Australian Society of Exploration Geophysicists

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PREVIEW

NEWS AND COMMENTARY

FEATURES

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FRONT COVER

Dr Sandra Occhipinti from CSIRO with colleagues in the field. See *Education matters* in this issue for more information

Preview is available online at
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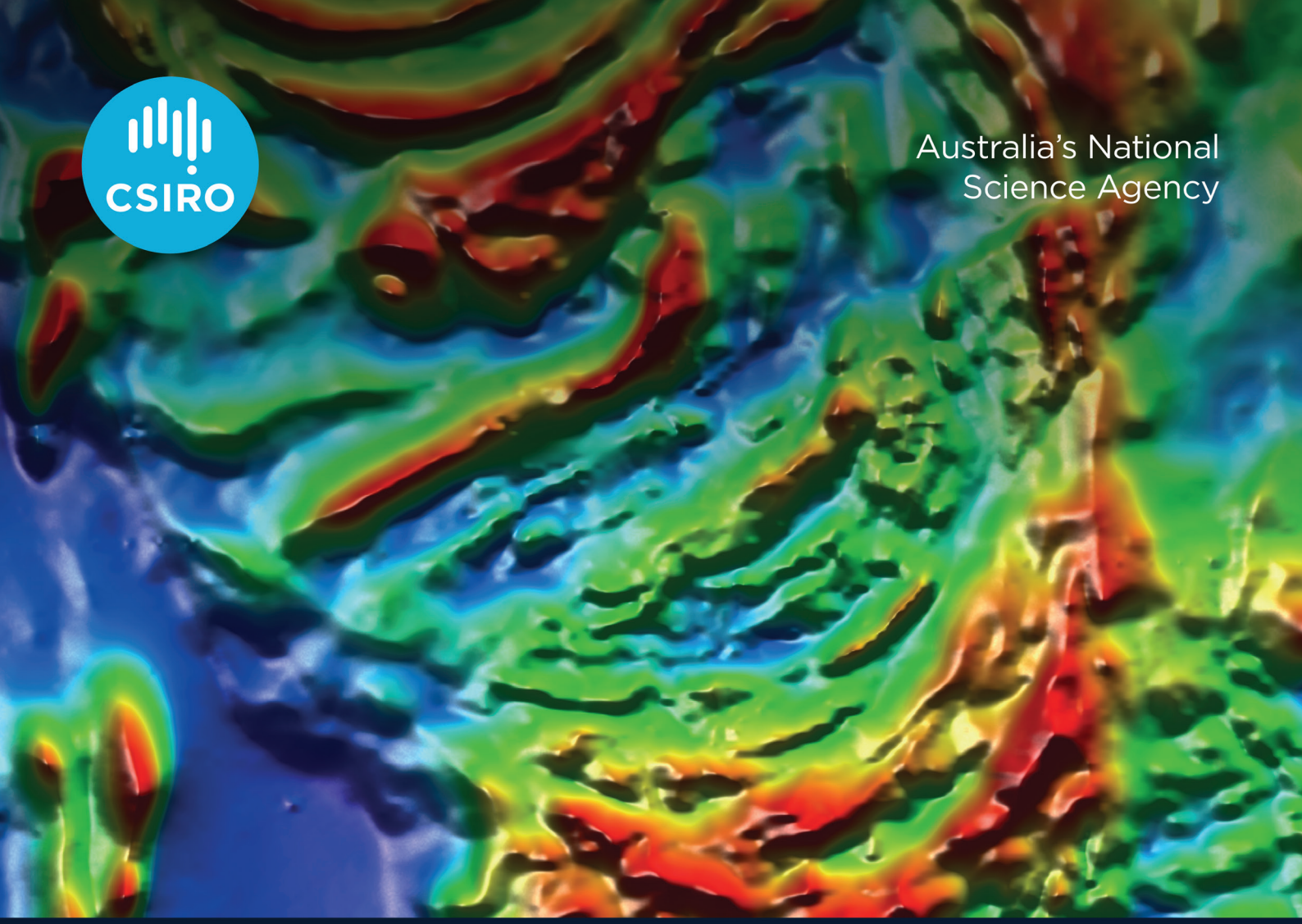

CSIRO

Australia's National Science Agency

Sub 22

From imaging structures to predicting processes

Our Deep Earth Imaging Future Science Platform presents Sub 22, an interdisciplinary subsurface conference.

The event will provide the geoscience community with:

- A platform to contribute, discuss and learn about the interdependence between the science pillars imaging, conceptualisation and prediction for the exploration, characterisation and management of energy, mineral and water resources.
- A forum for in-depth conversations about the transition from imaging structures to predicting processes and their outcomes, underway in the geosciences.

28–30 November 2022

The National Wine Centre of Australia, Adelaide

research.csiro.au/dei/sub22

B&M | 22-00094

Editor's desk

This issue of *Preview* features an article by Don Emerson on the conductivity of bornite, a copper-iron sulphide. Another go-to reference for anyone interested in copper exploration, and who isn't now that copper has been rebranded as a "New Economy" or "Green" mineral?

And speaking of new economies, Bhavik Harish Lodhia follows up on his mini feature in the last issue of *Preview* with an article on exploration for hydrogen – cutting edge stuff!

Whilst we are on the cutting edge (or is it the bleeding edge?) of the new economy, Tim Dean draws our attention to the looming shortage of geophysicists to support exploration, asking in his opinion piece "Is there a future for geophysics in Australia?".

In other news and commentary, David Denham (*Canberra observed*) takes a look at the Climate Change Bill that has just been passed by both Houses of Parliament. He also brings us up to speed on the latest government statistics on investment in exploration for minerals and petroleum. Marina Pervukhina (*Education matters*) interviews Sandra Occhipinti, Research Director in Mineral Resources Business Unit at CSIRO and Mike Hatch (*Environmental geophysics*) delivers the fifth and sixth episodes of Niels Christensen's adventures. Sadly, there is only one episode to go.

Terry Harvey (*Mineral geophysics*) fills us in on his recent experience with downhole geophysical logging. Mick Micenko (*Seismic window*) challenges readers with his interpretation of a subtle trap. Tim Keeping (*Data trends*) muses about the evolution of ASEG GDF3, and Ian James (*Webwaves*) reports on additions to the *Preview* digital library.

Finally, as a follow-up to the discussion about open access in the last *Editor's desk*, the White House Office of Science and Technology Policy (OSTP) has just announced a new policy designed to ensure that the results of all publicly funded scientific research in the US are freely available. All federal departments and agencies are required to fully implement updated publication policies, including ending optional 12-month embargos, no later than December 31, 2025. In the short-term, agencies are expected to work with the OSTP to update their public access and data sharing plans by mid-2023.

A space that bears watching!

Lisa Worrall
Preview Editor
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The Editor about to ski into a COVID storm - three days on the slopes followed by three weeks on the sick list.

Letter to the Editor

Dear Editor

I would like to congratulate David Dunkerley on his fascinating feature article entitled "Acoustic methods in geophysics - from the 19th century to contemporary developments", which was published in *Preview* **218**.

