain, where a short slab explains backarc extension and a thin upper plate, and also comparing with the SE Java subduction, where a long and deep slab explains a thickened upper plate, in Sumatra, a short slab interestingly correlates with compression and thickening of the upper plate. After extensively inspecting the geophysical data supporting such an inverse correlation in Sumatra, we use 3D numerical modelling to evaluate the effect of a slab-step on the strong interplate coupling and thickening in the Sumatran upper plate. We conclude that trench parallel slab-pull exerted by the long slab in the Java subduction can force convergence along the Sumatra segment, explaining the strong coupling and upper plate deformation and are well-matched with present-day observational data, i.e. seismicity.

The signature of the forced convergence is also investigated in the subducting slab deformation along the Sumatra margin. The time-series earthquake analyses show increased compressive deformation in the subducting slab at shallow depths (< 70 km) and the upper plate after the 2004 great earthquake in the Sumatra domain. Strikingly, a cumulative increase in the Java slab deformation at deeper depths (> 70 km) correlates with and precedes large Sumatra megathrust earthquakes ($M_w \geq 7.0$) in the period covering both pre-and post-great earthquakes. The forced tectonic coupling by the neighbouring deep slabs on the shallow subduction margins may play a critical role in defining stress conditions along the high seismic potential segments.

Sheng Wang, Australian National University: *Seismic-event coda correlation imaging of the Earth's and planetary interiors*

Seismic coda waves are the late part of the seismic energy generated by earthquakes. Global coda correlograms are constructed by cross-correlating and stacking seismic event late coda records that are noisy and seemingly useless, but they exhibit many prominent features sensitive to the Earth's internal structure. Thus, the coda correlation rises as a new paradigm in global observational seismology. As a new category of observation, the correlation features, if interpreted correctly, can provide new information about the Earth's and planetary interiors.

How to accurately utilise seismic event coda correlations, for instance, in "global coda correlation tomography," has been controversial and unresolved. Some attempts treat coda correlations as reconstructed seismic waves, which is on a par with methods developed in ambient-noise correlations, for they share similar data processing and computation routines. However, that introduces erroneous interpretation because theoretical analyses have demonstrated fundamental differences in the formation mechanisms of coda correlations and ambient noise correlations. Therefore, we need a solution, a correct approach, to allow us to use a massive amount of coda correlation observables to increase constraints on the Earth's interior.

My PhD study consists of theoretical analyses, method developments, and applications for utilising seismic event coda correlations to image the Earth's and planetary interiors. We first conduct comprehensive analyses to quantitatively 'dissect' coda correlations for their formation mechanism. The analyses reveal the mathematical relationship between coda correlations and the Earth's internal structure. Based on that, we build a novel framework toward global coda correlation tomography. We verify the new framework in experiments and compare it with the method based on the assumption of seismic wave reconstruction. We illustrate significant inaccuracy in tomographic images can arise if coda correlations are treated as reconstructed seismic waves. Then, in an application, we provide a new class of observation for inner-core shear-wave anisotropy utilizing coda correlations in the new framework. We find that inner-core shear waves travel faster by at least

5 s in directions oblique to the Earth's rotation axis than directions parallel to the equatorial plane (anisotropy of >0.8%). Our inner-core shear-wave anisotropy observations place new constraints on the inner core mineral composition. Finally, we extend the principles to cross-correlations between source events and devise a new way to build global inter-source correlations. We demonstrate that a single seismic station is sufficient to construct a global correlogram. The correlogram exhibits prominent features sensitive to the internal planetary structures. We show implementations to constrain the the Earth and Martian core size and confirm a large Martian core. This provides a new paradigm for imaging planetary interiors on a global scale with currently realizable resources in planetary missions.

Sheng has been awarded the 2022 American Geophysical Union's Study of the Earth's Deep Interior Award for Graduate Research (AGU-SEDI Award) for the research conducted for his PhD.

Jake MacFarlane, University of Adelaide: *Understanding marine magnetotellurics*

The theory of plate tectonics proposes that the Earth's lithosphere is separated into rigid plates, which are capable of motion through interactions with the underlying asthenosphere. Following its adoption in the 1960s, it has become the prominent theory used to understand geodynamic processes within the Earth. The mechanisms of tectonism are of particular interest due to their implications regarding the formation of economic resources. Despite numerous studies attempting to characterise these mechanisms, the lithosphere-asthenosphere rheological contrast (LARC) remains an enigmatic component of plate tectonic theory.

The magnetotelluric (MT) method is of particular interest when investigating the upper mantle as it is primarily sensitive to electrical conductivity. From electrical conductivity, conclusions regarding the temperature, pressure, physical and chemical state, porosity, and permeability of rocks can be inferred.

This thesis examines laboratory conductivity measurements with ocean-bottom MT data collected from the Pacific Ocean. From these data, I create an upper mantle reference model for electrical conductivity and propose a hybrid MT impedance which improves the bandwidth and confidence intervals of ocean-bottom MT data. Between 50 km and 100 km depth, MT data predicts variable electrical conductivity structures. My reference model is able to encapsulate this variability with a function which varies according to hydration, partial melt, and the age of the overlying oceanic lithospheric. For 200 km to 400 km, the hydrated end-member of this reference model predicts the convergence of conductivity structures with increasing depth observable in published conductivity structures. As such, this reference model constrains the presence of hydration and partial melt within the LARC for a range of lithospheric ages and is a representative model of the Earth's oceanic lithosphere and asthenosphere. Following an analysis of ocean-bottom EM field observations, I observe the attenuation of magnetic field variations by the conductive ocean water. This attenuation results in MT impedances that are difficult to interpret using available modelling algorithms. In contrast, the calculation of a hybrid MT impedance using ocean-bottom electric and continental magnetic fields is observed to improve the signal-to-noise ratio. This improved signal-to-noise ratio extends the usable bandwidth of ocean-bottom MT data from just over one decade to approximately four decades. It is important to note that this impedance represents the normalisation of ocean-bottom electric fields using continental magnetic fields. As a consequence, alterations must be made to modelling algorithms before attempting to reproduce hybrid impedances.

Finally, a case study is conducted to assess the validity of my reference model and hybrid impedance. To do so, structurally simple forward models of both standard and hybrid impedances are calculated. The conductivity structure of this model was constrained by a 3-dimensional inversion of continental MT data, controlled source EM (CSEM) data, and my reference model. From this model, hybrid impedances are observed to reproduces four decades of data measured by numerous receivers. From this evidence, I conclude that my reference model constrains the LARC and that it realistically represents the upper mantle. Additionally, I conclude that my hybrid impedance is a useful alternative to traditional MT impedance when conducting ocean bottom MT studies.

Khumo Leseane, Monash University*: Tectonic evolution of Macquarie Arc using constraints from geophysics*

This interdisciplinary study uses joint gravity and magnetic interpretation and modeling, geology, and a synthesis of geochronology and geochemistry data to understand the Ordovician to Permian tectonic evolution of the southeastern Lachlan Orogen. There is a focus on the role of pre-existing (or inherited) structures during major tectonic events.
The Lachlan transverse zone is an inherited structure that formed along the northern margin of a stranded microcontinent. This structure has influenced the distribution of magmatism, and has controlled

intensity of crustal extension, the size of continental back arc basins, and the modes of subsequent basin inversion.

Matthew Gard, University of Adelaide: *Constraints on the thermal state of the continental lithosphere*

The thermal state of the lithosphere is an important driver of many physical and chemical processes within the Earth. Understanding the distributions of heat flow and radiogenic heat production provides an important constraint on lithospheric thermal models. By some estimates nearly 40% of continental heat flow is produced by radioactive decay in the crust, however the distribution of heat producing elements is poorly constrained. Creating robust models of radiogenic heat production requires an understanding of its natural variability. The creation of a global whole-rock geochemical database provides a framework for discussing global distributions of thermal parameters. I have collated over one million digital rock entries with a range of sample data including major and trace element concentrations, isotopic ratios, and other metadata. Associated naming schema and physical parameter estimates are also computed in a standardised manner, including radiogenic heat production.

I then present a new model for continental igneous heat production from 4 Ga to the present using a novel silica-normalised igneous data set and compare that model to previous discussions of granitic and sedimentary trends in the literature. Crude normalisation for composition indicates lithological control is the dominant factor on heat production after the influence of decay is removed. I find that heat production at formation for different rock types has been relatively constant through time except for the early Archean to 2.7 Ga. I suggest the heat production–age pattern does not significantly reflect the influences of erosion, secular cooling, depletion, or the supercontinent cycle as suggested by some previous studies, but instead either reflects a shift in the bulk composition of the crust or evidence for bias in the rock record due to thermal stability.

Geophysical proxies provide additional constraints on the crustal thermal state. I have developed a global Curie Depth model from the latest satellite-derived lithospheric magnetic model using the equivalent source magnetic dipole method. Forward modelling was conducted to simulate the observed lithospheric magnetic field. Our updated methodology involves additional vector components utilised in the forward modelling calculations, a differing long-wavelength model, and inclusion of a spatially variable magnetic susceptibility estimate. Resultant continental Curie depth estimates show good agreement with observed heat flow observations and provide further evidence that Curie depth estimates can assist in estimates of the thermal state of the lithosphere.

Finally, I assess various heat flow models for Antarctica derived from geophysical proxies. Extrapolation from isotherm estimates at depth require models of heat production and thermal conductivity to model surface heat flow. Differences in models can have non-trivial influences on the results produced. Quantifying the uncertainty associated with these thermal parameters is also critical for understanding and interpreting the heat flow solutions. I propose a set of models derived from whole-rock geochemical data and guided by compositional studies of the crust. Uncertainties associated with this model are estimated via the Monte Carlo method. I show that applying models guided by global insights provides a reasonable fit to the Antarctica continent, and a method of estimating uncertainty in thermal parameters for regions lacking basement geology constraints.

Matt currently works at Geoscience Australia in geomagnetism.

Samuel Jennings, University of Adelaide: *Nature of the lower crust*

Knowledge of the compositional and thermal structure of the lower crust is crucial for developing geodynamic, thermodynamic, chemical and structural models of the earth. Our current understanding of deep crustal processes is predominantly based on seismic modelling and the ultimately rare surficial occurrence of lower crustal analogues in the form of xenoliths or granulite terranes. Determination of crustal geotherms, upon which all physical processes rely, are plagued by quality assurance and inaccessibility of existing surface heat flow estimates as well as uncertainties inherent in predicting thermal conductivity and heat production at depth.

In this thesis, I first establish an improved method for estimating thermal conductivity at depth based on the chemical compositions across a wide range of plutonic, igneous rocks. I relate the resulting model to estimates of seismic P-wave velocity and density which allows for prediction of thermal conductivity where rock samples are inaccessible. I supplement this new predictive model for thermal conductivity with a restructuring of the global heat flow database, which allows for improved assessment of quality and better interpretation of the underlying data. The new ThermoGlobe database includes direct relationships to raw thermal data such as temperature, conductivity and heat production, which allows for recalculation of older heat flow sites using updated techniques. ThermoGlobe has been made available online at Heat-Flow.org as an intuitive web application that allows heat flow practitioners, climate scientists and all interested parties easy access to the underlying data as well as some useful statistical aggregations.

The incipience of the magnetotelluric method (MT) as an alternative to seismic tomography for crustal and lithospheric scale applications provides researchers with an additional tool capable of describing the physical properties of the lower crust.

MT is particularly sensitive to both composition and temperature; however, its predictive capabilities are effectively limited by inconsistent results from the laboratory. I conduct my own laboratory investigation into the effect of *in-situ* metasomatism on the electrical resistivity of the lower crust and find no measurable difference between a fluid-altered eclogite and its direct granulite protolith. However, diligent comparison with previous experiments reveal a strong relationship with iron content among mafic, lower crustal rocks that can be used to provide compositional and thermal constraints on regional resistivity models.

Finally, I conduct an MT survey over the Mt Gambier sub province in southeast Australia and reveal a zone of low-resistivity spatially aligned with a large step in the lithosphere-asthenosphere boundary and crustal structures related to rifting along the southern Australian margin. Lowest resistivity is found beneath the town of Casterton, Victoria, and is associated with a small degree of partial melt that is expected to feed both the Mt Gambier and Mt Burr Group volcanoes. Magmatic plumbing systems are inferred with regards to known basement structures with implications for both gas and geothermal exploration in the region. Additional geophysical evidence is provided that may indicate a layer of up to 4 km thickness of basaltic magma emplaced within the mid-crust.

Sam is currently a postdoc at GFZ German Research Centre for Geosciences in Potsdam, Germany.

Cameron Adams, The University of Western Australia: *Integrating petrophysical, lithogeochemical, and mineralogical data to understand the physical properties of altered mafic and ultramafic rocks: Implications for geophysical exploration.*

Commonly, petrophysical data are classified solely by lithotype or lithology. This has led to the development of wide-ranging distributions in local and global petrophysical databases that make geological-geophysical interpretations uncertain and unreliable. Furthermore, these distributions are often multimodal and effected by alteration. The reliable characterisation of rocks (and petrophysical data) is best achieved through numerical interpretation. Quantifying alteration is therefore required to place petrophysical data in correct chemical and mineralogical (and geological) contexts.

My thesis purposely investigates mafic and ultramafic rocks because of their unusual, and often variable, petrophysical attributes that are, by and large, associated with alteration. For example, an important focus in nickel exploration is the interpretation of magnetism associated with magnetite production during serpentinisation, and, conversely, magnetite destruction during talc-carbonation. Quantifying serpentinisation and talc-carbonation is therefore crucial to properly understanding physical property data that are then used to interpret geophysical maps. Furthermore, the correct and reliable characterisation of mafic and ultramafic rocks is important for understanding other geoscientific data, not just petrophysics. However, the visual classification and characterisation of mafic and ultramafic rocks is difficult due to the presence of hard to identify dark, ferromagnesian silicate minerals, e.g., olivine, pyroxene, and amphibole. Mafic and ultramafic rocks are also commonly aphanitic and comprise fine grained mineral matrices that are too small to identify with a hand lens. Characterisation is further complicated by alteration, which is commonly pervasive and tends to erase magmatic textures and change rock colour. The result is that visual characterisation of altered mafic and ultramafic rocks is subjective, uncertain, and, in many cases, inconsistent due to the involvement of multiple people logging and documenting samples and core.

A new comprehensively integrated petrophysical-chemical-mineralogical database was created using diamond drill cores from four granitoid-greenstone belts in the Yilgarn Craton including the Plutonic Well Marymia Greenstone Belt, Sandstone Greenstone Belt, Minigwal Greenstone Belt, and Norseman-Wiluna Greenstone Belt. Data were collected by making many measurements on many samples using many different instruments. Furthermore, three constraints were imposed on data acquisition, i.e., 1) only non-destructive tools could be used, 2) only tools capable of rapid measurements could be used, and 3) only portable (and ideally easy to use) tools could be used. Consequently, my thesis contemporaneously reviews data-acquisition practices for many instruments used in the minerals exploration industry. In some cases, this also led to reviews of operational principles (physics), discussions about limitations related to hardware and sampling practices, and the development of new ways to identify and reject atypical samples that would otherwise complicate the interpretation of alteration, e.g., quantifying sample heterogeneity and oxidation state via pXRF and pVis-NIR data.

A new workflow is presented that addresses integrated pXRF and pVis-NIR usage from the ground up, i.e., instrument calibration and precision, sample quality, data correction (e.g., iron), and alteration and fractionation characterisation. The workflow is then applied to the studied rocks and used to interpret physical properties and define important trends.

Cameron's thesis can be accessed via the University of Western Australia research-repository: https://doi.org/10.26182/xg61-fa34

BSc (Honours) theses

Audrey Quealy, Monash University: *Palaeozoic evolution of northeast Queensland: Implications from the Inkerman Metamorphics.*

The Tasmanides, which make up the eastern third of the Australian continent, are a series of broadly N-S trending orogenic belts formed through Palaeozoic, progressively eastward accretionary tectonics. Whilst this ~N-S structural grain is preserved across much of northeast Queensland, anomalous geometries, including the ENE-WSW-trending Charters Towers Province (Thomson Orogen), indicate an intricately complex and vastly overprinted tectonic evolution, which has been interpreted to relate to orocline formation. In this study, a lithostructural geophysical interpretation of the junction between the Connors Subprovince (New England Orogen) and Charters Towers Province was undertaken to assess this major boundary. This interpretation found that Benambran deformation produced ENE-WSW-trending sinistral strike-slip faults in the Charters Towers domain and subsequent N-S to NNW- SSE eastward-dipping thrust faults associated with the early Hunter-Bowen Orogeny and the accretion of the Connors Arc system. A subsequent re-activation along ENE-WSW sinistral faults was observed and is interpreted to indicate localised migration to ~NE-SW directed shortening during the late Hunter-Bowen Orogeny.