David explains, in this delightfully comprehensive paper, that acoustic geophysics is to do with many types of sound that can be audible, ultra-audible or sub-audible. The latter, called infrasound, is, however, more felt than heard.

To me the applications of infrasound that are described are the most interesting, including the network of monitoring stations around the world that detect nuclear detonations and locate their origin, and the use of fibre optic cables on the surface and sea floor to monitor volcanic eruptions and their precursors in a field known as "distributed acoustic sensing" (DAS).

Other uses of infrasound include early warning of the hazard of land slips (as happening more due to extreme weather) and dust storms. Although one might think the monitoring of dust storms would have no relevance, David refers to the evidence of such storms observed on Mars and thus how knowledge of their behaviour here will inform our understanding of surface conditions there.

The extensive reference list, some very recent, invites the reader to expand their knowledge of the many topics discussed. One concerns the volcanic eruption in Tonga in 15 January this year, and the mechanics of volcano behaviour is referenced in relation to the eruption in White Island, NZ in December 2019. Another reference is to a video showing fragments of rock thrown into the air during a rock-splitting event that makes a sound resembling gunfire. This is apparently what the explorer Charles Sturt was thought to have heard in remote inland Australia. Studies of such ultrasound behaviour allow for a better understanding of rock weathering.

The sound of volcanoes considered as musical instruments and such usage of the human ear to detect patterns in time-series data generally (by "sonification" and "audification") would appear to have a developing future. A reward for reading David's article is to learn how to convert your smartphone into an ultrasound recorder using apps such as RedVox and Raspberry Boom.

In summary, an excellent article that I would urge all Members to read.

Roger Henderson
rogah@tpg.com.au

President's piece

Emma Brand

Members and readers

It has been another massive couple of months at the ASEG with significant progress made towards the organisation of AEGC 2023, and the finalisation of the logistics and planning of the inaugural Camp for Applied Geophysics Excellence (CAGE). In fact, by the time this issue of *Preview* goes to print, that camp will have been completed and 25 students and young professionals will have gone back to their universities and workplaces with an increased exposure and understanding of geophysical techniques. This is a fantastic outcome for geophysics in Australia, and the sponsorship and support for this camp by the ASEG is fully aligned with our aim and objects as an organisation.

You may recall that when the FEDEX came together in early April this year, we agreed that one of our most important outcomes as a learned society was improving the use of geophysics and the recognition of its value. As I've mulled this outcome over the last several months, I've really come to believe that this is the modern articulation of our purpose as a Society. And what strikes me as critical to this purpose, isn't just the quality of the science, but the clear and useful articulation and communication of that science. Science communication is fraught with pitfalls and traps. We have the difficult task of telling compelling, simple stories about complex concepts, and flexing our science and language into a form that the general public can understand. We also have to increasingly combat narratives that exist on social media that range from misconceptions of science to outright lies. Fortunately, Australia is in a privileged position. A recent global survey by 3M, which was highlighted by Science and Technology Australia indicated that almost nine in ten Australians trust science and scientists, however a third of Australians trust social media as a source of truth for science facts. This highlights to me the critical role we must play communicating the value of science, and geophysics in particular, and engaging in the right platforms to connect with Australians.

This year we've made significant and strategic investments to more purposefully engage in supporting geoscience communication. We have sponsored the Earth Futures Festival and Exploration Radio. We've just signed off on providing a year's free access for all ASEG Members to Geologize. And as a member organisation of the AGC we'll be actively supporting the organisation of GeoSciEd X. These investments are intended to support organisations that are actively communicating geoscience issues to a broad audience, to provide access to communications upskilling for our Members, and to contribute to the discussion of geoscience education.

The sponsorships of Earth Futures Festival and Exploration Radio are fantastic opportunities for the ASEG to actively support organisations who want to elevate and tell compelling stories about the value of geoscience in our society. The Earth Futures Festival was established to raise international awareness of the role of Earth Sciences in our sustainable future. The Festival is a global collaboration to showcase how geoscience is addressing current sustainability challenges through media, with a key focus on education, diversity and inclusion. 972 submissions from 89 countries were submitted, and through September and into October the final programme will be screened in Paris, New York, Sydney and Online, or you can view the finalist films in the comfort of your own home!

Exploration Radio on the other hand is a podcast that tells stories of human endeavour, often in the context of exploration geoscience and was created by co-hosts Steve Beresford and Ahmad Saleem in 2017. One of my favourite episodes from 2021 features Pete Betts, from Monash University and President of the Geological Society of Australia, talking about rethinking our narrative in the earth sciences and how we must fundamentally change the way in which we communicate and position the value of geoscience in society.

I'm also really excited about our one-year engagement with Geologize, an organisation whose aim is to train a generation of geoscientists to communicate clearly, effectively and powerfully in a way that promotes real change in society. This engagement will provide an opportunity for all our Members to access for free the Geologize content and upskill across a range of geoscience communications topics, such as Practical geocommunication and Social media in the geosciences.

I'm also delighted to announce to our ASEG Members that the AGC were recently successful in their bid to host GeoSciEd X in Australia in 2026. GeoSciEd is a series of conferences held every four years by the International Geoscience Education Organisation (IGEO), where Earth science educators, researchers, and students from around the world gather in order to exchange pedagogical ideas and practical experiences in Earth science education in their own countries. This is a fantastic outcome for the AGC and Australia, and as a member organisation of the AGC we have the important opportunity to shape the conference with ASEG Members sitting on the Organising Committee.

Finally, on the topic of communications, I'd like to give a massive shout out to Mosayeb Khademi Zahedi and the ASEG Communications Committee, including Kate Brand, Lisa Worrall, Mikayla Sambrooks, Tom Zhao, Timothy Hill and Mark Duffett. The Committee has done a brilliant and proactive job in promoting AEGC 2023, CAGE, MAG22 and geophysics in general, with the purpose of informing current Members, and looking to attract potential members. The team are focussed on enhancing the reputation of the ASEG to the broader geoscience community in Australia and abroad and as a committee are passionate about supporting our Members.

As I close if you have any suggestions on how the ASEG can better communicate with our Members, with other geoscientists or the broader community, please reach out. 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 August and September 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 August 2022 was:

Year to date income: $218 772

Year to date expenditure: $232 235

Net assets: $1 012 669

Membership

As of 7 September 2022, the Society had 808 financial Members, compared to 822 at this time in 2021. The ASEG currently has eight Corporate Members, including two Corporate Plus Members. They are: Velseis, Total Seismic, Santos, Southern Geoscience Consultants, Transparent Earth Geophysics, DUG, GDD and HiSeis. A huge thanks to all our Corporate Members for your continued support into 2022. Don't forget to have a look for our Corporate Members on the contents page of *Preview* and to support them as much as you can. Our state branches have additional local sponsors. These sponsors are acknowledged at all branch meetings and at the beginning of all webinars.

We have started the membership renewal process for 2023. Please consider renewing your membership early to take advantage of the early-bird pricing. The early-bird price offers full year membership for less than the standard rate of membership in 2022, so it's well worth taking up this offer. The early-bird offer is valid for renewals paid by 30 November 2022. Five-year membership options are available to Active/Associate and Retired Members, who can also take advantage of the early-bird special prices. Early and mid-career members are also encouraged to join the ASEG Young Professionals Network at www.aseg.or.au/about-aseg/aseg-youngprofessionals.

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

The SA/NT Branch has been busy tasting wines ahead of the wine offer later in the year. As usual some cracking wines have been selected to be offered to the ASEG membership. Notification of orders will be sent out soon, get your orders in early so you don't miss out.

Events

It's great to see the state branches are increasing their face-to-face events. Keep a look out for notifications from your state branches to see what is coming, and get out there and reconnect with your colleagues. The ASEG will also continue with the webinar series with some interesting talks in the pipeline. The webinars are coordinated and run at both state and federal level. Sessions are all recorded and available for viewing at the ASEG website or on our YouTube Channel.

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.

Leslie Atkinson
ASEG Secretary
fedsec@aseg.org.au

Welcome to new Members

The ASEG extends a warm welcome to nine new Members approved by the Federal Executive at its August and September meetings (see table).

First name	Last name	Organisation	State	Country	Membership type
Emad	Al-Hemyari	Curtin University	WA	Australia	Student
Karen	Aurisch		Qld	Australia	Active
Roger	Edgecombe	RPS Energy Pty	WA	Australia	Active
Florian	Forster		VIC	Australia	Graduate
Timothy	Huxley	University of Queensland	Qld	Australia	Student
Jyoti	Malik	GeoSoftware	WA	Australia	Active
Harikrishnan	Nalinakumar	University of New South Wales	NSW	Australia	Student
Sarath	Patabendigedara	CSIRO	NSW	Australia	Active
Hernan	Rivas	Teck Resource Chile	Chile	Chile	Active

ASEG Honours and Awards: Nominations for 2023 closing soon

All ASEG Members are advised that nominations will be closing soon for the next series of ASEG Awards, which are scheduled to be presented in conjunction with AEGC 2023 to be held in Brisbane between the 13 and 18 March 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 of benefit to Australian exploration geophysics in the field of instrumentation, data acquisition, interpretation or theory. The nominee does not need to be a Member of the ASEG.

Lindsay Ingall Memorial Award - for the promotion of geophysics to the wider community, including geologists, geochemists, engineers, managers, politicians, the media or the general public. The nominee does not need to be a geophysicist nor a Member of the ASEG.

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

ASEG Service Awards - for distinguished service by a Member to the ASEG, through involvement in and contribution to State Branch committees, Federal Committees, Publications, or Conferences over many years.

Nomination Procedure

Any Member of the Society may submit nominations for candidates meeting the criteria for the above awards. Details of all award criteria and nomination guidelines can be found on the ASEG website at https://www.aseg.org.au/about-aseg/honours-awards.

Proforma nomination forms are also available by contacting the Committee Chair. Nominations including digital copies of all relevant supporting documentation are to be sent electronically to the Chair ASEG Honours and Awards Committee via email awards@aseg.org.au.

ASEG branch news

Victoria

"How does it even snow in Australia?", was the first of several bombastic questions tossed my way from our first international guest presenter at a technical meeting night for 2022. "I mean, the Grand Canyon is higher than any point in Australia by about 1500 feet and then even that has a hole a mile deep in it!", exclaimed **Jeff Thurston**, geophysics consultant and native of Calgary in Alberta, Canada - home of the 1988 Winter Olympics. One point to Jeff, zero to me.

"You know, most of Canada is at such a high geomagnetic latitude that we don't have to worry about magnetic asymmetry. No one in Canada performs reduction-to-pole transformations." Two points to Jeff, zero to me.

I was taken aback after Captain Obvious stated some unremarkable differences between Australia and North America. I seriously thought, where is all this going and how badly will it end for me tonight?

"I've tried your bundy and coke and it's ghastly. It's nowhere near the same level as Canadian Club and dry." I had to give him the point on this one despite the non-comparison between rum and whisky. No one in their right mind would drink Bundy and coke unless you are a Queenslander, or it's being provided free of charge, or both. No one…right? Three points to Jeff, still zero to me.

I stood there like a stunned mullet. I had to fire one back, so I childishly shouted, "Well, at least we aren't infatuated with buying milk that comes in a bag, bladder, pouch or whatever you call it. What's up with that, huh?". "Well," Jeff responded, "they're much lighter than cartons or jugs, cheaper to manufacture and you can store them more neatly in the fridge." "But the use of plastics is not environmentally friendly!" I retorted. He simply shrugged his shoulders. Canadians have some weird perverse logic here. Four points to Jeff, one point to me.

On this particular night, I unwittingly found myself in what seemed to be an unwinnable debate. I quietly plotted my revenge during the networking drinks session before his talk. The night in question was August 16 where a large contingent of Victoria Branch members warmly welcomed Jeff Thurston to The Kelvin Club to hear Mr Canada himself deliver a presentation on a sensational topic, "New developments with your existing potential fields datasets: High-order derivatives and extended downward continuation".

Jeff left us in awe as he effortlessly waved his magical wand to show us how he used complex number theory to help stabilise high-order derivatives of potential field data. A simple image comparison between industry-established 2nd, 3rd and even 4th order derivatives against his new computations was almost scandalous. Jeff then really showed us his swagger by demonstrating with ease the application of this new method to disentangling an age-old problem – downward continuation of potential field. His colourful examples exhibited high-fidelity and low distortions that seemed to preserve broad bandwidth signals more readily. Jeff's images teased out more consistent and reliable features when compared to the fuzzy retail tech we are all currently using. Jeff, 500 points. Me, a measly one.

I never thought I'd see the day. A Canadian. Telling me to how to squeeze more out of my geophysics. Smarter. With nothing left in my rebuttal fuel tank, I was left with no choice but to concede utter defeat that night. For the first time in a long time, I felt broken.

On the last day of winter, ASEG Victoria joined forces with PESA and SPE societies to host the annual Winter Social absurdly for the first time since 2019. The event was held at the onomatopoeia BangPop restaurant along the Yarra River at South Wharf. The weather was surprisingly rather mild that night, which might go to half explaining the copious amounts of alcohol consumed during the evening. The turnout from ASEG Members this year was fantastic and everyone I managed to speak to thoroughly enjoyed themselves, which came as no surprise. If you only had to pay $10 in exchange for drinking ~$100 worth of alcohol, you'd surely enjoy it too! I had to personally drink an extra $300 worth of alcohol for the three (3) people that registered but never showed up. My liver thanks you. I won't name any names, but you know who you are. Our readers don't so I'll just quote some initials – GI, MS, FA 😂

I am pleased to announce there will be another international guest presenter later in the year at an as yet unscheduled future technical meeting night. Alas, it will be another North American! For better or for worse, I've recently started drinking milk from a bag to change my life perspective 😁

Jeff Thurston presenting to the ASEG Victoria Branch

Thong Huynh
vicpresident@aseg.org.au

ASEG Victoria Branch members at the ASEG/PESA/SPE Winter Social night

Western Australia

It has been quiet in WA since the last *Preview* edition, with somewhat of a hiatus in ASEG branch events, both technical and social. The state branch committee, however, has been working busily behind the scenes to organise a range of activities for the last few months of the year. This includes a visit from international guest speaker **Ken Witherly**, and our flagship technical symposium; MAG22. I'm happy to announce that the MAG22 registrations are now open, with the event to be held at the state reception centre at Frasers Kings Park.