A regional curvature evident in the structural grain of northeast Queensland is defined by remanent Late Proterozoic to Early Palaeozoic basement sequences and metamorphic belts. High-resolution (40 m) aeromagnetics and satellite imagery reveal intersecting NNW-SSE and WSW-ENE structural trends in the Inkerman Metamorphics (Connors Subprovince), proximal to the location of the fold axial trace of an inferred orocline. Geological field mapping reveals that no evidence of oroclinal bending is preserved in the Inkerman Metamorphics. Rather, the change in trend perhaps reflects overprinting of the Charters Towers Province by the Connors Subprovince or temporally separated periods of subsequent deformation.

Edgar Leong, Australian National University: *Maps to buried treasure: Exploring the geodynamic setting of enigmatic mineral systems*

To address the global exhaustion of surficial mineral deposits, a paradigm shift in exploration targeting is necessary for location of new resources that may be buried deep under cover. This endeavour requires an improved understanding of the geodynamic setting of high-grade mineral deposits. In this Honours thesis, we examine spatial links between several of these deposits and present-day lithospheric structure, as well as temporal relationships between mineralisation in sedimentary basins and the tectonic processes that govern their formation. Using robust statistical analysis, we show that 75% of the world's IOCG and 65% of magmatic sulphide deposits are found within 200 km either side of lithosphere that is 180 km and 210 km in thickness, respectively. We also investigate the subsidence history and formation mechanisms of the Isa Superbasin and find that its world-class sediment-hosted mineral systems likely formed during continental rifting, whereas its IOCG deposits postdate basin formation. This study demonstrates the potential for using lithospheric thickness and subsidence analysis as novel exploration tools, simultaneously providing implications for our understanding of the formation mechanisms of resource-rich basins and other enigmatic mineral systems.

Elliott Barrington, Monash University: *Multiscale analysis of the structural architecture of the under-explored South Hirono Domain within the Yamarna Terrane, Western Australia*

The Late Archean hosts much of the world's gold endowment, so understanding the distribution of mineralisation across time

is important. The Archean Yilgarn craton is a notable example of mineralisation being structurally controlled. The Yamarna terrane is the easternmost of the Yilgarn and has been relatively under-explored. In the Yamarna terrane, there is a working understanding that mineralisation is controlled by late sinistral transpression while no studies have suggested gold related to other deformation events. This study proposed a deformation scheme for the South Hirono Domain, in the Yamarna Terrane, to better understand the structural controls on mineralisation.

Petrophysical and structural data were collected across three diamond drill holes in the South Hirono Domain. The Domain predominantly consisted of differentiated dolerites that were classified into two sills: one magnetite-bearing differentiated dolerite sill and a differentiated dolerite sill. The magnetite-bearing sill and an intermediate porphyry unit were quite magnetically susceptible relative to other lithologies in this domain. The distribution of these two units at the regional scale was the basis for interpreting processed geophysical maps. These large-scale geophysical observations were used alongside structural observations at the core and petrographic scales to understand the deformation history as accurately as possible.

The dominant fabric identified in dolerites is a composite fabric of the primary layering and S1 defined by layer-parallel shear fabrics, which are axial planar to recumbent F1 folds. The dominant folding developed during D2, defining the regional F2 antiform. Potentially prospective quartz-carbonate and quartz vein sets formed pre-D3. D3 sinistral transpression that truncates F2 folds likely focused both prospective vein sets, as they are associated with elevated gold concentrations within the D3 Smokebush shear zone. Subtle open folding developed during D4 and affected previous D1-3 structures. Steep brittle dextral faults define D5 and crosscut all previous structures. The proposed deformation scheme informed the structural model of the domain's architecture.

Environmental geophysics

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Welcome readers to this issue's column on geophysics applied to the environment. We are now on the final scene of Niels Christensen's reminiscences about his career, which was largely based at Aarhus University in Denmark. I, for one, would like to thank Niels for giving me, and the ASEG community, the opportunity to know more about the development of geophysics in Denmark, and how his group's local experience has become part of the geophysical "scene" worldwide. While this particular part of the story may be seen to be centred on Denmark, it is not at all hard to see the parallels with Australia, and in fact with most countries, where competing interests complicate what often seem like simple (but important) decisions - politicians are then required to balance the needs of all constituents (that's the theory anyway). I am more convinced than ever that collecting high-quality data contributes towards good (better?) decision making. Perhaps not profound, but interesting, nevertheless. Over to Niels…

Pivotal moments: Seven scenes from a geophysics adventure

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Scene 7: So … what came out of it all …?

… in which the protagonist and his good colleagues ask the questions: So - how'd it all go? What came out of the efforts? What is the situation today? And what is needed in the future?

In this seventh and last scene, I will leave the reminiscences of my own past, turn around, and look at some of the aspects that are important for the present and the future situation regarding the precious resource of groundwater in Denmark. As always, the future is unknown and the present is more complex than anyone can grasp, but I have selected a few themes and collected the discussions under four headline questions:

- What is the status of geophysics in Denmark?
- What about hydrogeology?
- How do politics and administration affect these fields?
- And what can be expected in the future?

Geophysics

Unequivocally, we all (at Aarhus) agree that the discipline of geophysical research came out of past efforts with flying colours. The HydroGeophysics Group at Aarhus University has developed into an environment for research and development that must be counted among the five best groups in the world, and which has received, and still receives, international respect. It excels in the study of ground and airborne TEM methods, DC and time domain IP, and MRS, and the application of these disciplines to a wide variety of economical and societal issues: location and evaluation of groundwater resources, mining, environmental problems, geotechnical investigations, etc. There has been ongoing development in geophysical hardware, new instruments and field practices, and software for inversion of collected data. Several spinoff companies have come from the group. SkyTEM is a world leader in airborne TEM. The WorkBench software package for modelling, data processing and inversion of a wide suite of electrical and electromagnetic data formed the basis for Aarhus Geosoftware company, now part of Sequence. Aarhus GeoInstruments now manages development, production and marketing of geophysical instrumentation. The Aarhus Geophysics company providing inversion products for the industry, and I•GIS who specialise in visualisation software and machine-aided interpretation options of inversion results, are two more examples. On the international front, the HydroGeophysics Group has had and still has PhD students and postdocs from around the world, several of whom bring their expertise back to their home countries and geophysical institutions. Some of the larger Danish companies with strong geophysical departments have undertaken knowledge and systems export. An example is Rambøll who has a major hydrogeophysical project in California, USA.

Hydrogeology

As part of the National Groundwater Mapping Project, all of the most important aquifers in Denmark were mapped using various geophysical methods, combined with borehole drilling and other selected methods. As a result, there is now a hugely improved knowledge base regarding the presence of groundwater, its vulnerability and chemistry. All of these data sets and models are stored in the national data base: GERDA. This is a valuable resource for future generations to use and refine. The aim of the mapping was to eventually construct dynamic hydraulic models that would adequately describe the flow of water, the interaction between precipitation, groundwater, and surface water, and be able to predict the consequences of abstraction patterns so that the groundwater resource could be administered in a sustainable way.

From the very outset with the forming of the HydroGeophysics Group, its main task was development of geophysical methodologies and software and an advisory function in relation to engineering companies by formulating guidelines for instrumentation, field work, data processing and inversion. This was decided through collaboration agreements with the authorities responsible for the national mapping. In the early days, the ambition of the group was also to focus on the integration of geophysical results with the construction of hydraulic models, but unfortunately that aspect never became prominent. This line of research is ongoing and is more or less successful, depending on the number of hydrogeologists at the government department and specific members of the group.

Traditionally, the work flow for establishing a hydrogeological model would start with geophysical measurements and inversion results that would then, together with other information, form the basis for a geological model, which in turn would be the basis for a hydrogeological model. At the present stage of the national mapping, setting up geological and hydrogeological models is an ongoing priority. One of the demands on these activities is that the models for neighbouring locations eventually must be seamless at the boundary, but at the moment, this is not always achieved.

An interesting aspect of the geophysical mapping and the subsequent geological interpretation is that many new geological insights were produced, and quite a bit of that contradicted previous concepts and "truths". It was often a struggle to have the new knowledge integrated in the old models. This is also an ongoing process. GEUS, The Geological Survey of Denmark and Greenland, has a much-used, overall hydrogeological model based on a geological model of Denmark called the DKmodel. It is mainly based on older drilling results; the new insights have not yet been completely integrated.

The hydrological models based on new geophysical results and borehole information are used to define new catchments areas. However, there seems to be a scale problem. The deeper parts of the models are improved, but often the shallower parts of the model are not optimal: the geophysical results are sometimes insufficient and not infrequently over-interpreted. Often, once the catchment areas are defined, it is a difficult process to change them. Ultimately, it would be a costly affair to re-evaluate the work that has already been done, and a better dialogue between geophysicists and geologists/hydrogeologists is needed - plus of course the necessary financing and manpower.

A characteristic difficulty with constructing hydrogeological models is that primary hydraulic data are quite sparse, making it difficult to find a model that is both reliable and sufficiently complex to describe the complexities of the subsurface. Seen from the geophysical perspective, this poses a challenge to come up with attributes derived from the geophysical models that could eliminate some of the uncertainties in setting up hydrogeological models. Hydraulic models are only weakly sensitive to the location of boundaries between different hydrogeological units, but this geometrical information can often be provided by geophysical models. Ideally it would be helpful if geophysical results, *i.e.* the subsurface distribution of conductivity, could be used to estimate hydraulic conductivity, but it is well known that no generally valid relation exists. In some cases, locally valid relations can be found, but this is still an area of research.

Political and administrative issues

In Denmark, before 2007, public administration, political institutions, and the right to collect taxes, was a three-tier structure, divided between 271 municipalities, the 14 counties, and the state. By January 1, 2007, the county level was completely removed (by a liberal/conservative government), to be substituted with five regions (that are now, for example, almost exclusively responsible for the health system), and the 271 municipalities were merged to form 98 new and larger units.

Some of the important responsibilities of the counties were resources, water and minerals for example, and after the counties were abolished, a few regional offices were established to replace the old county-based departments. However, only one of those has survived. Another administrative change that took place around this time was that the ministries of environment and farming were merged. Considering the evident conflicts of (perceived) interests, it took a very strong minister to insist on the protection of our water resources. However, presently they are again separate. From having been a county-based affair since the beginning in 1999, the National Groundwater Mapping Project became a state affair from 2007, and each municipality was now on its own in terms of administering resources, a task not easily managed by many of them. Consequently, the continuity and coordination of the decisions between state, municipalities, regional offices, and the private water abstraction plants is seriously challenged.

One of the aims of the National Groundwater Mapping Project was to establish a knowledge base on which restrictions on land use could be formulated that would sufficiently protect the most important groundwater resources against pollution from surface activities, whether domestic, industrial, or relating to farming. There are quite a few success stories from the past of relocating proposed town extensions, as well as new areas for transport and industry, based on hydrogeophysical insights. But regulation of land use for the farming sector is still not in place, and the administration is clearly insufficient. There are presently of the order of 3000 regulation areas, each with an area less than 16 km^2 - much too large considering the geological/hydrogeological variability in most of the country. This, and the ever-present resistance towards regulation from the farming lobby, who insists on being regulated by data only, not models, means that effective regulations have not yet been implemented.

The future

The overall motivation for all participants in the national mapping efforts, and the proceeding extraordinary geophysical developments, was to maintain and protect the wonderful, and unusual, gift that we had in Denmark: pure water that we could just pump up from the ground and drink without any advanced treatment. In this overview of past and present successes and failures, did we actually succeed? Seen from the perspective of geophysical mapping and geological/hydrogeological modelling, we were very successful.

Though many tasks remain, there is now a huge and unprecedented knowledge base to assist in future physical planning. Nevertheless, the majority of the people I have consulted about this Seventh Scene call for a better coordination between state, municipalities, and other authorities, and also a better interdisciplinary dialogue between geophysics and (hydro)geologists to improve the hydrogeological models based on the huge amount of geophysical data and inversion models residing in our databases.

However, …

However, while developing wonderful, advanced geophysical practices and capabilities, while improving and updating the geological knowledge of this country, and while improving hydraulic modelling capabilities generally, it became evident that mapping and administering the groundwater resources was not enough to keep the water clean. While the national mapping effort successfully provided the information that would permit a more sustainable use of the groundwater in terms of its existence and vulnerability, another issue grew to large proportions - pesticides in the groundwater! The pesticide findings in Danish drinking water wells, which presently give rise to great concern, are primarily the result of past sins. Most of the active waterworks in Denmark abstract water from considerable depths, usually more than 30 m. Leakage from the surface to 30 m or more through an undisturbed series of soil layers takes decades, so the presence of pesticides and other contaminants we see in the wells now stem predominantly from activities that occurred before the results of the National Groundwater Mapping Project could be implemented in the planning and regulation of land use in areas with special drinking water interests.

In 51 % of all investigated waterworks wells in 2020, at least one pesticide was detected, and in 14.6 % of the cases, the concentration exceeded the Danish quality requirement of 0.1 mg L^{-1}. In half of the cases, namely 25.6 % out of the 51 %, the presence of the substance Dichlorophenol (DCP) was detected. DCP is a degradation product from the herbicide Chloridazon, which was mainly used in beet production, and which has not been approved on the Danish market since 1996. Nevertheless, DCP is the second most frequently found substance in the waterworks' extraction wells. Of course, the National Groundwater Mapping Project could not prevent this, as the use of this pesticide took place primarily before 1996, when the approval of the substance was withdrawn, and thus many years before groundwater mapping was launched at a national level. Furthermore, some of the main elements of the national mapping efforts, e.g., geophysical methods and geological descriptions, are insensitive to the presence of pesticides and their degradation products.

At the moment, the problem is alleviated by mixing water from less polluted and more polluted bores so that the concentration goes below the recommended limit. Both large and small waterworks stand with their backs against the wall having sounded the alarm to the Ministry of Environment. Most likely, at a significant number of waterworks, the water will have to be filtered, e.g., through active carbon filters, before the water is distributed for consumption. The Danish state has recently announced a 130 million DKK (~ € 20 million and over $AUS 31 million) research and development project to get a better handle on the situation and to find possible avenues for remediation.

View over Limfjorden from Venø. A typical landscape from the north-western parts of Denmark (Palle Møldrup: Oil on canvas, 1980).

Over the coming years, it will be interesting to see to what extent restrictions on land use will be introduced above the most important and most vulnerable groundwater bodies, based on the results collected over past decades. Under all circumstances, if it took 30 years or more for the pesticides to reach the groundwater, it may take at least that time - and require considerable political/administrative pressure - to reduce toxicity levels in one of our most precious resources.

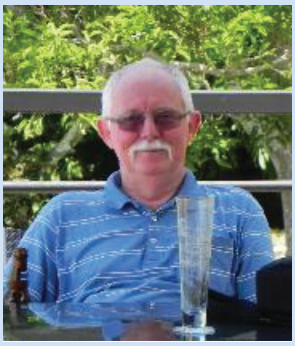
Acknowledgments

This seventh and last scene, my attempt at an overview of where we stand today, would not have been possible without contributions from: Anders Vest Christiansen, Nikolaj Foged, Kurt Sørensen, Esben Auken, Richard Thomsen, and Flemming Jørgensen. Their contributions and good will are much appreciated! Special thanks to Verner Søndergaard for his insightful contributions and for reviewing the last iterations of Scene 7. Most of all, I would like to extend my gratitude to Burke Minsley (AGU-NS monthly newsletter) and Mike Hatch (*Preview*) for their efforts that made it possible to publish and share these reminiscences with a wider audience. Without them it would never have happened!

Postscript

With this seventh scene about the present state of affairs in Denmark regarding the groundwater situation, I have concluded my professional memoirs. It was often difficult to decide what to include and what to leave out, and of course there are many situations and experiences that did not find their way into these scenes. I hope you have enjoyed reading them as much I enjoyed writing them. Please share them with people who might also enjoy them. And - if you feel inspired to write your own professional memoirs – I would encourage you to do so. I think that memoirs are an important contribution to the history of our science and the way it was conducted in the past. And I think they may be an opportunity for younger scientists to wonder about the "strange old days" and hopefully also inspire them in their present efforts.

Minerals geophysics



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Bits and bobs

In this piece, I'd like to touch on two somewhat peripheral propositions for mineral geophysics: that the range of petrophysical properties of minerals potentially usable for mineral exploration has not been exhausted, and, that the application of existing geophysical survey techniques extends well beyond mineral exploration usage.

For the first proposition, geophysicists are familiar with the mineral petrophysical properties normally utilised in mineral exploration: density, magnetic susceptibility, electrical conductivity/resistivity, IP effect, natural radioactivity, and sonic velocity. Expanding the category to include petrophysical properties of rocks would address the way minerals are distributed, and would include additional petrophysical properties such as porosity, permeability, etc. which are arguably more pertinent to the application of geophysics to other fields such as environmental engineering and the exploration for water and energy resources. But the petrophysical properties I'm interested in are the somewhat more esoteric mineral properties. Examples could include semi-conductor properties such as asymmetric electrical conductivity, and dielectric properties such as the piezoelectric and seismoelectrokinetic phenomena.