An important part of ASEG's activities is the promotion of geophysics to students. At the local branch level, we have the opportunity to do this at career events for high school and tertiary students. On July 19 we were invited to take part in the Hale School and St Marys Careers Fair. This event was held at Hale, and was attended by high school senior students and their parents. ASEG was represented by myself and **JJ Leong**, and we manned a booth stacked with brochures, photos, core samples and petrophysical instruments!

There is currently a lot of discussion about the "student problem" in geophysics, with difficulties in attracting students resulting in insufficient qualified graduates to meet industry requirements. The reasons become starkly evident at events like this, where we are competing for attention against well-resourced groups with flashy booths (looking at you – BHP). It is obvious during discussions that there is a very low level of awareness of geophysics amongst the community. The entry bar is set quite high academically for a lot of students, and the study path is convoluted, particularly for West Aussies.

For the parents that attend – the main questions they have are around stability of work in the industry. On this point we have to be honest about the ups and downs of the resource sector, but there is a good story to tell about the search for new resources (battery materials, anyone?) presaging ongoing demand for geophysics. I have been asked many times by parents about how my own career has panned out. Fortunately, I'm able to reflect positively on my career and describe a few highlights.

The students that visit the booth are usually brutally honest in their assessments; happy to tell you that geophysics seems "boring" or "nerdy", or mostly that its "just not for them". Sometimes the parents look interested in the booth but the kids just roll their eyes and walk off! Geophysics is only ever going to appeal to a small minority. However, there are a handful of students at every career event who respond really enthusiastically. The large colour photos of field work (from the ASEG photo competitions) quite often make people walking past the booth stop in their tracks. Combining professional work with travel and the outdoors is a huge drawcard for the young explorers out there. It's also common to speak with students who love physics, but weren't aware of any practical career applications until they saw our booth. Having a conversation with someone who has just heard about geophysics for the first time is such an encouragement, and this is what makes the hard work of attending these events worthwhile.

At the end of the night, we had given away every single ASEG brochure from a huge stack that we brought with us, as well as all the merchandise (hats, mugs) left over from previous industry events. We left in the knowledge that we had at least increased the awareness of geophysics to a small extent.

I love taking part in these career functions, it gives me a huge sense of pride in representing ASEG to the next generation of students. My hope is that one day some of the young people we have chatted to at these events will one day be working alongside us in geophysics. I can recommend getting involved in career nights with your local branch, it is a very rewarding way to contribute to the future of geophysics, and I guarantee it will give you a new perspective on the industry in which you have chosen to make your own career.

Darren Hunt
wapresident@aseg.org.au

Australian Capital Territory

Spring has arrived and the days are getting longer and warmer. The ACT Branch took advantage of the situation by holding the postponed joint networking event with Geological Society of Australia ACT's chapter on September 14. The event gave Members of both associations a chance to socialise with their colleagues after a very cold couple of months.

Several Members are assisting with ASEG's Camp for Applied Geophysics Excellence (CAGE), including presentations showcasing outcomes of the various techniques utilised throughout Australia. The camp is being run near Adelaide under the auspices of the ASEG Professional Development Chair **Kate Brand**, who is partnering with AuScope. The participants will gain valuable insights and skills to carry into their careers.

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

There was a change to our usual routine for July, we had a joint meeting with the Sydney Minerals Discussion Group (SMEDG) where **Steve Collins** (Arctan Geophysics) presented a talk entitled "A completely different geophysical way to explore for sulphides. Heterodyne method - latest progress and field results". For a good summary, go through the abstract that Steve provided – it's an enjoyable read. But here is also a brief overview; the heterodyne method is how semiconductors are detected and can be used to distinguish between sulphides and graphite. This project follows up on work completed by **Bob White** almost 50 years ago, and was largely supported and funded by Fender Geophysics. The method was tested at Argent Minerals' Kemfield deposit and it looked like an induced polarisation survey was measuring a different physical property. A few field trips and workarounds later, Steve was tentatively optimistic of the method whereby it responded to sulphides but could not differentiate black shales. The talk was very engaging and thoroughly enjoyed by both the SMEDG and ASEG cohort.

In August **Cameron Fink** from Bridgeport Energy presented "Quantum gravity; a new way of looking at the subsurface". The last sentence of Cam's abstract enticed much of the audience "may be replacing seismic altogether…?!", Cam outlined how Bridgeport is working with a small start-up company based in Singapore; Atomionics, to conduct a gravimeter survey over some permits in the Cooper-Eromanga Basin in the latter half of this year. Recent developments in technology have permitted advances in cold atom interferometry where sensors are now 1000 times more sensitive than prior gravimeters. At a fraction of the cost compared to seismics, the quantum gravimeter method is environmentally friendly, is conducted with light vehicles, and there will be continuous sampling. Cam's talk was very interesting and generated much discussion that was continued at the bar, stay tuned for part two!

Both F**ender Geophysics** and **Bridgeport Energy** sponsored the entirety of the July and August meetings (respectively), if you are interested in sponsoring a Branch meeting, please contact the NSW committee.

An invitation to attend NSW Branch meetings is extended to all interstate and international visitors who happen to be in town at the time. Most talks are livestreamed on zoom and uploaded to ASEG's YouTube page later, so you also have the option to join us online. 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. All are welcome.

Steve Collins presenting to the SMEDG and ASEG audience in NSW.

Steph presenting a token of thanks to Cam Fink.

Stephanie Kovach
nswpresident@aseg.org.au

Queensland

Recently the Queensland Branch had a few technical talk cancellations, so in their place we held events with a more social slant. Our Zoeppritz social night was held on 22 July, together with Brisbane Brews in collaboration with the AIG. The cold and wintery night (by Brisbane standards) didn't keep people away, and we visited several spots in the Valley for drinks and conversation.

On 18 August we were proud to join other societies, including the AIG, PESA and SEG, in sponsoring a students and industry Q&A Panel Night: Machine learning, carbon capture & future energies.

We welcomed 40 people, with a diverse mix of students, early, mid and later career attendees and four panellists. The four panellists were **Russ Eley** of Rio Tinto Exploration, **Kane Maxwell** of Matrix Geoscience, **Candice Bell** of KPMG and **Jess Godfrey** from Origin.

Discussion focussed on how geophysicists and geologists in the oil, gas and minerals exploration industries can drive the transition to a lower carbon economy. Data science and analytics played a large part in the discussions, including what skills are required of future industry professionals. The Queensland ASEG would like to thank all the panellists for their input to a successful and thought-provoking night.

As usual, the Queensland committee are working hard to get some technical talks

The Q&A session at the Qld ASEG/AIG/PESA/SEG students and industry night

locked in for the end of the year, as well as a date for our joint Christmas and end of year event. We look forward to welcoming **Ken Witherly** to Queensland in November, and an event notification will be sent out well in advance of any upcoming events.

James Alderman
qldpresident@aseg.org.au

South Australia and Northern Territory

Following a quiet couple of months, the SA/NT Branch has been back in action. On 9 September we held the annual ASEG wine tasting event, which was a great success. The event was well attended, even playing host to some impromptu geophysical discussions between drinks. Following an exhaustive sampling process, the three winners were chosen via a vote. Ordering details will be emailed out soon, so keep an eye on your inbox.

The committee has also been busy organising the annual SA/NT Branch Melbourne Cup event to be held on 1 November. This is always a fantastic social event allowing our Members and sponsors to release their inner competitive streak. You'll hear more about this by email as we formalise details.

And 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 **SA Department for Energy and Mining**, **Zonge**, **Santos** and **Heathgate**.

Paul Soeffky
sa-ntpresident@aseg.org.au

Networking at the Qld ASEG/AIG/PESA/SEG students and industry night.

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

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.					
01 Nov	SA/NT	Cup lunch	TBA	1200	Cumberland Room, Cumby, Adelaide
08 Nov	Qld	Tech night	Gerrit Olivier	TBA	TBA
09 Nov	WA	MAG22	Various	0800	Frasers Kings Park, Perth
11 Nov	WA	YPN (ASEG/PESA/SPE)	TBA	1700	Shoe Bar, Perth
21 Nov	Qld	Tech night	Ken Witherley	1200	Cumberland Room, Cumby, Adelaide
23 Nov	Vic	Tech night	TBA	1800	The Kelvin Club, Melbourne
24 Nov	Qld	Christmas drinks	TBA	1730	Port office, Brisbane
25 Nov	Tech night	Ken Witherley		1700	Celtic Club, Perth
30 Nov	WA	2022 AGM	TBA	1730	Shoe Bar, Perth
07 Dec	NSW	Annual dinner	TBA	1800	TBA

SEE YOU IN *Brisbane*

AEGC 2023

The Australian Exploration Geoscience Conference will be returning to Brisbane Convention and Exhibition Centre.

Date

13 - 18 March 2023

Venue

Brisbane Convention and Exhibition Centre

Co-Chairs

- Megan Nightingale
- Bill Reid

S3, The Precinct 12 Browning Street
West End, QLD 4101, Australia

aegc@arinex.com.au
2023.aegc.com.au

AEGC
Australasian Exploration Geoscience Conference

#17SAGA2022

South African Geophysical Association's 17th Biennial Conference & Exhibition

The Conference's Organising Committee invites the ASEG to the 17th Biennial SAGA Conference & Exhibition to be held within Sun City from the 28th of November to the 1st of December 2022. With the world recovering from the Covid-19 health and economic crisis, "RECONNECT. REIMAGINE" has been chosen as the event's theme. Not only did pandemic-related lock downs disrupt most global economies, they also accelerated deep change in supply chains to key global sectors such as mineral exploration, mining, energy, environment, and technology. Whilst hybrid events have become more common, in-person collaboration, whilst observing sensible safety measures, remains the preferred medium.

The theme of "reconnect. reimagine geophysical collaboration for growth" broadly aims to promote new thinking, innovation and expansion to collaborate more closely with other disciplines. Authors will challenge conventional solutions and showcase cutting-edge methods and applications which can bring about effective solutions for the future. After a long hiatus between meetings, we encourage exciting projects submissions that will inspire new synergies and unlock sustainable solutions for future generations.

SAGA 2022 presents a unique opportunity to reconnect across the industry to discover as well as share emerging technologies and research discoveries with one of the world's leading assemblies of geoscientists, young professionals, decision makers, and technical experts.

Our venue, Sun City, is located along the border of the Pilanesberg National Park, in the North West Province of South Africa – a premier conference venue with all that Africa has to offer. Conveniently situated just 2 ½ hours' drive from Johannesburg's OR Tambo International Airport, it provides a serene atmosphere and contemporary style to the 17th Conference & Exhibition.

Here's what delegates have to say, "…I have attended a great number of conferences over the last few years …SAGA always rates on top with its organisation, technical content and social aspects. Well done.", and "…the SAGA format is such that there are lots of opportunities to actually sit down and talk with people".

The technical sessions span all aspects of exploration, mining and engineering geophysics and are an ideal platform to engage directly with colleagues, clients and industry experts to develop thinking, share knowledge and showcase one's brand.

reconnect . reimagine

geophysical collaboration for growth

With more than just a technical conferencing programme, additional options for continuous professional development in the form of CPD workshops and both technical and recreational field trips are available. Realise value in sharing knowledge with the global community, secure your workshop opportunities at #17SAGA2022, space is limited for 28 November so book your place now. Keep a look out for workshop registration options on the event website.

An integral component of the event is the exhibition & trade show which has steadily grown at each event – this year's venue provides world class facilities allowing both exhibitors and delegates to interact in style. Hosted on the doorstep of the largest mineralised and mined province in the world, the show provides a one stop shop for all the best geophysical products and professional services drawn from across the globe – exploration and mining, geology and engineering professionals cannot afford to miss out.

One needs no further incentive to participate, however once again SAGA is honoured and grateful to First Quantum Minerals Ltd for their continued sponsorship of our Conference awards. For the fourth conference running, FQML sponsor four 1/10th ounce Krugerrands for the best paper & poster in both professional as well as student categories.

Themes and topics include, but are not limited to, the following:

ENERGY:

- Hydrocarbon exploration
- Geothermal exploration
- Coal exploration
- Renewable energy, helium & hydrogen gas exploration

MINERAL EXPLORATION & MINING:

- Mineral exploration & mining
- Rock physics & physical properties
- Geotechnical assessment

ENGINEERING & ENVIRONMENTAL GEOPHYSICS:

- Near-surface geophysics
- Environmental, anthropogenic, seismic & geohazard
- Engineering, infrastructure planning & monitoring
- Groundwater exploration & management
- Geophysical studies for CO_2 & waste storage