Semi-conductor properties are of particular interest in mineral exploration geophysics because metallic sulphides, including ore minerals such as chalcopyrite and galena, exhibit these. One geophysical survey application under development is the biased heterodyne technique which seeks to discriminate between the non-linear electrical response of disseminated semi-conductor metallic sulphides and the linear electrical response of disseminated graphite, clays, etc. If you're interested, as a starting point, two papers (Oertel *et al.* (2018) and White *et al.* (2018)) discussing this technique were presented at the 2018 AEGC Sydney Conference. I've previously alluded to this work (see *Mineral Geophysics* in *Preview* **193**), and I won't elaborate further.

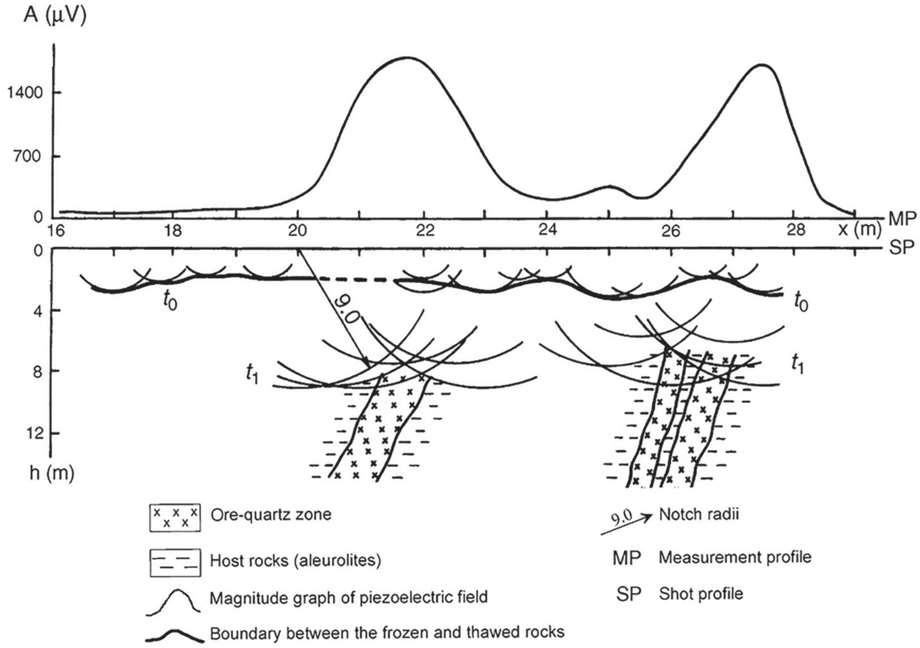

Figure 1. *Piezoelectric measurements at a gold-bearing quartz deposit at Ustnerinskoe (Yakutia, Russia). The observed signals are the t 0-wave generated at the interface of thawed and permafrost ground and the t 1-wave generated by ore-quartz zones (Neishtadt et al., 2006).*

Piezoelectricity is the electric charge that accumulates in certain solid materials in response to applied mechanical stress. Quartz, a frequent accompaniment to epithermal gold mineralisation, can exhibit strong piezoelectric effects, and the potential application of piezoelectric and seismoelectrokinetic phenomena to mineral exploration geophysics have sparked (sorry about that!) interest at various times in the past. In fact, the rather dim memories I have of reading a paper on the application of piezoelectric effect in mineral exploration early in my career, prompted the inclusion of this topic in my piece for this issue of *Preview*. My initial search on the net found two papers (listed in the references) which trace developments in this field over a wide time range; both include tables of properties and comprehensive reference lists for further study. And, to whet your appetite, I've included an illustration (Figure 1) from the paper by Neishtadt *et al.* (2006).

For the second proposition, utilisation of geophysical field techniques beyond the field of mineral exploration includes the more obvious extensions into environmental, archaeological, engineering, water and energy resource exploration disciplines, and even treasure hunting with portable metal detectors. Less obvious, for example, is the adaption of geophysical techniques for the detection, mapping and assessment of buried pipes and cables. This latter field is surprisingly diverse, both in the range of geophysical techniques used and in the way they are used. A preliminary search on the net shows that magnetics, galvanic resistivity, electromagnetics, ground penetrating radar and seismics may be employed. The ingenuity in the application of some of these techniques is impressive. In electromagnetics, for example, a wide range of frequencies may be utilised, and the technique can be used in the passive mode (receiver only), active mode (transmitter and receiver), and activation mode (transmitting a signal along the target pipe or cable itself).

So, utilisation of geophysical techniques to take advantage of petrophysical properties extends well beyond mineral exploration, and we might well look to take advantage of experience in other disciplines.

References: Biased heterodyne exploration technique

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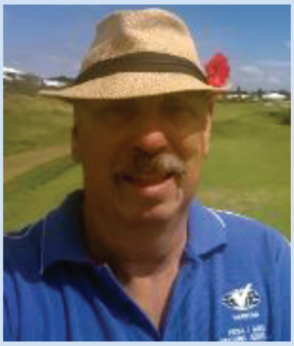
Seismic window



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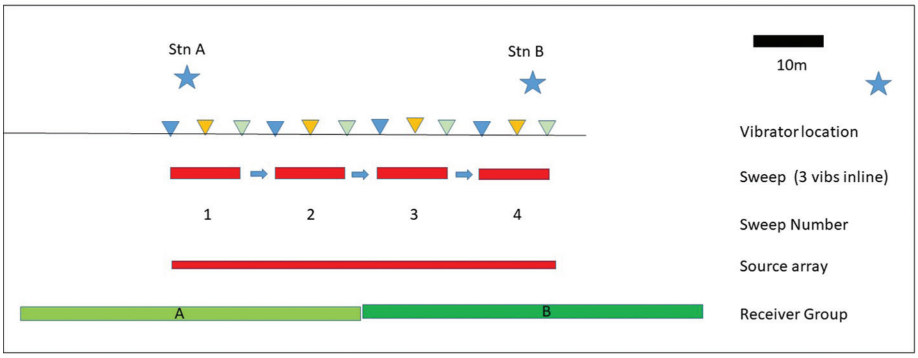

Figure 1. *Example vibroseis source array of the 1980s. At each source location three vibrators would sweep simultaneously then move along the line until four sweeps (1-4) were recorded. These were then stacked and correlated to give a single record for the shot point. It is easy to make a simple adjustment to record every sweep individually and sum traces to form appropriate arrays. Note: Receiver groups are centred on the station while source arrays are between stations. This is to maximise the benefits of stacking.*

Point source acquisition

My home office was recently invaded by water leaking through the ceiling and while I was moving things to safety, I stumbled across a technical brochure published by GSI in 1984. It was titled "GSI single sweep recording". Back in the eighties, a typical vibroseis seismic crew had 48 channels (maybe 96 at best) and receivers were planted in an array of up to 50 m length. Each source "point" consisted of three vibrators in line with four sweeps of 12 seconds at regular intervals between the receiver stations. These parameters were devised to reduce noise in the 12 fold data and were a massive effort. More vibrators boosted the signal, as did the number and length of sweeps, while using source and receiver arrays reduced the amplitude of horizontally travelling noise. The GSI brochure suggested the effort could be redistributed as continuous equally spaced source points without adversely affecting production rates. An example source and receiver layout is shown in Figure 1, and it is easy to see how the vibrator array could be changed slightly to record each sweep separately while simultaneously saving summed records. To maintain the sweep time per kilometre the sweep length was shortened while the number of source points is increased – more sweeps but shorter sweeps.

Recording single sweeps was a novel concept that we would not think twice about today, but this was all new in 1984 and single sweep recording required improved instrumentation such as higher density tape drives and real time correlation while also performing a stack of the correlated records.

Coincidentally, this week I attended an industry presentation about "Challenging Land Surveys". Apparently land surveys still have challenges. Today closely spaced point source and point receivers are the norm (or should be) with crews equipped with thousands of channels. We no longer have to design arrays to minimise noise because the close receiver spacing is sufficient to model the noise and remove it in processing. As it turns out, random noise is not so random after all. The increased fold allows better velocity analysis and improved residual statics both of which result in a better stacked section.

With so many channels available the current trend is to move away from cables and use cableless recording systems that are standalone and record continuously for a month on a single battery charge. These instruments are possible because of the development of low cost, low power GPS chips used to locate the receivers, and also provide accurate timing. Simple, but harvesting the data from so many individual boxes and formatting it appropriately may take several days.

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Data trends

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Remanence mapping using tilt angles and MMTs

Last year the Geological Survey of South Australia released several grids with the latest state TMI grid. The cryptic BigT and BigE grids were derived using Petar Stavrev and Daniela Gerovska's method of magnitude magnetic transforms (MMTs) for correcting horizontal position of magnetic anomalies, an alternative to the RTP (Gerovska and Araúzo-Bravo, 2006, Stavrev and Gerovska, 2006).

Rainer Wackerle of Intrepid Geophysics has explored combining the BigT with Tilt Derivative to detect remanence. BigT is his nickname for the sum of squares of first order components of T(MI), or the Total Field of the Analytic Signal (Tx*Tx + Ty*Ty + Tz*Tz). Remanence is a timely topic since Jim Hanneson recently demonstrated in this magazine the importance of even minor remanence (Hanneson and Baxter, 2022).

Rainer's advice is that "when only induced magnetisation is present, the curvature of an RTP and BigT should be in synchronicity and if not, there is a likelihood of remanence. Therefore where the RTP tilt (curvature) is negative and the BigT tilt is positive there is (possible) remanence."

Following the Intrepid cookbook and example scripts, the method has been applied to the Coompana area of South Australia. An area well known for a large negative magnetisation anomaly, also known as the Giant Skull, since a detailed airborne survey in 2015. The blunt application used raster arithmetic to colour black any points of coinciding negative RTP and positive BigT (Figure1). According to Rainer "This works quite well on sharp (near surface) anomalies but fails in basin areas. My thresholds are DC based, *e.g.*, if the RTP tilt is smaller than -X and BigT tilt is larger than +Y it is classified as remanent."

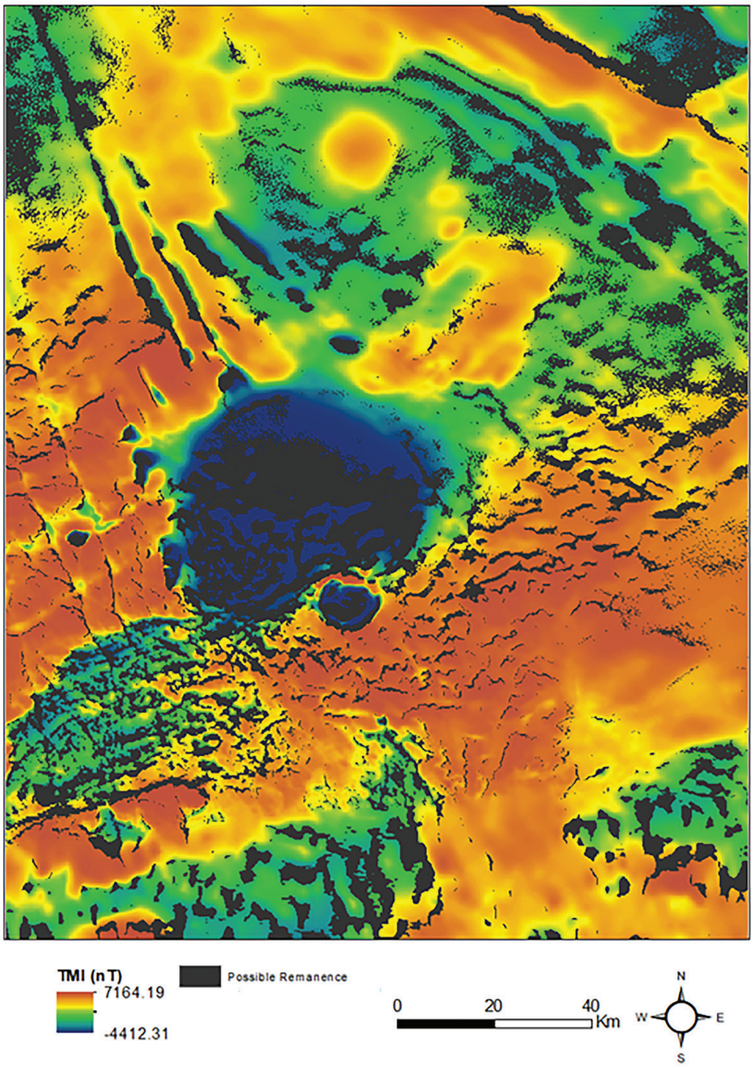

Figure 1. *Coompana MMT remanence.*

As previously stated, my blunt application is simply to illustrate the possibilities of where remanence could be included in your geological model or where to search for remanent rocks, and hopefully this is another inroad to progressing past just magnetic susceptibility in models.

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Hanneson J.E. and C. N. Baxter, 2022. Discovery of the Havieron Gold-Copper deposit, WA, *Preview*, 219: 42-47, DOI: 10.1080/14432471.2022.2103941

Webwaves

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Scams awareness week

In September 2022, Optus announced a data breach following a cyberattack with the potential to affect up to 9.8 million customers. In October 2022, Medibank announced a cyberattack that, at the time of writing this, could have affected 3.9 million customer records. This represents a considerable portion of the Australian population (25.89 million in the 2021 Census) who may have had their personal information obtained in the last three months alone.

In light of this, Scams Awareness Week 2022 is of particular importance. In 2021, there were 286 607 reports made to Scamwatch with reported losses of $324 million. Already in 2022, reported losses are considerably higher, at over $425 million. The most common type of scam reported in 2022 is phishing (attempting to con you into providing personal information, passwords or credit card numbers). The three most prevalent delivery methods are phone call (>51 000), text message (>50 000) and email (>33 000). The least common method reported was fax with 50 reports - so be careful, whatever technology you are using (https://www.scamwatch.gov.au/scam-statistics).

Other than phishing, two common types of scams include:

- Hacking - involving scammers breaking into the victim's computer or device to obtain personal information.
- Identity theft - where the victim's personal information is used to obtain money or while committing other crimes. Data can be obtained both digitally and by accessing mailboxes or improperly disposed personal documents.

The Government Scamwatch website https://www.scamwatch.gov.au/ provides a wealth of information and statistics including dedicated pages for the aforementioned Optus and Medibank data breaches. In addition, they have a webpage for reporting scams https://www.scamwatch.gov.au/report-a-scam and an educational book on the various scam types https://www.accc.gov.au/publications/the-little-black-book-of-scams.

The theme for Scams Awareness Week 2022 is spotting a scam, for which Scamwatch offers the following tips (https://www.scamwatch.gov.au/news-alerts/scams-awareness-week-2022-empowers-australians-to-spot-a-scam):

- Stop

Take your time before giving money or personal information to anyone. Scammers will offer to help you or ask you to verify who you are. They will pretend to be from organisations you know and trust, like a business you deal with, police, government or fraud service.

- Think

Ask yourself could the message or call be fake? Never click a link in a message and ask a trusted friend or family member what they would do. Only contact businesses or government using contact information from their official website, or through their secure apps. If you're not sure say no, hang up or delete.

- Protect

Act quickly if something feels wrong. Contact your bank immediately if you lose money or personal information or if you notice some unusual activity on your cards or accounts. Seek help from organisations like IDCARE and report online crime to ReportCyber. Help others by reporting scams to Scamwatch.

Multifactor Authentication, as mentioned in previous *Webwaves* columns is another method for securing your online accounts.

Other tools include:

IDCARE https://www.idcare.org/- Australia and New Zealand's national identity and cyber support service. IDCARE offer support for both individuals and organisations that have had their personal information obtained by scammers.

Australian Cyber Security Centre (ACSC) https://www.cyber.gov.au/- ACSC is the Federal Government body related to cyber security. The ACSC have a portal to report cybercrime https://www.cyber.gov.au/acsc/report

Before you go, take the spot the scam quiz: https://www.scamwatch.gov.au/about-scamwatch/tools-resources/online-resources/spot-the-scam-quiz

MEASURING TERRESTRIAL MAGNETISM

the evolution of the AIRBORNE MAGNETOMETER and the first anti-submarine and aeromagnetic survey operations – People, Planes, Places and Events 1100s –1949

W. D. (Doug) Morrison

This book, covering a global expanse of more than 800 years, recounts the largely untold story of 'measuring terrestrial magnetism' and of the extraordinary 'people, planes, places and events' that have contributed to the evolution of the magnetometer and the first anti-submarine and aeromagnetic geophysical survey operations. It is a unique journey of science and engineering, of inventions, new methods and instruments – a compelling story of how the measurement of terrestrial magnetism has influenced the history of the world.