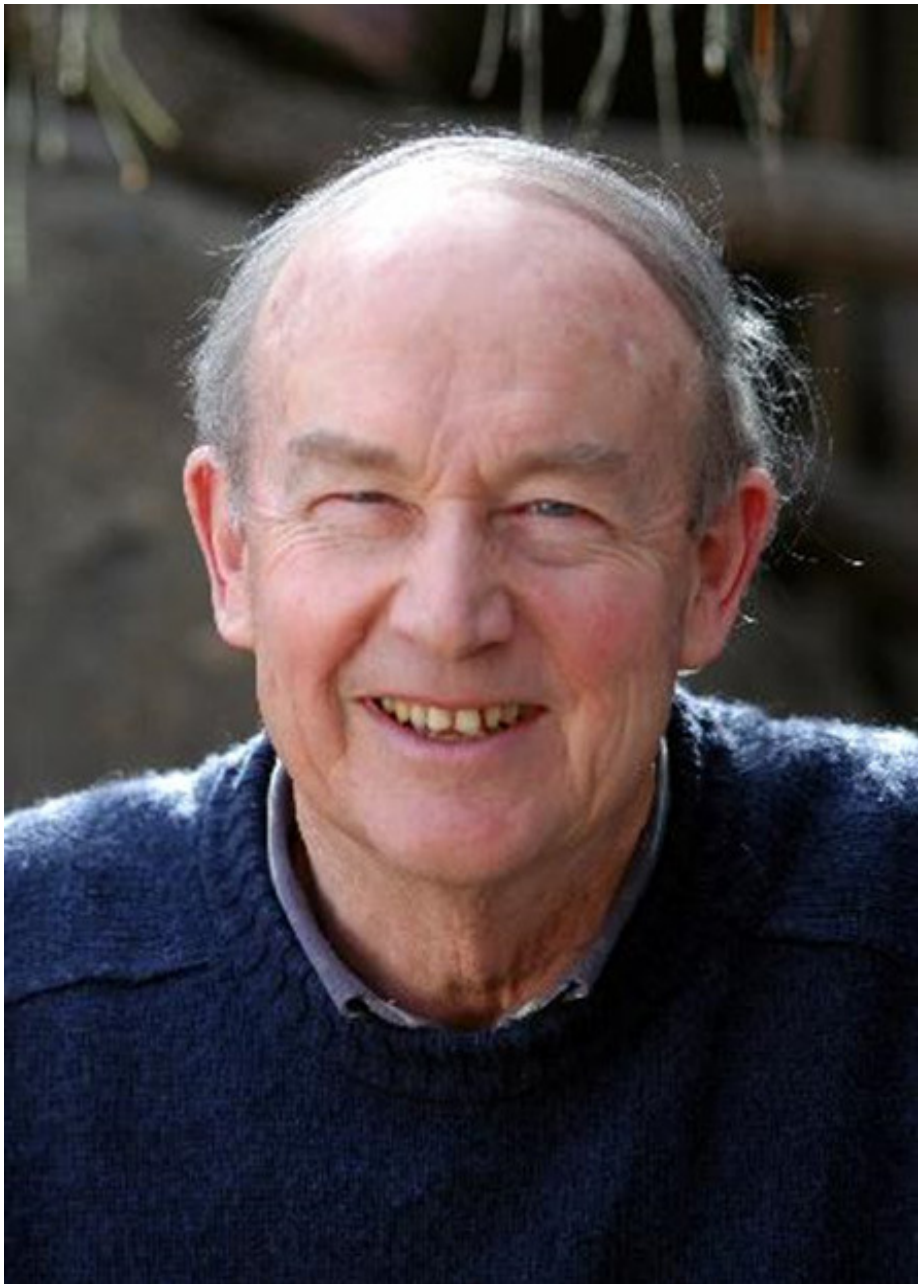
GEOLOGY:

- Depositional systems
- Plate tectonics & structural geology
- Mineral systems
- Petroleum systems
- Petrophysics

GENERAL:

- Data science, data integration, machine learning & AI
- Earthquake & mine seismology
- Forensic geophysics / geosciences
- Archaeo-geophysics
- New developments & approaches in geophysics
- Palaeomagnetism
- Geomechanics & pore pressure
- 3D modelling & visualization
- Safety & standards

Vale: Frederick Edward Mulhearin (Ted) Lilley (1940 – 2022)



Ted Lilley

F.E.M. (Ted) Lilley, a pioneer of electromagnetic induction studies in Australia, passed away on 4 July 2022 in Canberra following some years living with cancer. Ted's life-long study of geomagnetic-field changes with time and space helped build a new understanding of the electrical structure of the Australian continent, and fuelled his wonder at being able to measure geophysical processes in the Earth.

Ted was born in Tasmania. After graduating from Hutchins School in Hobart he won an Australian Atomic Energy Commission cadetship to undertake a BSc (Honours) degree at the University of Sydney between 1957 and 1960.

Upon graduation, Ted joined the Bureau of Mineral Resources (BMR) Airborne Group in Melbourne. The Group was then pioneering airborne magnetic-field measurements in Australia using a World War II-era DC3 aircraft (VH–MIN) and an AN/ASQ–8 fluxgate magnetometer originally developed for maritime patrol and submarine detection applications. Ted led field testing of newer, lighter BMR-designed MNZ1 proton-precession magnetometers in a smaller, more-manoeuvrable Cessna 180–B aircraft (VH–GEO).

In the early 1960s Ted began an MSc and PhD program at the University of Western Ontario. Here he initially continued working in aeromagnetics, investigating the practical problem of how flight direction affected the detection of magnetic anomalies on the ground. His later doctoral research, on "Magnetoelastic effects in a non-uniform field", investigated how seismic waves travelling through Earth's core would be affected by the intense and highly non-uniform magnetic fields present in the core. This interest in core studies was further fuelled by Sir Edward Bullard during postdoctoral research at the University of Cambridge. Here his investigation of models of fluid flow in Earth's core required the use of the recently built IBM 360/model 91 computer at the NASA Goddard Space Flight Center, at that time the most powerful in operation.

Ted returned to Australia in 1968 to take up a research position in the Australian National University (ANU) Department of Geophysics and Geochemistry. Established by John Conrad Jaeger in 1952, the Department became the Research School of Earth Sciences (RSES) in 1973 with Anton Hales its first Director. Some of the buildings used to house the new Research School included weatherboard-style buildings from the old Canberra Hospital that originally occupied that part of the ANU campus. For the latter part of Ted's tenure at RSES, he and his students occupied what was once a maternity ward of the old hospital. While at RSES, Ted delivered ten PhD graduates and three Honours graduates.

His research there studied the electrical structure of the Australian continent. Initially Ted and his first students used instruments they had built themselves, and then a sabbatical by Ian Gough from the University of Alberta gave access to a pool of 25 instruments, which he later encouraged RSES to copy. These magnetometers recorded magnetic-field variations at field sites for weeks or months at a time. After a survey, each instrument had metres of photographic film that needed to be developed, measured and transcribed to useful numbers for analysis. Ted's Research Assistant Merren Sloane managed this process meticulously.

Ted and his early students, Hans Tammemagi, Dave Bennett and Dennis Woods, deployed arrays of these

instruments in central and southern Australia. They collected magnetic-field data across the south of the Northern Territory and western Queensland, extending to much of South Australia, western and southern New South Wales, all of Victoria, and northern Tasmania. These studies found large electrical conductivity anomalies in the Flinders Ranges of South Australia, the Eromanga Basin in southwest Queensland and the Otway Ranges of southern Victoria. They also found evidence of the "coast effect" in which magnetic-field changes are affected by the strong contrast in electrical conductivity between the continent and the ocean.

In the early 1980s Ted, BP Singh, Baldev Arora and other Indian collaborators used the ANU magnetometers to investigate electrical conductivity anomalies in India. This work identified a major conductor running from the Himalayan foothills southwest towards Delhi, and another running between the southern coast of India and Sri Lanka. Ted always remembered fondly the wonderful hospitality he enjoyed in India, and the chai breaks on trips through the mountains.