This is an operational historical record rather than a history of the theory of terrestrial magnetism. The story begins at the earliest documented geomagnetic discoveries and moves on to observations of magnetic intensity and the first ground magnetic surveys. We see how the instruments used for geomagnetic observations from moving airborne platforms evolved in parallel with the evolution of flight from balloons (from 1784) to airships and eventually aircraft.

In the 1930s and 1940s there were major advances in magnetometry, in USSR, Japan and Germany as well as in USA and UK. In USA and UK these advances were applied in military surveillance systems, including in the detection of submarines. Landmark World War II induction coil and fluxgate instruments – the first of the modern technologies – enabled aeromagnetic acquisition, mapping and direct detections of ore bodies from the air from mid-1944 onwards, foreshadowing today's airborne magnetic surveys. The military developments of magnetometers were taken up, rapidly advanced and applied by the mineral exploration industry to find new economic deposits of magnetic mineral ores. Countries including Australia, Canada and the United States charged their national mining and geological survey departments with investigating and establishing programs of major aerial magnetic surveying and mapping in the search for minerals and energy.

The story explores the inextricable cross-discipline connections of terrestrial magnetism and magnetometers as used for navigation, geodesy, anti-submarine and military purposes, and their role in the geophysical oil and mineral exploration industry. Organisations, people and specific instruments and aircraft are noted, including (at times coincidental) Australian connections. The extraordinary depth and scope of research, over many decades, by the author W.D. (Doug) Morrison, as well as his collection of photos and illustrations, and his astonishing attention to detail, make this book an amazing and immersive historical reading experience and a future primary reference work. Through several decades Doug has developed an extensive 'reference' network of geophysical survey practitioners, and former experts in military, aviation and maritime matters. Through their little-known stories and personal reflections, and his access to personal and official archive material from this network, Doug's narrative brings unique insights into the evolution of the airborne magnetometer. Along that timeline he has produced details that are not available in public historical material.

Measuring Terrestrial Magnetism is a major work of 630 pages, illustrated throughout with 156 plates of figures and photos, and including comprehensive Endnotes, Appendices, References and Index.

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Coping with ambiguity in geophysical data

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Introduction

All geophysical datasets are to some degree ambiguous. Figure 1 is hardly necessary for geophysical readers; however, geological readers might find it informative. It illustrates that the size of a buried dense or magnetic spherical body cannot be determined solely from variations in the field values measured at the earth's surface. From gravity data the depth to the centre and the excess mass (density contrast x volume) can be determined, but the diameter can't be determined without knowledge of the density, and *vice versa*. Consequently, the depth to the top of such a feature, needed to optimize drillhole design, would remain unknown.

The smaller sphere has a density of 6.4 gm/cc, a magnetic susceptibility of 0.64 SI and a radius of 50 m, while these values for the larger one are 0.1 gm/cc, 0.01 SI and 200 m, respectively. The earth's magnetic field is typical for central South Australia. The responses for both spheres are precisely the same — as though the causes of the anomalies are concentrated at the sphere centres; furthermore, this is approximately true a short distance above an irregular but equant-shaped body where length, width and height are comparable. This problem, which includes the magnetisation-volume product in magnetics and the conductivity-thickness product for dikes in electromagnetics (EM; not shown), justifies calling geophysical data ambiguous.

Avoiding this ambiguity would seem to be a forlorn hope. However, if a target body has more than one physical property contrast, the ambiguity can be resolved (or at least reduced) by the collection and analysis of an additional (independent) dataset, as the following example illustrates.

The Dubawnt Lake Gabbro

The feature of interest is a bull's eye magnetic anomaly near longitude 103.1 W, latitude 63.0 N in the Canadian Arctic.

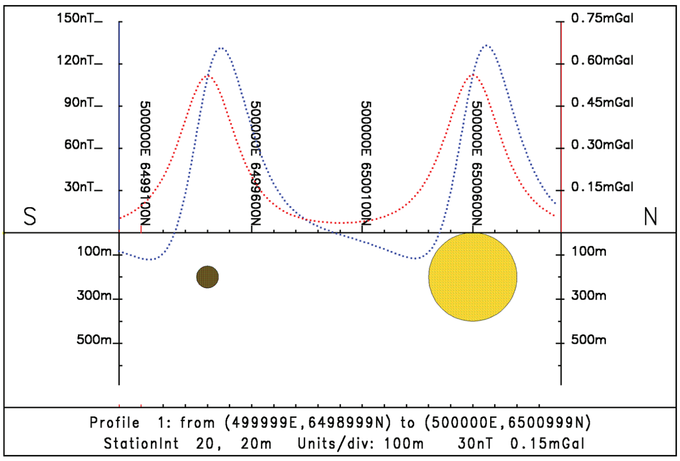

Figure 1. *Profiles of the calculated gravity (red) and magnetic (blue) responses along a north-south cross-section through two spheres with the same excess mass and susceptibility-volume product.*

Figure 2 shows aeromagnetic contours for a 9.5 x 6.4 km area covering what I call the Dubawnt Lake anomaly. It is on the boundary of map sheets 75P/1 and 75P/8 of a *c.* 1978 version of the Geological Survey of Canada's Aeromagnetic Series. Figure 3 shows hand drawn contours from the original processing of a more detailed aeromagnetic survey, and Figure 4 shows the gravity stations and contours for the same area.

In 1978, I was asked to estimate the depth to the top of this feature to determine if drill testing was feasible. I have used here the original diagrams, partly to save work and partly to hint at what internal technical reports often looked like and how geoscientists coped with data presentation in the pre-digital age.

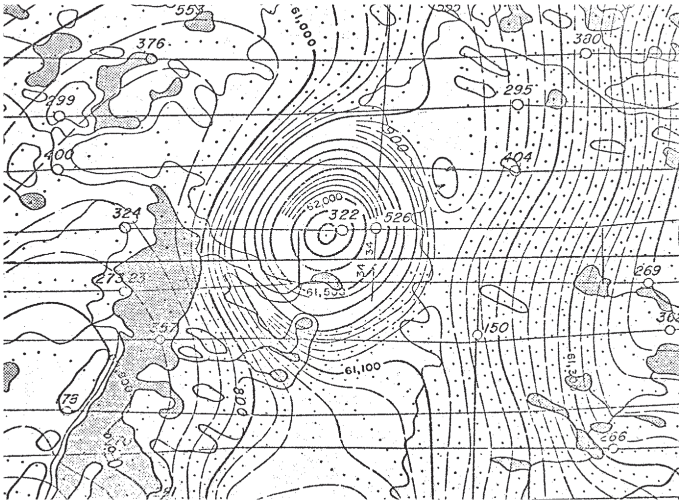

Figure 2. *Aeromagnetic map. Sensor height 305 m, Map area is 9.5 x 6.4 km and the contour interval is variable.*

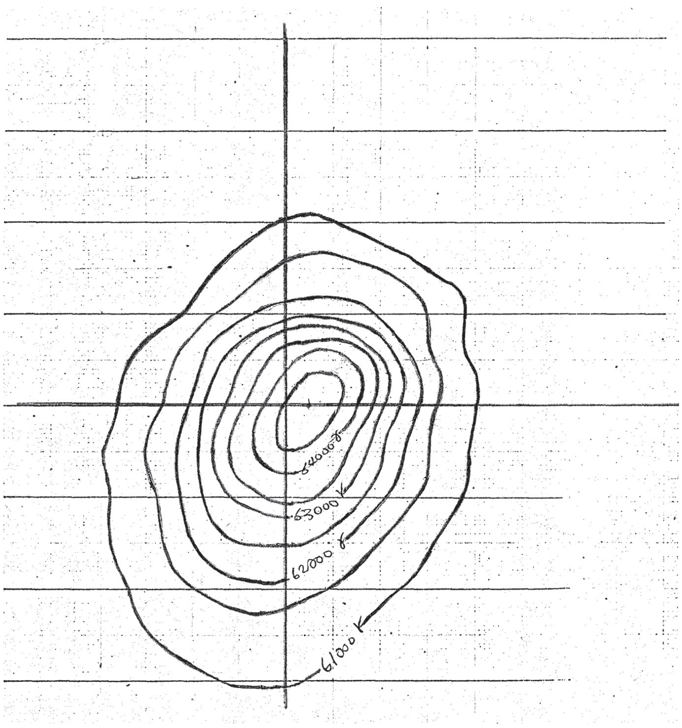

Figure 3. *Detailed aeromagnetic map. Sensor height of 46 m. Map area 850 x 975 m. Contour interval 500 nT.*

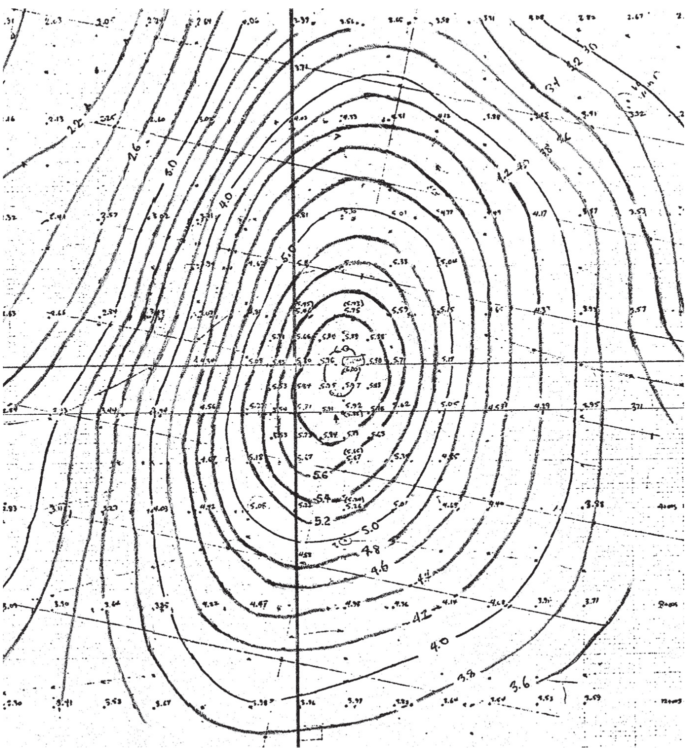

Figure 4. *Bouguer gravity map. Map area 850 x 975 m. Contour interval 0.2 mGal. Correction density 2.67 gm/cc.*

My interpretation relied on the responses of simple shapes as described by Nettleton (1940), and I soon satisfied myself from the shapes of the curves that the source of the ovoid anomalies was more in the nature of a sphere than a vertical cylinder with large depth extent. Both magnetic and gravity contours seem elongated slightly in the NNE direction, so I applied Nettleton's analysis to lines of data that were parallel and then perpendicular to the direction of elongation and came up with an average depth to centre of 900 m, but the sphere diameter remained unknown and so, too, the depth to the top.

Modelling vs. interpretation

Defining the density structure under a local area of the earth and calculating the gravity field that would be measured at the surface has been possible since the time of Newton (1642 - 1727) – at least for simple shapes like spheres and cylinders – even though there may have been little need to do so. Since Newton, other more complicated physical processes like magnetism (magnetostatics) have succumbed to theoretical analysis making possible what we now call *forward modelling*. Significant progress with even more complicated processes like electromagnetism was made by Maxwell (1831 - 1879) and others before and after him; however, the solution of many practical problems had to wait for the advent of the digital age, and today EM remains an important field of study. It is noted that in defining a model and calculating its response, there can be only one correct answer in the forward modelling of any of the physical processes. A world where Cause (the model) precedes Effect (the calculated response) is one that philosophers refer to as "mechanistic".

While the development of forward modelling algorithms is an important endeavour, it is necessarily confined to theoreticians familiar with mathematical aspects of the relevant theories. A practicing exploration geophysicist, by contrast, is confronted with a quite different problem: he/she has the Effect (the data) and needs to know the Cause (the model that has given rise to the observed effect) in order to design a drill test. This apparent need to "reverse the arrow of causality" is problematic because there are always infinitely many models that can simulate any given data set (as illustrated in Figure 1), and, to offer one model as an explanation for an anomaly rather than another which may simulate the data equally well or even better, is itself an act of interpretation (and, potentially, subject to the interpreter's biases). Interpreters are encouraged to advise their readers of this difficulty in order to help appraise risk (and, perhaps, in the hope of receiving condolences rather than aspersions when an interpretation proves unhelpful). It might therefore seem quite wonderful that, that with the odds of infinity-to-one against selecting the correct model, we come as close as we do (to providing useful results) as often as we do.

A world in which the arrow of causality is, or seems, reversed is referred to by philosophers as "teleological". For this word, both my Oxford and Webster speak unhelpfully of the religious doctrine of predestination; however, Russell (2000, p84) provides an everyday example by posing the question, "Why does the baker make bread?", and answers it with, "Because people *will be* hungry" (my italics). The Effect (making bread) precedes the Cause (future hungry people). It is interesting to note that in a teleological world, going from Effect to Cause the baker can proceed in infinitely many ways, and how he/she goes about it may well affect the result. When looking back (retrograde in time) from Cause to Effect there can, however, be only one correct history of the way in which past events unfolded. Uniqueness in going from Cause to Effect, be the relationship mechanistic or teleological, may not be a universal requirement, but it seems no less important than allowing us to make sense of the world around us. It may be going too far to suggest it as a precondition for the evolution of intelligent life, but this would at least be consistent with Hawking (1988, Ch 9), whose sophisticated argument embraces scales ranging from quantum to cosmological.

The world for the geophysical data interpreter is closer to teleological than mechanistic, and, to seek the physical model that best describes what we want to know of our study area is akin to the baker trying to make the best possible bread.

An ancient example

It's not just geophysical data that can be ambiguous. Historians report that an Alexandrian Greek called Eratosthenes (*c*.276 – 194 BCE) knew that at noon on a certain day when the sun shone directly into a well in Upper (southern) Egypt, an obelisk in Lower Egypt cast a shadow, and, that he used the inherent parallax to correctly calculate the diameter of the Earth and prove it to be a sphere. The geometry is shown (not to scale) in Figure 5a, but a glance at Figure 5b shows that proof can be elusive. Historians seem not to report, or not to have noticed, that Eratosthenes' data was ambiguous and that he might just as well have been calculating the distance of a burning rock in the sky above a flat Earth (and if truth were established by democratic consensus, the Earth, in ancient times, would certainly have been flat).

Figures 5a and 5b can now be seen as the end members of a range of infinitely many solutions, all permitted by the data, which combine different values of sun distance and earth diameter. Eratosthenes could not have known that the sun's rays are essentially parallel, so the truth that came out of his

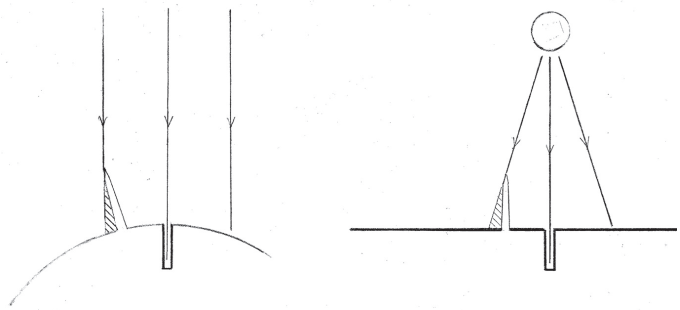

Figure 5. *(a) Rays from a distant sun impinging on a spherical earth. (b) Rays from a nearby sun and a flat earth.*

calculations might be construed as having been due to a lucky guess. But he was also an astronomer, having measured the angle between the ecliptic and the rotational plane, and was probably aware of the writings of Pytheas, who, in the fourth century BCE voyaged to northern Britain and probably Iceland, (Cunliffe, 2001), returning with stories of the midnight sun and a "congealed" (frozen) sea. Eratosthenes would also have been aware of the lines of latitude proposed by Hipparchus (c.180 – 125BCE). He would have had suspicions from these and other bits of independent information (like a ship just over the horizon that shows first its sails and only later its hull when it gets closer), that allowed him to select the correct solution from a myriad of possibilities. His deeper thoughts on the matter, if indeed they were recorded, probably went up in smoke along with many other ancient writings when the Library of Alexandria, having stood for 700 years, suddenly burned (391CE) just when Theodosius I (347 – 395CE) was expressing his preference for Christian dogma over ancient knowledge and was shutting down pagan institutions.

Ambiguity resolved?

Returning to the Dubawnt Lake problem, I constructed two equations which I took to be self-evident. Equation 1 gives the density of an arbitrary mixture of mafic rock and magnetite, and Equation 2 gives the magnetic susceptibility of the same mixture. Thus

$$d_1 p_1 + d_2 p_2 = d_m \qquad \text{Eq. 1}$$

$$s_1 p_1 + s_2 p_2 = s_m \qquad \text{Eq. 2}$$

where, *d* and *s* refer to density and susceptibility, and subscripts 1, 2 and *m* refer to magnetite, mafic rock and the mixture, respectively, while p_1 and p_2 refer to the proportion (0 – 100%) of each component. Eq. 2 was not used at the time but it is reasonable, and I present it now for later reference. In fact, I used a power law relation given by Grant and West (1965, p367) who reference Mooney and Bleifuss (1953) to estimate magnetic susceptibility as a function of magnetite content.