The 1980s also brought new students - Ian Ferguson, Nathan Bindoff, Richard Kellett and Graham Heinson. With them, and in collaboration with Jean Filloux from Scripps Institution of Oceanography, Phil Mulhearn from the Royal Australian Navy Research Laboratory, and Tony White from Flinders University, Ted's research began to focus more offshore. Seafloor instruments were deployed off the New South Wales coast using the naval oceanographic vessel *HMAS Cook*, the CSIRO research vessel *RV Franklin*, and a lobster fishing boat out of Ulladulla. They provided the opportunity to study the electrical conductivity of oceanic crust, the electrical and pressure signatures of ocean tides and currents, and the "coast effect" from the ocean side. These new data permitted the first computer models of the electrical structure of the Tasman Sea to be developed using the "thin-sheet" modelling method developed by John Weaver's group at the University of Victoria, British Columbia.

Into the 1990s, with his final students Robert Corkery, Liejun Wang and Adrian Hitchman, Ted's research began to bring together some of his work of the past two decades. Rob and Liejun worked with Ted to amalgamate data from all the Australian array studies, including by Francois Chamalaun, Charlie Barton, Tony White and Peter Milligan, to build the first conductivity model of the entire continent. With Adrian, Ted investigated how all this electrical structure might affect aeromagnetic survey data.

Through the 2000s, Ted worked with John Weaver on the inventive use of Mohr circles in the analysis of magnetotelluric data, and authored book chapters, review papers, and, increasingly, articles about boats and yachting – a lifelong passion.

Ted and Penny, his wife and steadfast supporter of 59 years, built a loving, nurturing family life in the Canberra suburb of Aranda with their children Matthew, Jo and Jim. Together they were valued members of their neighbourhood, suburb, school and church communities. Their home was renowned for its warm hospitality, for over 50 years welcoming many visitors, new arrivals to the city, academics and students.

Ted considered himself very fortunate in the colleagues with whom he shared the pleasures and satisfaction of making geophysical studies in Australia, once observing that science is best when it is done with one's friends. Ted's colleagues describe him as famously patient, utterly kind, generous and gentlemanly, a mentor and champion, a supreme communicator, always generous with wise counsel, encouragement and carefully considered comment, a scientist to emulate, a strong influence not only on careers but on lives.

Ted was a foundation member of the Australian Society of Exploration Geophysicists and its ACT Branch. He served as ACT President in 1980/81 and Vice-President in 1981/82. Between 1981 and 1983 he was Editor of the *Bulletin of the Australian Society of Exploration Geophysicists* and, in 2004, his lasting contributions to Australian geophysics were recognised with the award of ASEG Honorary Life Membership.

Ted is survived by Penny, Matthew, Jo and Jim, their spouses Elizabeth, Josh and Jane, and grandchildren Lucinda, Francis, Charles, Sophia, Gabriel, Molly, Freya and Eliza. He will also be ever present in the lives of his students and colleagues around the world.

Vale Ted.

Phillip Wynne
Phill.Wynne@ga.gov.au

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.

Darling-Curnamona-Delamerian (active) seismic survey

Under the Exploring for the Future programme, Geoscience Australia completed the acquisition of the Darling-Curnamona-Delamerian seismic survey in August 2022. This survey acquired 1200 km of deep crustal data in South Australia, Victoria and New South Wales, and 57 km of high-resolution data in the Upper Darling floodplain in western New South Wales. Data processing will take place during the latter part of 2022. The survey data will be used, among other objectives, to create an image of important crustal boundaries including the structure of the Delamerian margin, which runs through New South Wales, South Australia and Victoria, separating older rocks of the Gawler Craton and Curnamona Province from younger rocks of the Lachlan Fold Belt (Tasmanides).

Reprocessing legacy industry seismic data

Reprocessing of industry 2D reflection seismic data acquired between 1974 and 2008 in the Pedirka and Simpson basins is now complete. A total of 88 seismic lines across the Pedirka Basin in South Australia and Northern Territory and the Simpson Basin in the Northern Territory, for a total of around 3800 km, were reprocessed as part of the Exploring for the Future programme. The objective is to produce a modern industry standard 2D land seismic reflection dataset to assist industry to better image the subsurface, including salt for hydrogen

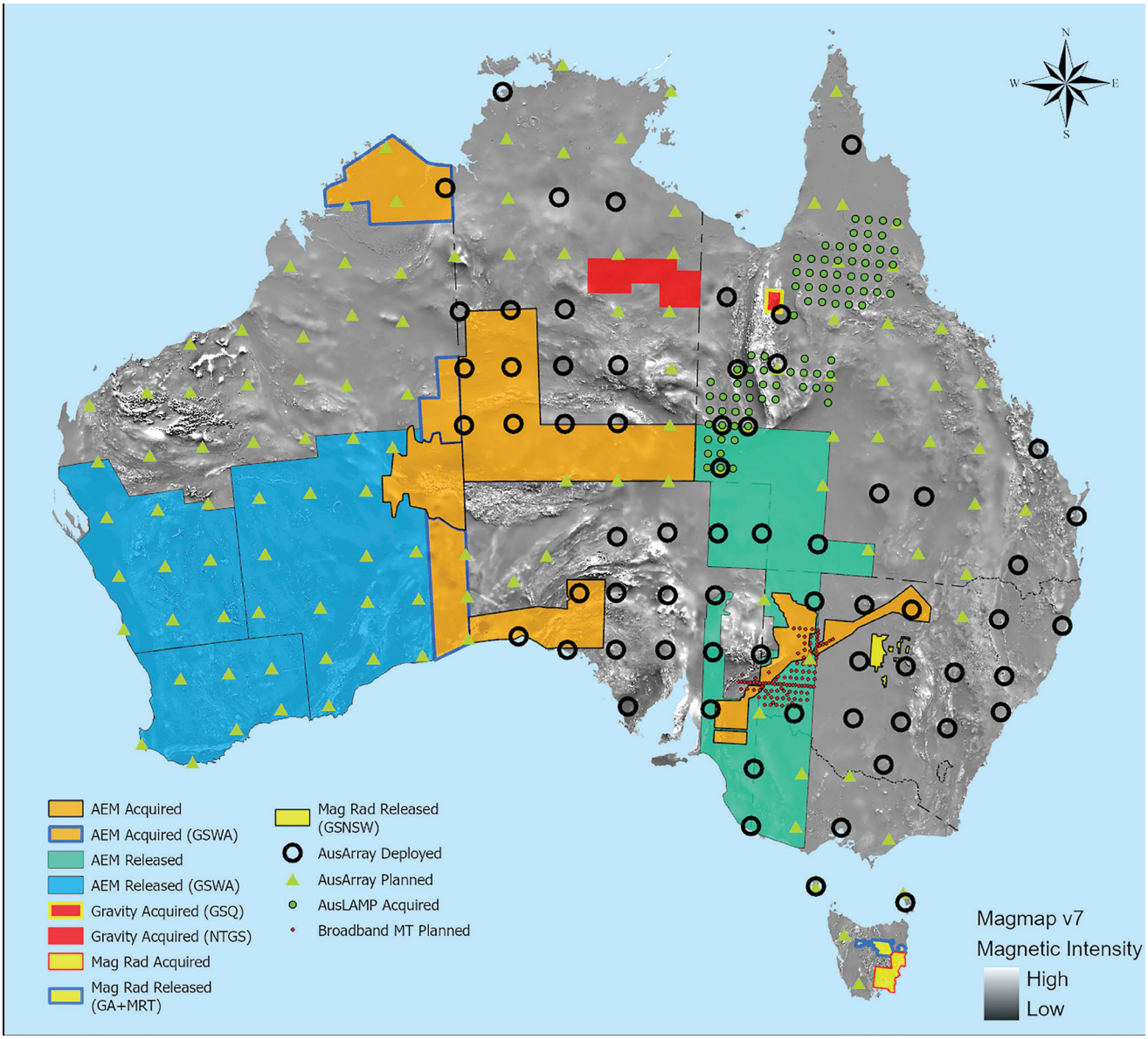


Figure 1. *2021 -2022 geophysical surveys – in progress, planned or for release by Geoscience Australia as part of the Exploring for the Future (EFTF) programme and in collaboration with State and Territory agencies. Projects with funding contributions (whole or part) from state government agencies are 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. *"Hands-on" AEM workshop, hosted by GA and AIG in Perth on 11 August.*