I was therefore able to tabulate the density and susceptibility for a mafic + magnetite mixture in increments of 10% magnetite, starting with a mafic rock (gabbro), and then for each mixture I calculated the diameter that a sphere would need to have in order to generate the anomaly amplitude observed in both the magnetic and gravity data. In plotting the results shown in Figure 6, and, because I knew both the density and susceptibility for each mafic + magnetite mixture, I was able to

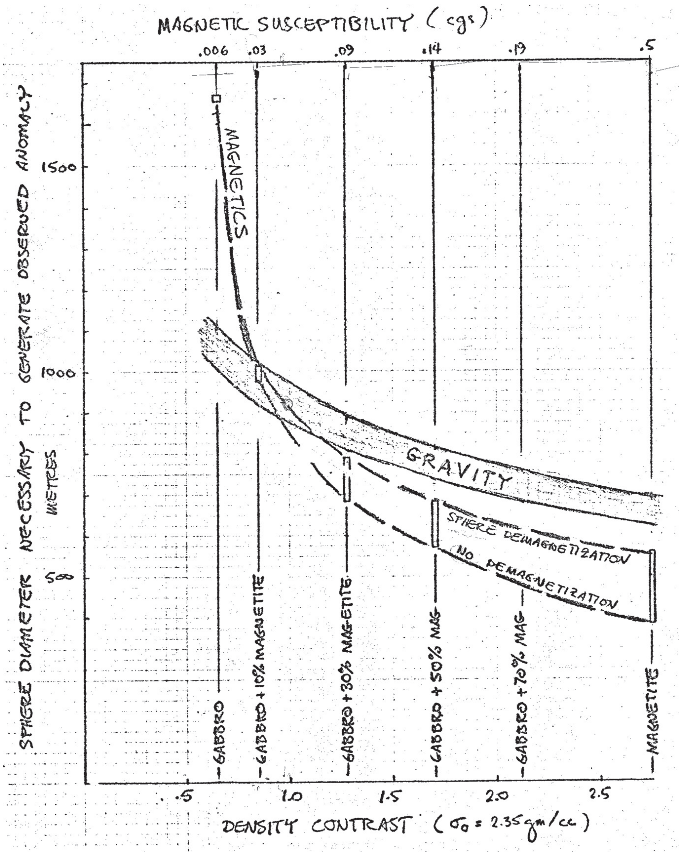

Figure 6. *Sphere diameter required to generate the observed anomaly amplitude for both magnetics and gravity.*

merge the horizontal density and susceptibility scales for the range of calculated sphere diameters.

One more assumption, in this case easily accepted, that the body causing the gravity anomaly was the same as the body causing the magnetic anomaly, allowed me to infer from Figure 6 that the sphere that simulated both the gravity and magnetic data would be characterised by the intersection point of the two curves. Evidently, the source body would need to have a diameter of about 900 m, and with a coincidentally similar value for the depth of the centre, the top would be at about 450 m depth. Furthermore, the abscissa of the intersection point allowed me to estimate that it would comprise gabbro plus about 10 percent magnetite. The reason that the curves in Figure 5 have different shapes is because when we recede from the vicinity of the sphere, the rate of fall-off of the field intensity is different for gravity, $1/r^2$, than for magnetics which is complicated by the dipolar nature of the field and falls off as $1/r^3$, see Blakely, 1995, p75.

When the drilling results confirmed the interpretation, it seemed like I had solved the ambiguity problem, and, while I was happy to receive the accolades of my colleagues, deep down I knew I had made some lucky guesses.

Further developments

Following this, the next decade or so was dominated by my attempts to understand EM theory, but it did leave time to implement an algorithm based on Talwani's (1960, 1961) theories for the magnetic and gravity responses of almost arbitrary shapes - in the hope that such a modelling code would benefit the search for iron-oxide copper-gold (IOCG) deposits. When K. Ehrig (*pers com., c.*1996) commented on the similarity between certain gravity contours at Olympic Dam and the outline of the deposit as she then understood it, we launched into an attempt to refine an earlier model reported by Esdale, *et al.*, (1987), using more arbitrarily shaped bodies and constrained by more detailed data than were available to the earlier workers. This work predated the final stage of development of what came to be called the *MagGravJ* Method (Hanneson, 2003), but it was nevertheless successful in directing drilling that led to the discovery of the Far North Mine Block at Olympic Dam.

My growing involvement in the search for IOCGs prompted a re-think of the Dubawnt Lake problem. This led to dividing the second component (the barren mafic rock) into two; namely, barren felsic rock and a dense non-magnetic component like a mixture of hematite and sulphides. (Hematite and sulphides must be lumped together because they are similarly dense and are non-magnetic and therefore have similar effects on gravity and magnetic responses). Thus Eq. 1, above, becomes

$$d_1p_1 + d_2p_2 + d_3p_3 = d_m \qquad \text{Eq. 3}$$

and Eq. 2 becomes

$$s_1p_1 + s_2p_2 + s_3p_3 = s_m \qquad \text{Eq. 4}$$

where now, subscripts 1, 2, and 3 refer to magnetite, hematite + sulphide and the barren lithology, respectively. (I discuss revising term 1 in Eq. 4 as $s_1p_1^x$ in the 2003 report.) Equations 3 and 4 permit calculating the density and susceptibility of a defined mixture but are otherwise unhelpful. The *eureka moment* that allowed me to move forward came with the realisation that if the physical properties of the three components span the full ranges for the rock-forming minerals, then the volumes of the three components would sum to the volume of the mixture, as in

$$p_1 + p_2 + p_3 = 100 \qquad \text{Eq 5}$$

which, with Equations 3 and 4, form a 3x3 simultaneous set. The density and susceptibility of the mixture (and the assumed physical properties of the components) can then be used to calculate the proportions of the three components. This was essentially the starting point in the original discussion of the *MagGravJ* method, which seems to reduce the ambiguity that is inherent in data sets considered separately, because it permits calculating the gravity response of the dense non-magnetic component separately from the gravity response of the dense magnetite. This is useful in the search for IOCGs which, in the classic scenario, exhibit a spatial separation between a shallower dense non-magnetic component (hematite + sulphides) and deeper magnetic rocks. It also permits calculating how much magnetite and hematite + sulphides a felsic rock would need to have to exhibit a given density and susceptibility. Such estimates are more helpful to a geologist assessing the bodies of a model than simply stating the physical properties.

MagGravJ uses empirical rules to estimate percentages of the three components from the density and susceptibility of a mixture but still requires assumptions about the physical properties of the barren lithology of model bodies and the host rocks. There remains another aspect of ambiguity in that felsic rock with 14% hematite + sulphides (plus a given amount of magnetite) has about the same density as barren gabbro (with the same amount of magnetite).

Eratosthenes, enjoying the benefit of independent evidence, nevertheless profited from a lucky guess that the sun's rays were parallel. Like him, I too had made a lucky guess (influenced by geological opinions) when I assumed that the lithology of the Dubawnt Lake feature was mafic. A less, or more, dense lithology would not have yielded the depth-to-top and percent magnetite estimates from Figure 6 deemed to be correct by my geological colleagues after drill testing.

Conclusion

So, provided a given anomaly is expressed in different independent data sets, acquiring data using different methods and applying a *joint* interpretation of both can significantly reduce the ambiguity inherent in any given dataset considered in isolation. But as we comb through the remaining multiplicity of allowed physical models, it is impossible to overstate the importance of another form of independent information; namely, geological credibility. While allowing for the possibility of incorrect geological opinions, if we cannot create a physical model that both simulates the data and seems reasonable to our geological colleagues, a manager is unlikely to support a proposal to expend funds drill testing it. In exploration, geophysics can be a useful servant, but beyond the control of geological credibility, it can be a cruel master.

My boyhood hero, Jonnie Bower, goalie of the Toronto Maple Leafs (*sic*) Hockey Club, when asked why he was so good at keeping the puck out of the net, said with some humility, "You've got to be lucky to be good", but then threw humility aside and added, "but you've also got to be good to be lucky". He seemed to hint that with hard work and diligence, it may be possible to influence one's own luck, and, as I have suggested above, anyone who thinks luck is unimportant in geophysics is on a different wavelength from me.

A final thought is provoked by one reviewer (CNB) who is uncomfortable with the notion of "luck". Indeed the term is rather defeatist, admitting to a kind of randomness over which we have no control as events unfold. When contemplating the vagaries and pitfalls in exploration, he prefers the more optimistic term "risk management", part of which would amount to doing everything possible to reduce ambiguity in the geophysical data through the joint interpretation of multiple data sets.

Acknowledgements and addendum

I thank Chris G. Anderson, Terry V. Harvey and Callum N. Baxter for suggesting many improvements to early versions of the manuscript.

I owe a special debt to Ken C. Cross whose query prompted me to revisit Figure 6. Evidently in 1978, I thought 0.006 cgs (left end of upper horizontal axis) was a reasonable estimate for the susceptibility of barren gabbro. However, I'd have done better by extrapolating the Mooney and Bleifuss (1953) power law at least as far as 0.05% magnetite to get 0.0001 cgs which is consistent with 0.00008 cgs at the lower end of a range of measurements (that don't indicate magnetite content) given by Telford, *et al.*, in a later version (1980) of their book. The effect of using a lower value for barren gabbro is to steepen the top end of the curve labeled "*MAGNETICS*". If the nearby box symbol were moved upwards to the axis and to the right by the width of the symbol, it would define the sphere required for gabbro with 2% magnetite. We must then suspend our calculations because lesser concentrations of magnetite yield spheres whose radii exceed the depth to the centre, which is geologically disallowed because no gabbro was seen at the surface.

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Henderson Byte: Deeper drilling for geothermal energy

Geothermal resources at depths of 8 km and more can provide an unlimited heat source which is free of CO_2 emissions. This energy source is, therefore, a highly desirable replacement for fossil fuels in a world increasingly conscious of a climate crisis. However, depths of the order of 8 km have generally been impossible to reach with existing drilling equipment, as the rocks are extremely hard and their heat (of the order of 400°C to 500°C) destroys mechanical drill bits. In fact, the maximum depth drilled in the world so far is 12 km, on the Kola Peninsula in Murmansk. It took 15 years from 1970 to 1994 to drill the hole, and the final temperature reached was a relatively low 180°C.

As a consequence, existing geothermal plants are located in places where conditions allow for energy extraction at relatively shallow depths and the number of geothermal energy plants being built has plateaued world-wide. However, geothermal heat at greater depths, if it can be accessed, has an almost unlimited potential.

There are several newly proposed ways of drilling to great depths, including high energy laser beams and high temperature electrical plasmas, however, the technique that currently has the most promise is **"millimetre wave" drilling** - an outgrowth of fusion research at MIT's Plasma Science and Fusion Centre guided by Paul Woskov. The technique employs a continuous beam of energy waves with wavelengths of only a few millimetres. These millimetre waves can be produced by a commercially available **gyrotron**, and the waves are guided straight down by a gravity-controlled waveguide. Due to the intense heat of the energy waves, the sides or lining of the borehole are melted and then solidified into a vitrified wall, creating a completely sealed borehole.

Another method of drilling to greater depths is **"electrical plasma" drilling**. In this technique, an electric arc, formed by an electrical breakdown of a gas, produces an ongoing plasma discharge resulting from a current flowing through normally nonconductive media such as air or gas. It has several advantages over other technologies, including the ability to produce boreholes with a wide range of diameters, and drilling in the presence of water. A team at the Research Centre for Deep Drilling in the Slovak Academy of Sciences has developed this drilling concept based on utilisation of electrical plasma. One company involved is GA Drilling, headquartered in Bratislava, Slovakia.

John Bishop, an active "geothermalist" and a Member of the ASEG since its inception, has been pursuing the goal of abundant energy from geothermal sources in Tasmania (as KUTh Energy) and now in the Hunter Valley, NSW (as Spa*ark Energy), where he hopes to make use of the existing coal power generation infrastructure present in that region.

Further reading

Drilling Deep, *New Scientist*, 13 August 2022, p.25.

Tapping into the million-year energy source below our feet, Zach Winn, MIT News Office, June 28, 2022 https://news.mit.edu/2022/quaise-energy-geothermal-0628

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The Do-It-Yourself geophysicist

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My path to DIY

My undergraduate degree was a BSc with a major in physics at UWA in Perth. Prior to the 1990s, a degree in physics or electrical engineering was not an uncommon path to geophysics. My interests in electronics and programming started much earlier, and I considered a degree in electronic engineering in my teens, but that seemed too specialised for me. Instead, I went to university to learn and discover rather than train for a profession. Physicists are traditionally trained to anticipate that they may have to make their own equipment, and so as well as fundamental physical concepts and much mathematics I was taught skills in electronics, including programming embedded microprocessors in assembly, and many techniques in measurement. Even basic machining skills on a lathe were taught. Thus, armed with knowledge and deeper skills, I went to UBC in Vancouver, Canada, to become a geophysicist via a PhD. I joined Don Russell's Geophysical Instrumentation Group and became a professionally trained Do-It-Yourself (DIY) geophysicist. These DIY electronics and programming skills have been applied over three decades in research and assisting the commercialisation of various "inventions". It has been invaluable. In addition, I have selected, purchased, tested, and used many millions of dollars in geophysical equipment. The understanding of "how things work", and the corollary "why it doesn't work", is incredibly valuable when selecting, buying and operating equipment. This article is an extension and update of a presentation at AEGC 2021 (Kepic, 2021) where I encouraged a path to becoming a DIY geophysicist, different to the one I took. Herewith is an abbreviated guide to opportunity and hints for a much, much shorter path, but it still requires acquiring knowledge via discovery and experiment.

Enabling technologies

There is a lot of choice when it comes to the ability to make our own measuring instruments and analysis of data. This is not obvious to most of us who have mostly lived in a "production environment" in our professional careers. There are many occasions where a bit of customisation makes a huge difference in capability and marketability for the entrepreneurial. An example is the migration to drone platforms with "strap on" instruments (Franke and Verezub, 2020).

There are three important developments for the DIY geophysicist: powerful embedded microcontrollers becoming ubiquitous and available on easy-to-access platforms; open software and hardware from the philosophy of the GNU movement (www.gnu.org); and advances in transducer electronics including modern power electronics. Consumer and industrial electronics developments, especially the "green revolution" and "internet of things", have made many very sophisticated components looking for new markets accessible.

Changes in the marketing and use of many micro-electronic devices over the last decade also help where there is less use of Original Equipment Manufacturers (OEM) engineering as an intermediatory, and more reliance on direct sales to the end user manufacturers. To aid this change the manufacturers have made available engineering Computer Aided Design (CAD) drawings and specifications including the Computer Aided Manufacture (CAM) files to manufacture ready-to-go evaluation systems, often mounted on single printed circuit boards (PCBs). These designs and the specifications of these evaluation boards are freely available to copy and repurpose because the manufacturer is in the business of selling components and not the evaluation boards themselves. Thus, any reasonably skilled and brave person that can use a computer and perform purchases online can create sophisticated measurement tools for specialised needs.

Challenging times

The recent COVID pandemic and war in Ukraine have presented challenges to my original assertions in the AEGC 2021 presentation. Parts that were plentiful and abundant in 2020 have disappeared due to part shortages or export restrictions. The nationalisation of strategic electronics and the huge demands in progressing Western economies to greater energy independence has been a big factor. However, the electrification of the car industry with a wave of demand for consumer electronics during the pandemic also contributed to shortages in many semiconductor devices (chips). This is not hyperbole, every design engineer I have talked with in the last year, and myself, has stalked the internet in the evenings looking for wanted electronic parts to appear in stock, and to quickly buy before they disappear before the next batch is ready in mid-2023… perhaps. Manufacturing and buying from China has often become painful with respect to delays. Some of my recommendations in 2021 are already a bit dated due to quickly changing world events. If you want it fast, buy from the US and sometimes Australia, if you want it cheaper buy from China, or India perhaps. By 2023 it seems that many issues will have worked themselves out to a new order. For example, Texas Instruments (based in Austin, US – originally Geophysical Services Inc and started by DIY geophysicists) will be producing 100 million chips each day (Analog – amplifiers, ADC, DAC, power regulators, precision devices etc) from newly constructed semiconductor "fab" plants in Richardson, US. Adversity creates opportunities for the entrepreneurial.

Tools for the DIY geophysicist

Useful tools in your workshop will be a PC workstation (Windows, or Linux), which you likely have already, a multi-meter, a regulated (voltage and current) DC power supply, and a quality soldering iron. A current limiting power supply is a godsend for testing and preserving electronics from wiring misadventure. Once you are of an age requiring reading glasses, then a magnifier is handy too (many parts are tiny and delicate to work with). A small portable oscilloscope (can be found online for $500 or less brand new) is invaluable to assist in understanding "mystery" circuits. The initial capital outlay to begin exploring what can be done yourself is relatively modest, the cost of a hobby rather than the cost of setting up a small business, and can be almost nothing other than the parts purchased.

Most geophysicists are trained as scientists and are taught some form of programming. Python (the language) is currently the most adopted tool and is relatively easy to use and learn. Engineers tend to be trained in C language and variants because C is a language designed to be put onto "bare metal" directly (i.e. hard programmed into computing systems as it was originally designed to create Unix operating systems). In our present era a C language compiler exists for every type of microprocessor and the Python interpreter is coded in C itself. C or C ++ may be used to implement and refine a concept tested with Python. If there is a commercial outcome for the DIY geophysicist then an engineer can easily take the Python (or MicroPython) code and, for a fee, turn it into a propriety embedded code, if need be. However, in many cases this will not be needed. MicroPython code can be partially compiled into m-code with a little extra effort using the mpy cross-compiler; thus, requiring less space in flash memory and executing more quickly.

Embedded computers for data acquisition and control

Good examples of a modern foundation tool for the DIY geophysicist are the new MicroPython embedded systems. These single board systems (pictured in Figures 1, 2 and 3) are focussed upon allowing access to analog signals and "hardware" pins on the microcontroller with standardised high-level software. Previous microcontrollers such as the popular Raspberry Pi series (www.raspberrypi.org) and Arduino (www.arduino.cc) require reasonable knowledge of Linux and a C ++ compiler and multiple code-build-flash cycles in developing code. Both Rasberry Pi and Arduino have recently embraced MicroPython-based embedded computing and invested considerably into it by collaborating to develop an independent microcontroller, the RP2040.

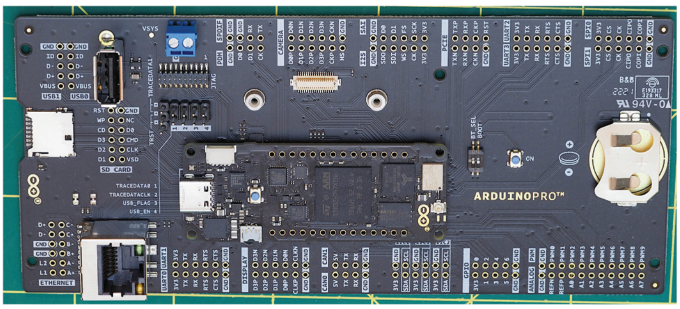

Figure 1. *The relatively new Arduino Portenta H7 (66 mm x 25.4 mm) with WiFi/BT mounted upon a larger expansion card that adds easier access to many pins and ports plus a microSD card socket that appears as flash drive when connected to a Windows PC. The H7 has two processors, one running at 480 MHz the other at 240 MHz, that perform independently and untethered tasks such as collecting sensor data with numeric transformation at multi-kilohertz rates and then to storage or re-communication with a power consumption of about 200-500mW. This system could serve as a master controller for hundreds of sensors, which is exactly what is planned for this unit.*

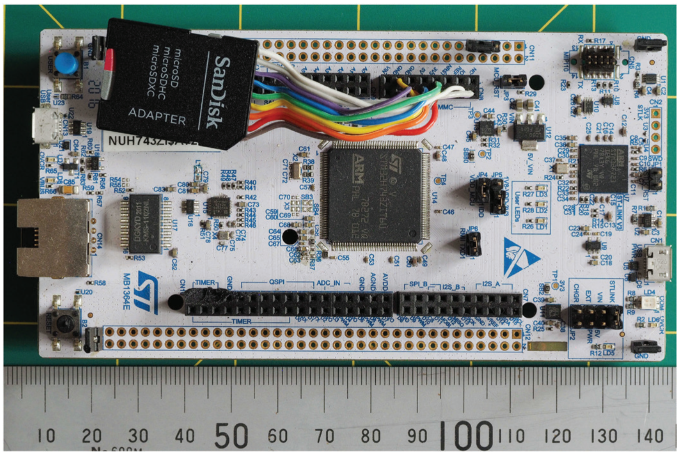

Figure 2. *A STM embedded microcontroller evaluation board, Nucleo H743 running MicroPython interpreter with a 480MHz ARM M7. This board has had minor modifications including adding a microSD card and to improve the 16 bit ADC noise. It is capable of measuring 8 x Analog channels with 16-bits and storing the results to a microSD card at data rates of 20kS/s.*

MicroPython started as a Kickstarter crowd-funded project by Damien George (www.microphython.com) to remove the added complexity of a largely unneeded Linux operating system in embedded systems and rarely used Python language elements to produce a very small python kernel stored in the flash inside the microchip that directly run Python scripts with a standardised library of hardware access to microcontroller functions; such as Analog-to-Digital conversion (ADC), Timers, Interrupts, Pulse-width-modulation (PWM), standard digital interfaces such as I2C, SPI and SD Card access. In practice, Python code is saved onto flash memory that often appears as a USB drive while simultaneously the USB interfaces as a remote terminal to a PC to run and test the code, or the terminal interface is used to run MicroPython scripts interactively.

The popularity of the MicroPython approach has been implemented by the Raspberry Pi organisation with their own custom integrated circuit, the RP2040, released in March 2021 to meet the needs for simple embedded sense, compute and

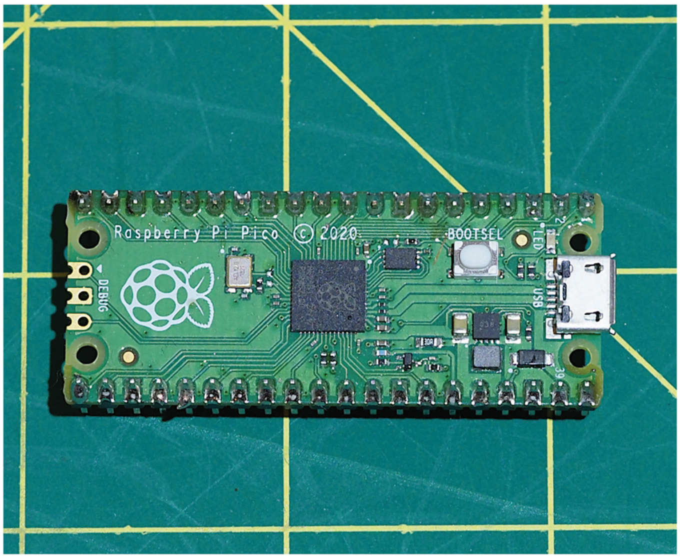

Figure 3. *The new Raspberry Pi Pico, tiny at 22 mm x 50 mm, the current lowest cost option at about $10 with or without WiFi/BT. Perfect for a small nodal sensor system – wired or wireless, or transmitter controller for a resistivity/TEM transmitter.*

control. The Arduino system has also adopted this IC and their extensive daughter board sensor and peripheral systems will be available (as used by Dean *et al.*, 2018(b)). The microcontroller systems can be inexpensive, currently costing less than $10-50 for each item.

The various embedded microcontroller systems, often based upon Advanced RISC Machine (ARM) architectures (similar to microprocessors used in mobile phones) are far more capable in directly controlling signal inputs and outputs. Without sophisticated human interface devices and high overhead peripherals these little systems can respond to external input in in less than a microsecond even with MicroPython code via hardware interrupts, or the use of timers running with less than 10 ns of resolution. Many modern ARM microcontrollers have internal bus switching to allow MicroPython to directly command Serial Peripheral Interface (SPI) and I2C streams into on-chip memory while executing instructions and data from other areas, known as direct memory access; a technology developed for mainframe computers in the 1970s. These little microprocessors using less 100 mW of power can be faster than the original supercomputers, even in 32-bit floating point.

My current recommendations for embedded microcontrollers are:

- Pyboard v1.1 – versatile and extensive peripheral set and the foundation of MicroPython support
- Arduino Portenta H7 – relatively costly but extremely capable and well supported
- Raspberry Pi Pico/Pico W– inexpensive, well supported, Wi-Fi version, and widely available
- Arduino Nano RP2040 – less costly with Wi-Fi and well supported Nano accessory shields

The PyBoard systems with a small daughter add-on board for external programable amplifiers are capable of performing as simple engineering 12 channel seismographs storing 4 second records at 1 ms sample rate, then streaming the data to a FAT file on a microSD card. The data on the mSD card can be later harvested or read directly by a PC connecting to the board via USB (as the mSD card presents as a flash drive). A related microcontroller, STM32H7 series processor, has within the Integrated Circuit 16-bit ADC conversion and pin access to eight channels, or three differential channels on the evaluation board when not using external buffer amplifiers (Figure 2). The PWM waveforms and external signals can be controlled to a precision of less than 20 ns. There are many tips and tricks on various forums, such as GitHub (https://github.com/) and the IC manufacturer's website www.stm.com. Thus, simple seismographs, EM or electrical resistivity acquisition and transmitter control may be made from these boards. The analog signals (with or without amplifications and buffering) may be directly soldered/wired to the terminals with equipment costing hundreds of dollars, or as little as $50 for a decent low voltage soldering iron.

The Arduino Potenta H7 lite with the breakout board (Figure 1, order codes ABX00042 and ASX00031) provides an affordable ready-to-go acquisition system and data logger with microSD card plus relatively easy to solder and wire to fast 16-bit ADC, 12-bit DAC, multiple peripheral interfaces (I2C, SPI, and UART). It's very capable and a newly maturing system with respect to software support and hardware add-on boards (shields). The microcontroller in the Potenta H7 (and the RP2040) has two separate processing units that can execute separate programs in parallel and share data (basic support in MicroPython for explicit multi-threading). Best of all you can buy these devices and get underway immediately. Least costly by far is the Raspberry Pi Pico (Figure 3, and Pico W), which outside of the MicroPython interpreter also needs a special programming environment for Windows- and Mac-based programmers to download code/scripts to run (*e.g.* Thonny, https://thonny.org/). The Pico is very minimal in mass storage support. Thus, I feel the Arduino and Pyboard systems are the quicker path to satisfaction if you do not have many electronic skills and tools.

Sensing and measurement

Traditional sensors such as geophones may be directly wired to pins on the embedded processors, but while simple it often produces very poor performance. The typical 12-bit resolution found in most microcontrollers may seem primitive and too poor in performance for most geophysical applications. This isn't true, despite modern production geophysical systems typically using 24-bit conversion. Adding an instrumentation amplifier, or two, will result in better utilisation of dynamic range and signal buffering (Dupuis *et al.*, 2020). Recording a single sensor with two measurements at different gains, or even different types of sensors, will provide very good performance in many cases after some post-processing of signals (*e.g.* gain merging of channels as we once did with TEM systems). For example, a conventional geophone sensor recorded with multiple gains (*e.g.* gain =2 and gain =100, for later gain merging) allows high dynamic range (90-100dB) even with limited 12-bit ADC resources.
My recommendation for an amplifier for most purposes is an instrumentation amplifier. For example, Analog Devices AD623 for use with 3 to 5V systems and directly compatible with 3.3V powered microcontroller ADCs. Another very fine and easy to use instrumentation amplifier is the Analog Devices (Linear Technology) LT1920, or if you want to measure down the fundamental thermal noise of geophones then use the SSM2019 or INA103/163/849. These are all "relatively" easy to use and implement, but all analog circuits are trickier to work to specification than digital devices.

As a basic datalogger the Pyboard v1.1 appears to be well suited for many basic data logger geophysical measurements. The STM Nucleao-144 STM32H743/753 evaluation board is inexpensive and has greater access to various pins and function than the Portenta H7 but requires more work and expertise to interface to measurement and control. Like the Pyboard it has both ADC and DAC channels, with native 16-bit ADC x 9 and 12-bit DAC x 2. However, beware the specs: the ADCs will barely achieve better than 12-bit Signal-to-noise without modification of the reference circuit (removing a resistor on the board and feeding a stable low impedance reference voltage). Many on-chip ADCs cannot perform better than 12 bits because of noise from the digital circuits nearby. An issue challenging even experienced engineers. The STM Nucleo is also unfortunately currently out of stock everywhere and it is not looking likely to be in stock until mid-2023.

For those wanting more resolution and instantaneous dynamic range "out of the box" then connecting the embedded microcontroller board to an external dedicated analog-to-digital convertor via SPI or I2C serial interface is a good option. An example of a capable 16 bit converter not requiring much electrical know-how (or soldering) to interface are small daughter boards based upon the ADS1115 (eg manufactured by Adafruit) and distributed by Core Electronics (in Australia), Digikey (US) and Mouser (US). Core electronics also have a tutorial on connecting a geophone to the ADS1115 and a Raspberry Pi to trigger a camera logger (https://core-electronics.com.au/guides/raspberry-pi/geophone-raspberry-pi/). Need more? If you really need and want 24 bits and sampling to 10 kS/s or higher then I would recommend the ADS131M04 or ADS131M08 devices, providing a programmable amplifier input (gain =1 to 128) and 80-to100dB dynamic range. These ICs are designed to perform well on simpler two-layer boards and interface via the SPI interface. The data sheet from Texas Instruments has pseudo-code (and C code on their support web site) examples on how to program and then set-up of the device to access the streaming data. Plus, these are in stock and available for less than $10 each by the thousands. To save time you can buy the evaluation board (ADS131M08EVM) and with one to three of these boards you have yourself the basis for a decent (4 ch) MT, TEM system or (8 to 24 ch) engineering seismograph system. Hint for happiness, make the connection between your microcontroller and the EVM less than 15 cm and run the SPI Clock at a frequency just high enough to get the data reliably to the microcontroller, say 2MHz. While it might cost you almost $1000 dollars to purchase a few ADS131M08 EVM boards and a Portenta H7 embedded system for data logging and communication to your laptop PC (via USB/Ethernet/Wifi), that cost pales in comparison to the price of a new geophysical acquisition system, which usually costs many tens of thousands of dollars.

Lastly, when measuring analog signals be mindful of what the voltage is with respect to "what"! This aspect is a little tricky for novices and sometimes people who should know better. A geophone element is a "floating" voltage source of both positive and negative polarity so it must be tied to a reference potential, either directly or via a resistor. With single ended analog inputs (one pin for input as in most microcontrollers) it is best to have the "sensor reference potential" at approximately half of the ADC power supply voltage (*e.g.,* 1.65 volts from 3.3V) for bipolar sensors such as geophones, pick-up coils, or electrode stakes in the ground (and most natural signals). The sensor reference voltage can be made via a resistive divider (https://en.wikipedia.org/wiki/Voltage_divider), or use a 1.5V alkaline/lithium battery (in a holder), or a special rail splitter device such as the TLE2426 (my favourite approach). Tie one end of the geophone to the "sensor reference potential" and the other to the input using twisted pair wires (as in CAT5/6 ethernet) between geophone and microcontroller. With the differential input of the ADS131M08 connect a resistor to ADC/microcontroller "ground" at each geophone output -to– ADC input (it has a charge pump circuit to allow measuring small negative voltages with respect to "ground"). With an instrumentation amplifier, such as the AD623 and others, connect each geophone terminal to sensor reference potential via a 10k-100k resistor. A buffered voltage splitter such as the TLE2426 or a resistive divider buffered with a unity gain Op-Amp should be used. Otherwise, confusion will reign supreme as the ADC will likely give a reading of either max or min regardless of sensor input.

Excitation

Many geophysical measurements require changes to electric or magnetic fields or use electrically controlled (seismic) sources (Dean *et al.*, 2018(a)) and we may use modern developments in power electronics to our advantage. Over forty years the technology of power switching has evolved considerably from Silicon (Si) transistors to Si MOSFETs (Metal Oxide Semi-conductor Field-Effect Transistors) to SiC and GaN MOSFET lately. The green revolution of solar, wind, and electric vehicles is creating a flood of new efficient electric power switching devices, with many evaluation systems providing ready-made devices for incorporation into new ideas.

New power switching devices and the use of microcontrollers to precisely control the switching provide the geophysicist with new possibilities. Traditionally, we tend to switch electrical currents into a H-bridge (https://en.wikipedia.org/wiki/H-bridge) that allows efficient bi-directional current through a load, which in our case is usually the earth (resistive) or a loop (inductive). If we are satisfied with switching on or off in less than 200 microseconds and at a rate of less than 10s of Hertz then for moderate power (100-1000W) for each switch I would use a photovoltaic optocoupler, such as the Broadcom ASSR-V621/V622 device (DIP8 package), or Panasonic APV1121S (SOP4 package) with a N-channel MOSFET (TO-220 or TO247 package, with input capacitance of less than 2000 pF – hundreds available at various voltage current ratings e.g., IRF540). The photovoltaic optocoupler is basically a LED light source coupled to a small photovoltaic diode within a plastic package. The combined photovoltaic optocoupler and MOSFET makes a solid-state relay that can isolate up to 2500V between the power switches and the microcontroller electronics. The optocoupler needs only 5 to 10 mA of current (in the LED section) to operate reliably and can be driven with the digital output pins from a microcontroller directly (if you program the digital output to be "open collector" to sink current). Ready-made solid-state relays using this approach can be bought too, such as the CPC1779 (good for 2-4 amps at 500 V, and shallow resistivity), which are slightly easier to wire but a more expensive and a difficult-to-find solution. The optocoupler plus MOSFET solution will suffice for the majority of DIY geophysics resistivity applications and basic TEM transmitters (equivalent to the old SIROTEM systems).

Faster switching with high voltages can be found by utilising ICs intended to drive muti-kW single and 3-phase motors, with the Infineon IM828-XCC a good modern example of switching 20 A at 600 V in 100 ns. The lowest frequency of switching is determined by a bootstrap capacitor that can be large enough to keep the auxiliary supply powered for 100 ms or longer to seconds. An evaluation board design is available for pre-packaged convenience and the 3 half-bridge outputs could be used with a bit of creativity for resistivity measurement into two dipoles simultaneously with a shared electrode stake (*e.g.* with three pseudorandom binary sequences PRBS into the three digital control lines to the U,V,W half-bridge-tied load outputs). Or as a small but powerful CSAMT transmitter. Possibilities are now available you didn't think you could buy before, let alone for less than $500.

Another approach is to use a Class-D amplifier (designed for audio sub-woofers) to drive the resistive or inductive load. The DAC output from many microcontrollers (eg Pyboard v1.1 and Portenta H7) can provide an encoded analog signal (0 to 3 Volts) such as a swept sinewave or random signal (uniform distribution random noise or limited Gaussian noise) to the amplifier. A slightly clumsy alternative is to use a resistive-capacitor low-pass filter on a digital stream from one of the microcontroller pins, either pulse-width-modulation or PRBS, can generate the signal (this is the approach recommended on user forums for the RP2040, which has no DAC). A nice integrated class D amplifier example is the TPA3255 integrated circuit. It's a fiddly surface mount chip to design and mount directly, but the evaluation board can either be bought or copied to have a small 300 W

RMS amplifier to put out all types of useful transducer-ground stimulus. I am currently using a Pyboard and class-D amplifier to control an electromagnetic shaker system for shallow seismic applications (Figure 4, like Dean *et al.* 2018(a)). Plus, I have been experimenting with the TPA3255 system driving the output via a 300 VA toroidal transformer to increase the output voltage (and coupled power) with programmed random waveforms for resistivity and find that even with 12-bit ADCs (measuring output current and sensor voltage) I can obtain very high precision and sensitivity (and perhaps even IP, not tested) with a modest outlay in equipment and monies. Such an approach could also work as a broad-band EM system providing both frequency domain and time-domain responses when processed later. Possibilities that were once merely theory are now tangible. Note that using the same set of ADC channels to measure the sensors and the current/voltage into the excitation source/transducer compensates for various changes in ADC and excitation source properties.

Communication between nodes

What if we want to have an array of sensors? Or have a remote node that measures and another that processes, stores and passes the data onward for real-time quality control. There are two practical solutions: a data logger with no real-time communication and then harvest later or use wires to send power and communicate in real-time. I will say right now that I don't tend to use Wi-Fi, or wireless, unless I really must. After watching more than one thousand Wi-Fi nodes trying to download data to a central repository, I can say that it isn't a very practical solution for most field measurement and expensively complex to implement well. Wireless requires batteries and then drains these quickly. Wires are not cumbersome when the nodes are close together and they carry power with high data throughput-bandwidth and communication is easier to implement in code. If your measurement node is down a borehole, then wireless isn't practical anyway.

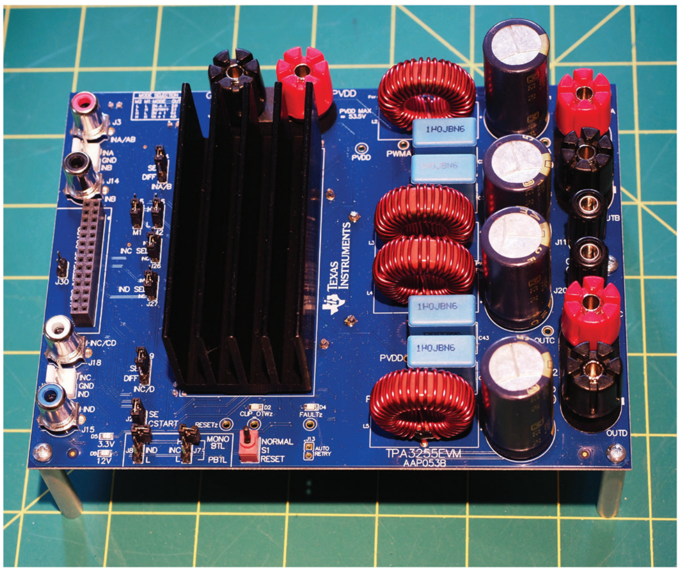

Figure 4. *This photo shows an evaluation board for class D audio amplifier using a TPA3255 chip (under the black heatsink. It will send out 300 W of power into a 4 Ohm load all day without overheating at 95% efficiency with less than 10% distortion, or 100 W with less than 1% distortion. Complex waveforms such as uniform random noise can be transmitted into the earth or transducer and then correlated with sensor data to provide high signal-to-noise.*

Two developments are here to assist the DIY geophysicist who needs to communicate between nodes and send power with wires: 10BaseT1L ethernet, and communication over powerlines IC (*e.g.* smart metering) such as the THVD8000. Ethernet has a lot of software/processing overhead, but many IC makers have incorporated much of this into hardware and there is a lot of software support of ethernet protocol stacks, including MicroPython. Ethernet using10BaseT1L is fairly new and evaluation boards are a bit hard to obtain, but if you need a robust full duplex (both directions simultaneously) 10Mbits a second over two wires up to a kilometre between nodes that uses far less power than Wi-Fi, then this technology is for you. Look for EVAL-ADIN1110EBZ and DP83TD510E-EVM for testing and the related ICs.

Communication over powerlines has been around for a long time and is either geared towards running Ethernet via the wall-plug through the house with fiendishly complex circuits placed into chips with over two hundred pins and proprietary code information, or low data rate modems of less than 10 kbaud. I bring your attention to the Texas Instruments THVD8000 instead, a tiny 8 pin IC that you use a simple UART interface to an embedded microcontroller to send OOK (on-off modulation encoding) as simplex (one directly at a time data transfer) over two wires 30kBd to 1 Mbaud. Dr Christian Dupuis and Masters student Andre Mercier, at the University of Laval, has used this IC for borehole communication and power over a 500 m single (poor quality co-axial) wire winch for a VSP tool stack (https://github.com/Geophysical-Instrumentation-Group-UL/Geophysical-Open-Seismic-Hardware). The THVD8000 is a very nice balance between simplicity in use and to implement on any pair of wires in a cable - bits in one end and bits out the other end - with good throughput performance with low power consumed.

Making it from scratch

If you cannot buy exactly what you want, then you can still design and make it yourself. The IC datasheets and CAD-CAM files made available by the microcontroller and IC manufacturers can be used and reworked sightly. When making a daughter-card for plugging into one of the embedded microcontrollers it is a very useful approach, especially if you want the best in performance, size and capability, or you wish to manufacture many sensor nodes. I have done this for the Nucleo H743 board to allow buffering, amplification and voltage isolation into the 16-bit ADCs with level shifting via signal transformers (Figure 5). Another example, combining the CAD files for the Pyboard 1.1 and ADS131M04EVM would make a very capable, generic 4 channel data acquisition system for a nodal resistivity, 3-C seismic or EM system, such as that described by Dean et al (2018(b)). KiCad (https://kicad.org/) is freeware for PCB design and can be used to create electrical schematics to producing the Gerber files and CNC drill files for quite complex and useful parts. It is relatively easy to learn and very powerful in its functions. Templates for the integrated circuits and parts number in the many thousands (from major parts supplier such as Digikey and Mouser via SnapEDA and Ultra Librarian links) so time is spent designing not creating footprints and other basic work. Another free product, Altium Circuitmaker (https://www.altium.com/circuitmaker), is loosely based upon the industry standard Altium PCB design software package. The caveat is you must "share" your designs. I have not tested it, but for public good and education projects it seems a good option. To transition to proprietary designs the Altium

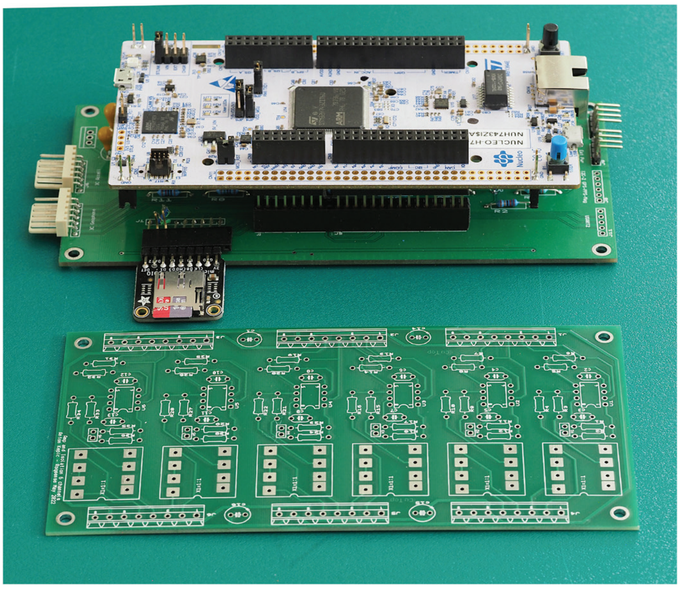

Figure 5. *Custom circuit design examples for add-on boards (the green PCB's) using free-to-use software. One board sits under a STM Nucleo H743 to provide analog signal conditioning before conversion plus host a microSD card for storing logged data. The other unpopulated board in the foreground is for six channels of very high gain (x100 or x1000) amplification and an audio transformer to galvanically isolate and voltage level shift the signals before analog conversion on the microcontroller. These PCBs were specifically designed for ease of hand-assembly with low-cost soldering tools.*

Designer software can be rented via subscription. It can cost less than $200 to manufacture ten PCBs in a few weeks, and then later have your concept and idea to be fully assembled and ready to test in less than two months.

Enabling attitudes

DIY geophysics also allows for a revolution in our learning. Constructing a measurement device and then using it appropriately to perform a test survey teaches many basic aspects of geophysics better than canned routines or recipe-like instructions for production equipment. In this era of learning at a distance, on-line learning (possibly with small groups exchanging ideas as in engineering teaching) but still having a hands-on kit-based approach would appear to offer the quality education that is assisted, yet self-directed. Many graduate students in other disciplines do not need expensive production geophysical survey equipment, they just need some basic measurements to assist their understanding. Fostering curiosity, whether it is for commercialisation, research, education, or simply self-directed learning, often leads to innovation and invention. I feel that current education systems do not cater for developing curiosity in professional degrees, and that limits the potential entrepreneur and innovator within all of us. Measurement with a DIY approach allows any of us to experiment and test new ideas, or ideas nearly forgotten but very worthy.

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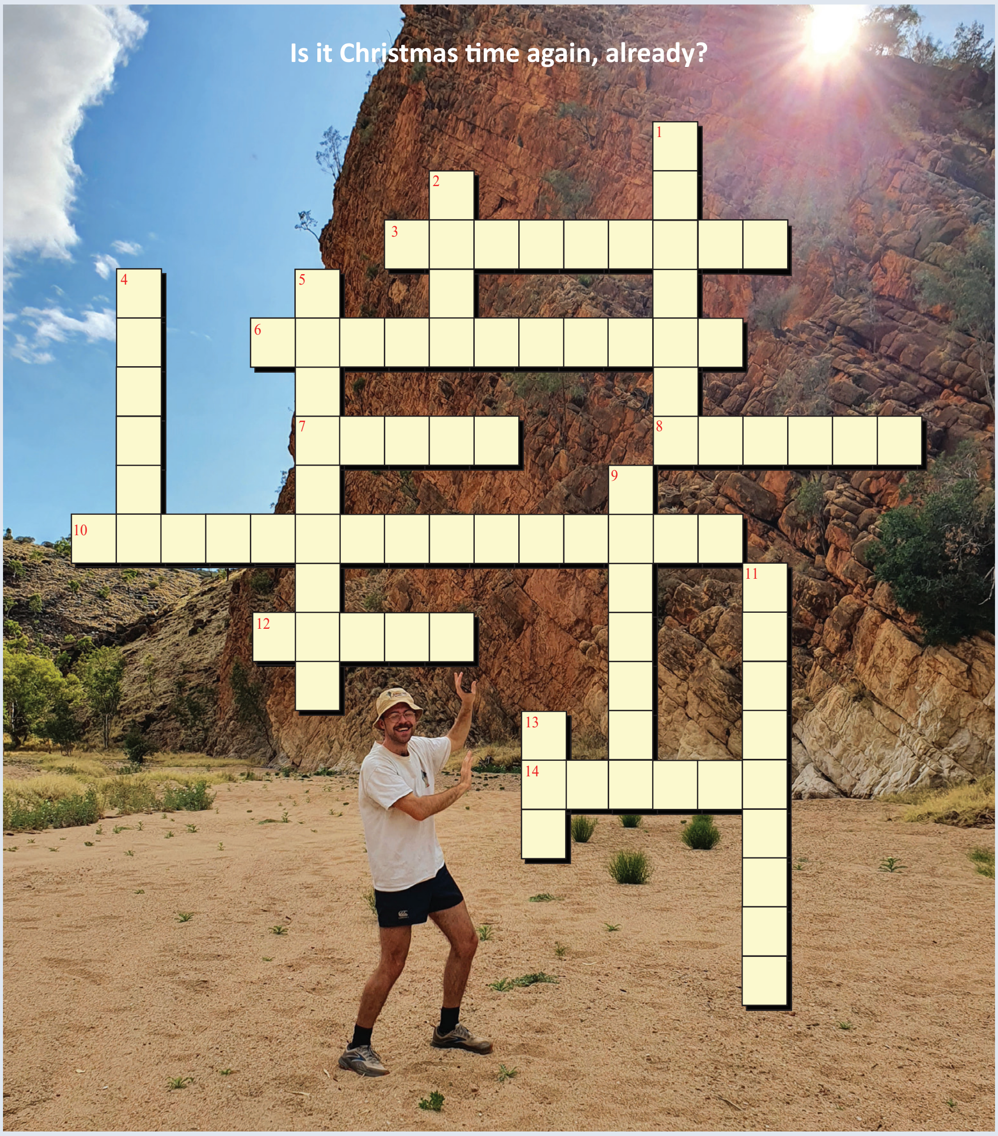
Preview crossword #23



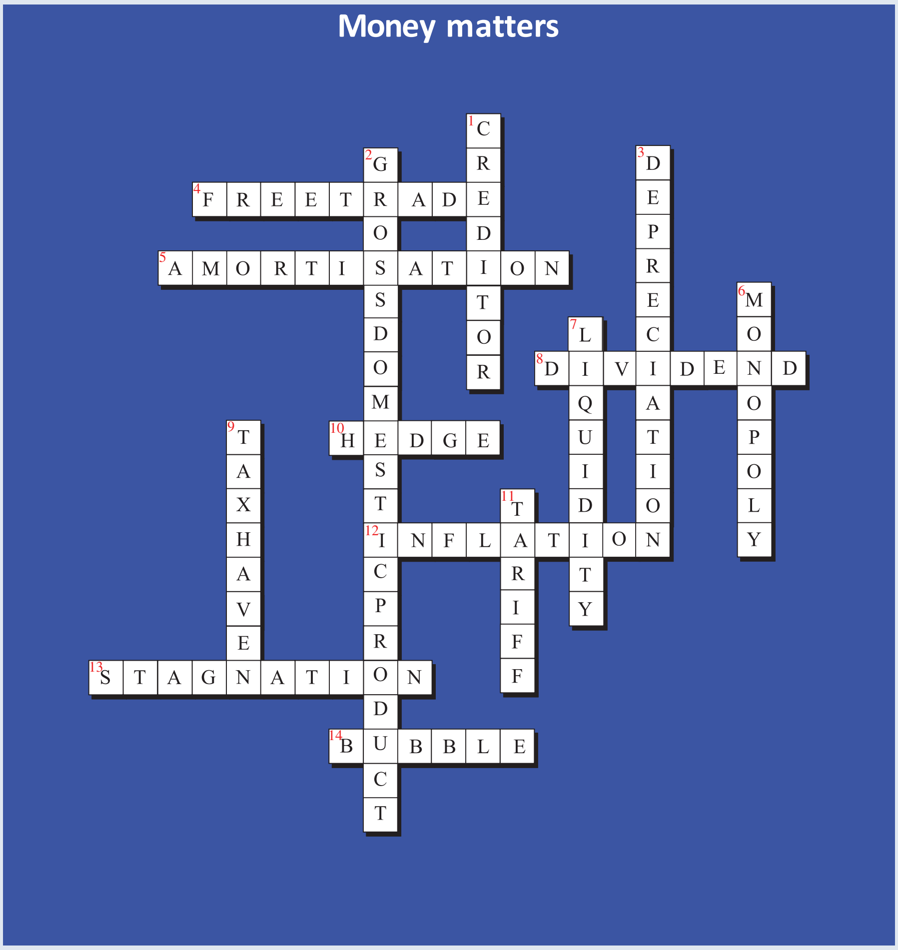
Across	Down
3 This day gets its name from all the money collected in church alms-boxes for the poor	**1** This reindeer made his debut in 1939 in a giveaway colouring book as part of a marketing gimmick
6 This was the first song played in space, which was written for Thanksgiving, not Christmas [6,5]	**2** The Latin word *natalis*, which means "day of birth," is the origin of this word
7 This cyclone devastated the city of Darwin on Christmas Day 1974	**4** The Medieval eggnog
8 The postcode of Santa's North Pole address (in Canada)	**5** *Viscum album* or 'dung on a twig' [6,3]
10 At 225 tonnes, this is the biggest Christmas gift in the world [6,2,7]	**9** This mythical beast is said to come around at Christmas time to punish naughty children
12 This military installation tracks Santa and provides his flight updates every year on Christmas Eve [Acronym]	**11** Christmas gifts are usually exchanged on New Year's Day in this country
14 Elf on the Shelf	**13** Turkey is near impossible to find in Japan, so most Japanese eat this as a traditional meal on Christmas Day [Acronym]

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. The answers will be published in the next edition of *Preview.*

Good luck!

Preview crossword #22 solution



Business directory

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Application for Active & Associate Membership 2022

INSTRUCTIONS FOR APPLICANTS

1. Determine the membership level you wish to apply for, according to the eligibility criteria outlined in Section 2.
2. Fill out the application form. Note that applicants for Active Membership must nominate a proposer and a seconder who are Active Members of ASEG. Under exceptional circumstances the Federal Executive Committee may waive these requirements.
3. Submit the two pages of your application to the Secretariat at the address shown on the top of this page, retaining a copy for your own records. The Secretariat will generate an invoice for payment that includes payment instructions.
The invoice will be sent electronically so please check your email inbox and spam folders.

Section 1. Personal identification

Surname | Date of Birth

Given Names | Mr / Mrs / Miss / Ms / Other (list)

Address

Country | State | Post Code

Organisation

E-mail

E-mail (alternate)

Mobile | Phone (W) | Phone (H)

Section 2. Choice of Membership grade (Active or Associate)

- ❑ Active — Please complete all sections
- ❑ Associate — Please complete all sections
- ❑ Graduate — Please complete Active or Associate application and also check this box
- Student — Please complete the separate Student Membership Application Form

Active – an applicant must be actively engaged in practising or teaching geophysics or a related scientific field. Conditions for Active Membership include a relevant academic qualification. Any person who does not have such qualifications, but who has been actively engaged in the relevant fields of interest of the Society for at least five years, shall also be eligible for Active Membership upon the discretion of the Federal Executive Committee.

Associate – an applicant must be actively interested in the objectives of the Society. Associate Members are automatically eligible for election to Active Membership after five years as an Associate Member.

Graduate – Active or Associate Membership is subsidised by 50% for no more than two years after completion of studies. Members accepting the graduate grant are expected to contribute to Society activities and publications with the goals of raising their profile in the Society and showing ASEG's support of young professionals.

Student – an applicant must be a full-time graduate or undergraduate student in good standing, registered at a recognised university or institute and working towards a degree in geophysics or a related field. Eligibility for Student Membership shall terminate at the close of the calendar year in which the Student Member ceases their graduate or undergraduate studies. The duration of a Student Membership is limited to five years.

Section 3. Academic and professional qualifications

Month/Year (From – To)	Organisation/Institution	Position/Degree (incl. Major)	Professional Record Only: Years of Independent Work

Section 4. Nominators (must be ACTIVE Members of ASEG)

Nominator	Name	Postal or e-mail address	Phone/Fax
Proposer			
Seconder			

Section 5. Membership of other societies

Australian:

❑ Aus IMM Grade ________ ❑ AIG Grade ________ ❑ GSA Grade ________ ❑ PESA Grade ________

International:

❑ AAPG Grade ________ ❑ EAGE Grade ________ ❑ SEG Grade ________ ❑ SPE Grade ________

❑ Others ____

Section 6. ASEG Member record

Include me in the ASEG Member Search on the Secure Member Area of ASEG's Website (search is only available to current ASEG Members who opt-in)

❑ **Yes** ❑ **No**

Please complete this section for the ASEG Membership database.

Employment area:

❑ Industry	❑ Contract/ Service Provider	❑ Government	❑ Student
❑ Education	❑ Consulting	❑ Other ________________	

Type of Business:

❑ Oil/ Gas	❑ Ground Water/ Environmental	❑ Coal	❑ Survey/ Geotechnical/ Engineering
❑ Minerals	❑ Petrophysics/ Log Analysis	❑ Research/ Education	❑ Data Acquisition
❑ Solid Earth Geophysics	❑ Archaeology/ Marine Salvaging	❑ Computer/ Data Processing	❑ Other________________

Section 7. Membership grades and rates

❑ Active/Associate (Australia) - $182.00	❑ Active/Associate 5 Year Membership (Australia) - $910.00
❑ Active/Associate (Group IV Countries) - $165.50	❑ Active/Associate 5 Year Membership (Group IV Countries) - $827.50
❑ Active/Associate (Group III Countries) - $49.70	❑ Active/Associate 5 Year Membership (Group III Countries) - $248.50
❑ Active/Associate (Group I & II Countries) - $18.20	❑ Active/Associate 5 Year Membership (Group I & II Countries) - $91.00
❑ Associate-Graduate (Australia) - $91.00	

Section 8. *Preview & Exploration Geophysics*

The ASEG produces a magazine called *Preview* and a peer-reviewed journal called *Exploration Geophysics*. Please read and agree to the following in order to receive ASEG publications:

1) I grant permission for the ASEG to provide my email and postal address to the Taylor & Francis Group so that I can receive copies of the ASEG publications. Taylor & Francis will not use the Member list for any purpose other than advertising and for distributing *Exploration Geophysics* and *Preview*.

2) I understand and agree that online access to *Exploration Geophysics* is for my private use and the articles shall not be made available to any other person, either as a loan or by sale, nor shall it be used to substitute for an existing or potential library or other subscription.

3) I understand and agree that *Exploration Geophysics* articles shall not be networked to any other site, nor posted to a library or public website, nor in any way used to substitute for an existing or potential library or other subscription.

4) I understand and agree that any Member who is discovered by the publisher to be in breach of these conditions shall have their subscription access immediately terminated, and the publisher shall have the right to pursue recompense at its discretion from that Member.

❑ **Yes** ❑ **No**

Section 9. Promotional opportunities

The ASEG provides opportunities for special category listings (eg. Consultants, Contractors) from the ASEG Internet Web Page.

❑ I (or my business) am interested in having a link from the ASEG Internet page. Rates will be advised when links are implemented. (Corporate and Corporate Plus Members get a complimentary link.)

❑ I (or my business) am interested in advertising in ASEG's publications.

Section 10. 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.

*Signature:*____________________________ *Date:*______________

ASEG CODE OF ETHICS

Clause 4 of the Articles of Association of the ASEG states that "Membership of any class shall be contingent upon conformance with the established principles of professional ethics":

1. A Member shall conduct all professional work in a spirit of fidelity towards clients and employees, fairness to employees, colleagues and contractors, and devotion to high ideals of personal integrity and professional responsibility.
2. A Member shall treat as confidential all knowledge of the business affairs, geophysical or geological information, or technical processes of employers when their interests require secrecy and not disclose such confidential information without the consent of the client or employer.
3. A Member shall inform a client or employer of any business connections, conflicts or interest, or affiliations, which might influence the Member's judgement or impair the disinterested quality of the Member's services.
4. A Member shall accept financial or other compensation for a particular service from one source only, except with the full knowledge and consent of all interested parties.
5. A Members shall refrain from associating with, or knowingly allow the use of his/her name, by an enterprise of questionable character.
6. A Member shall advertise only in a manner consistent with the dignity of the profession, refrain from using any improper or questionable methods of soliciting professional work, and decline to accept compensation for work secured by such improper or questionable methods.
7. A Member shall refrain from using unfair means to win professional advancement, and avoid injuring unfairly or maliciously, directly or indirectly, another geophysicist's professional reputation, business or chances of employment.
8. A Member shall give appropriate credit to any associate, subordinate or other person, who has contributed to work for which the Member is responsible or whose work is subject to review.
9. In any public written or verbal comment, a Member shall be careful to indicate whether the statements or assertions made therein represent facts, an opinion or a belief. In all such comments a Member shall act only with propriety in criticising the ability, opinion or integrity of another geophysicists, person or organisation.
10. A Member will endeavour to work continuously towards the improvement of his/her skills in geophysics and related disciplines, and share such knowledge with fellow geophysicists within the limitation of confidentiality.
11. A Member will cooperate in building the geophysical profession by the exchange of knowledge, information and experience with fellow geophysicists and with students, and also by contributions to the goals of professional and learned societies, schools of applied science, and the technical press.
12. A Member shall be interested in the welfare and safety of the general public, which may be affected by the work for which the Member is responsible, or which my result from decisions or recommendations made by the Member, and be ready to apply specialist knowledge, skill and training in the public behalf for the use and benefit of mankind.

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Email: secretary@aseg.org.au Website: www.aseg.org.au

Application for Student Membership 2022

INSTRUCTIONS FOR APPLICANTS

1. Student Membership is available to anyone who is a full-time student in good standing at a recognised university working towards a degree in geophysics or a related field.

   Eligibility for Student Membership shall terminate at the close of the calendar year in which the Student Member ceases their graduate or undergraduate studies.

   Student Membership must be renewed annually.

   The duration of a Student Membership is limited to five years.

2. Fill out the application form, ensuring that your supervisor signs Section 2.

3. Submit your application to the Secretariat at the address shown on the top of this page, retaining a copy for your own records.

Section 1. Personal details

Surname		Date of Birth
Given Names		Mr / Mrs / Miss / Ms / Other (list)
Address		
Country	State	Post Code
E-mail		
E-mail (non-University alternative)		
Mobile	Phone (W)	Phone (H)

Section 2. Student declaration

Institution	
Department	
Major Subject	Expected Year for completion of studies
Supervisor/Lecturer	Supervisor Signature

Section 3 Membership grades and rates

❑ Student (Australia & Group IV Countries)	FREE
❑ Student (Group III Countries)	FREE
❑ Student (Group I & II Countries)	FREE

Section 4 *Preview* & *Exploration Geophysics*

The ASEG produces a magazine called *Preview* and a peer-reviewed journal called *Exploration Geophysics.* Please read and agree to the following in order to receive ASEG publications:

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4) I understand and agree that any Member who is discovered by the publisher to be in breach of these conditions shall have their subscription access immediately terminated, and the publisher shall have the right to pursue recompense at its discretion from that Member.

❑ **Yes** ❑ **No**

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.

Signature: ____ Date: ____________________

ASEG CODE OF ETHICS

Clause 4 of the Articles of Association of the ASEG states that "Membership of any class shall be contingent upon conformance with the established principles of professional ethics":

1. A Member shall conduct all professional work in a spirit of fidelity towards clients and employees, fairness to employees, colleagues and contractors, and devotion to high ideals of personal integrity and professional responsibility.
2. A Member shall treat as confidential all knowledge of the business affairs, geophysical or geological information, or technical processes of employers when their interests require secrecy and not disclose such confidential information without the consent of the client or employer.
3. A Member shall inform a client or employer of any business connections, conflicts or interest, or affiliations, which might influence the Member's judgement or impair the disinterested quality of the Member's services.
4. A Member shall accept financial or other compensation for a particular service from one source only, except with the full knowledge and consent of all interested parties.
5. A Member shall refrain from associating with, or knowingly allow the use of his/her name, by an enterprise of questionable character.
6. A Member shall advertise only in a manner consistent with the dignity of the profession, refrain from using any improper or questionable methods of soliciting professional work, and decline to accept compensation for work secured by such improper or questionable methods.
7. A Member shall refrain from using unfair means to win professional advancement, and avoid injuring unfairly or maliciously, directly or indirectly, another geophysicist's professional reputation, business or chances of employment.
8. A Member shall give appropriate credit to any associate, subordinate or other person, who has contributed to work for which the Member is responsible or whose work is subject to review.
9. In any public written or verbal comment, a Member shall be careful to indicate whether the statements or assertions made therein represent facts, an opinion or a belief. In all such comments a Member shall act only with propriety in criticising the ability, opinion or integrity of another geophysicists, person or organisation.
10. A Member will endeavour to work continuously towards the improvement of his/her skills in geophysics and related disciplines, and share such knowledge with fellow geophysicists within the limitation of confidentiality.
11. A Member will cooperate in building the geophysical profession by the exchange of knowledge, information and experience with fellow geophysicists and with students, and also by contributions to the goals of professional and learned societies, schools of applied science, and the technical press.
12. A Member shall be interested in the welfare and safety of the general public, which may be affected by the work for which the Member is responsible, or which my result from decisions or recommendations made by the Member, and be ready to apply specialist knowledge, skill and training in the public behalf for the use and benefit of mankind.

November	**2022**		
28	SAGA 2022 https://m.facebook.com/events/sun-city-conference-centre/saga-2022-17th-biennial-conference-exhibition/1846354198894057/	Sun City	South Africa
28–29	Asia Petroleum Geoscience Conference and Exhibition (APGCE) https://icep.com.my/apgce	Kuala Lumpur	Malaysia
28–30	Sub 22 https://research.csiro.au/dei/sub22/	Adelaide	Australia
December	**2022**		
1	Geological Survey of South Australia Discovery Day www.energymining.sa.gov.au/discoveryday	Adeliade	Australia
2	South Australian Exploration and Mining Conference http://saemc.com.au/	Adelaide	Australia
6–8	Role of Geophysics in Carbon Capture and Sequestration https://seg.org/Events/Carbon-Capture-Sequestration	Al Khobar	Saudi Arabia
February	**2023**		
21–23	2nd AAPG/EAGE Papua New Guinea Petroleum Conference & Exhibition https://www.aapg.org/global/asiapacific/events/workshop/articleid/51699/1st-aapg-eage-png-petroleum-geoscience-conference-exhibition	Port Moresby	Papua New Guinea
March	**2023**		
1–3	The International Petroleum Technology Conference (IPTC) https://2023.iptcnet.org/	Bangkok	Thailand
6–9	Asia Pacific Meeting on Near Surface Geoscience & Engineering https://eage.eventsair.com/5th-asia-pacific-meeting-on-near-surface-geoscience-engineering/	Taipai	Taiwan
13–18	Australasian Exploration Geoscience Conference (AEGC 2023) https://2023.aegc.com.au/	Brisbane	Australia
20–22	EAGE Digitalization Conference and Exhibition https://eagedigital.org/	London	United Kingdom
May	**2023**		
2–5	Offshore Technology Conference 2023 https://2023.otcnet.org/welcome	Houston	USA
June	**2023**		
5–8	84th EAGE Annual Conference & Exhibition https://eageannual.org/	Vienna	Austria
August	**2023**		
27 Aug–02 Sep	International Meeting for Applied Geoscience & Energy (IMAGE) https://www.imageevent.org/	Houston	USA
September	**2023**		
4–8	8th International Airborne Electromagnetics Workshop (AEM 2023) aemconference@theassociationspecialists.com.au	Fitzroy Island	Australia
October	**2023**		
17–20	Seventh International Conference on Engineering Geophysics (ICEG)	Abu Dhabi	UAE

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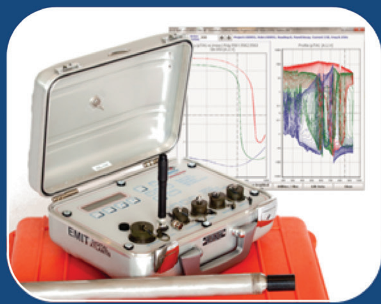

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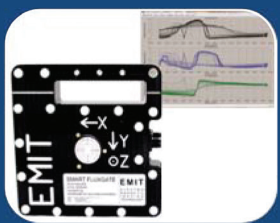

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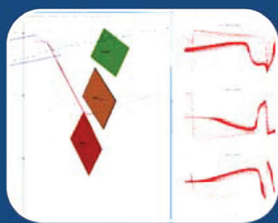

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