storage. The data package is available on request via http://pid.geoscience.gov.au/dataset/ga/146309.

AEM workshop

Geoscience Australia ran an AEM workshop on 11 August 2022 as part of the Exploring for the Future 'mid-term' deliverables. Run in collaboration with the Australian Institute of Geoscientists (AIG), it was attended by 36 representatives from industry, contracting operations and government agencies (Figure 2). The one-day programme in Perth provided a practical guide from data acquisition, quality control, through to data inversion and interpretation.

Updated from the website (https://www.aig.org.au/events/geoscience-australia-aig-short-course-airborne-electromagnetic-workshop-a-practical-guide/):

"Geoscience Australia has been heavily involved in developing airborne electromagnetics (AEM) as a geophysical method, from its origins as a qualitative "bump finding" survey technique to a quantitative tool for subsurface modelling. This advancement had led to rapid expansion of Australia's AEM coverage over the last half a decade through Geoscience Australia's Exploring for the Future programme and collaborations with state and territory geological surveys. The team at Geoscience Australia is experienced across all aspects of AEM programmes including survey planning, managing data acquisition, data QA/QC, processing and inversion, and geological interpretation. In this one-day workshop we aimed to pass on our experience by demonstrating AEM theory and practice.

The workshop had three sessions covering data acquisition, AEM inversion, and interpretation. In the first session, we introduced the theoretical principles of airborne electromagnetic surveys, walked through the process of planning data acquisition and demonstrated our best practices for QA/QC in the context of Geoscience Australia AEM technical deed, which assures AEM data are acquired to a high standard.

In the second session, we explored the inversion of AEM data to generate bulk conductivity models. This session included a tutorial on the range of inversion codes developed in-house, including deterministic Occam inversions that produce a smooth model with a good data fit, as well as advanced Monte Carlo algorithms that sample hundreds of thousands of models with good data fit and allow rigorous specification of prior knowledge of subsurface conductivity.

In the final session, we explored how we interpret subsurface features from AEM conductivity models at Geoscience Australia. The focus of this session was on avoiding some of the common pitfalls in AEM interpretation by understanding the considerable uncertainty and ambiguity involved. By facilitating this workshop and providing practical examples for participants to work through, we aimed to build an AEM community within Australia that can make the best use of these valuable and relatively easy to acquire data".

Due to the level of interest and positive feedback received, we are hoping to run the workshop again in early 2023.

Airborne geophysical survey updates

Airborne EM programmes through the Western Resources Corridor (see Figure 1, blue hashed areas straddling the SA/WA/NT borders) and through the Eastern Resources Corridor (see Figure 1, blue hashed areas through NSW and Vic) are expected to be completed by mid-October. Survey datasets, including inversions with GA's own deterministic products, should be available early next year.

This month also saw the delivery of final contractor products to GA for the East Tasmania airborne magnetic and radiometric survey. This 57 000 line km survey across south eastern Tasmania (see Figure 1) was conducted in collaboration with the Mineral Resources of Tasmania, with one of the key aims of providing a high resolution dataset to map the base metal (and critical minerals) potential. We are expecting to publish the dataset within the next month.

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

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 12 September 2022)

The survey details are provided for information only, and on the understanding that 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 Adrian Hitchman Adrian.Hitchman@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 (km^2)	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)	TBA

TBA, to be advised.

Table 2. Ground and airborne gravity surveys

Survey name	Client	Project management	Contractor	Start survey	Line km/ no. of stations	Line spacing/ station spacing	Area (km^2)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
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	TBA	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)	Set for release 2022
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 (km²)	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	TBA	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	TBA	See Figure 1 in previous section (GA News)	TBA
Upper Darling River	GA	GA	SkyTEM	Mar 2022	25 000	.25 – 5 km		Jun 2022	TBA	See Figure 1 in previous section (GA News)	TBA
Darling-Curnamona-Delamerian	GA	GA	SkyTEM	Jun 2022	14 500	1 – 10 km		Oct 2022	TBA	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 32 stations deployed in 2021	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 2022	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

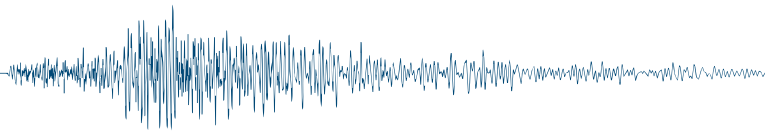


Table 5. Seismic reflection surveys

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, South Australia and Northern Territory, as part of the Exploring for the Future programme.
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. The new seismic data obtained will provide greater certainty in planning for future drilling. Data acquisition was completed in May 2021. CINSW contracted Velseis to process the data and the GA seismic team is QCing the processing of this dataset. Processing of these data is complete and a data package will be released in mid-2022.
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 New South Wales, South Australia and Victoria, 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 Western Australia 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: New geophysical data on SARIG

Geophysicists at the Geological Survey of South Australia are pressing forward in their task to release all mineral geophysical surveys in the public domain via the Geonet pages available via SARIG (South Australia Resources Information Gateway). Geonet acts as a landing site when following spatial hyperlinks on SARIG, and allows users to search for geophysical surveys with keywords or by survey code and download data packages via a hyperlink.

This ever-growing collection of data is available for free download, and updates are reported quarterly on the Department for Energy and Minerals website. The website (link below) includes hyperlinks to the metadata and a direct link to download each dataset. These downloads include original data and reports as supplied to the SA Government, as well as processed data: Intrepid datasets, grids of the data, and shapefiles illustrating flightpaths and boundary shapefile. These packages come as-is, and cannot be cookie-cut online as they can be via Jetstream.

Figure 1 shows the geographical position of the surveys released in September 2022. This link https://www.energymining.sa.gov.au/industry/minerals-and-mining/exploration/exploration-data-releases#Geophysical will take you to a webpage which includes a table listing the surveys in the latest release, with hyperlinks to quickly access the data packages.

As always, if you need any help accessing geophysical data in South Australia, please don't hesitate to contact customer resources at +61 8 8463 3000 or DEM.CustomerServices@sa.gov.au

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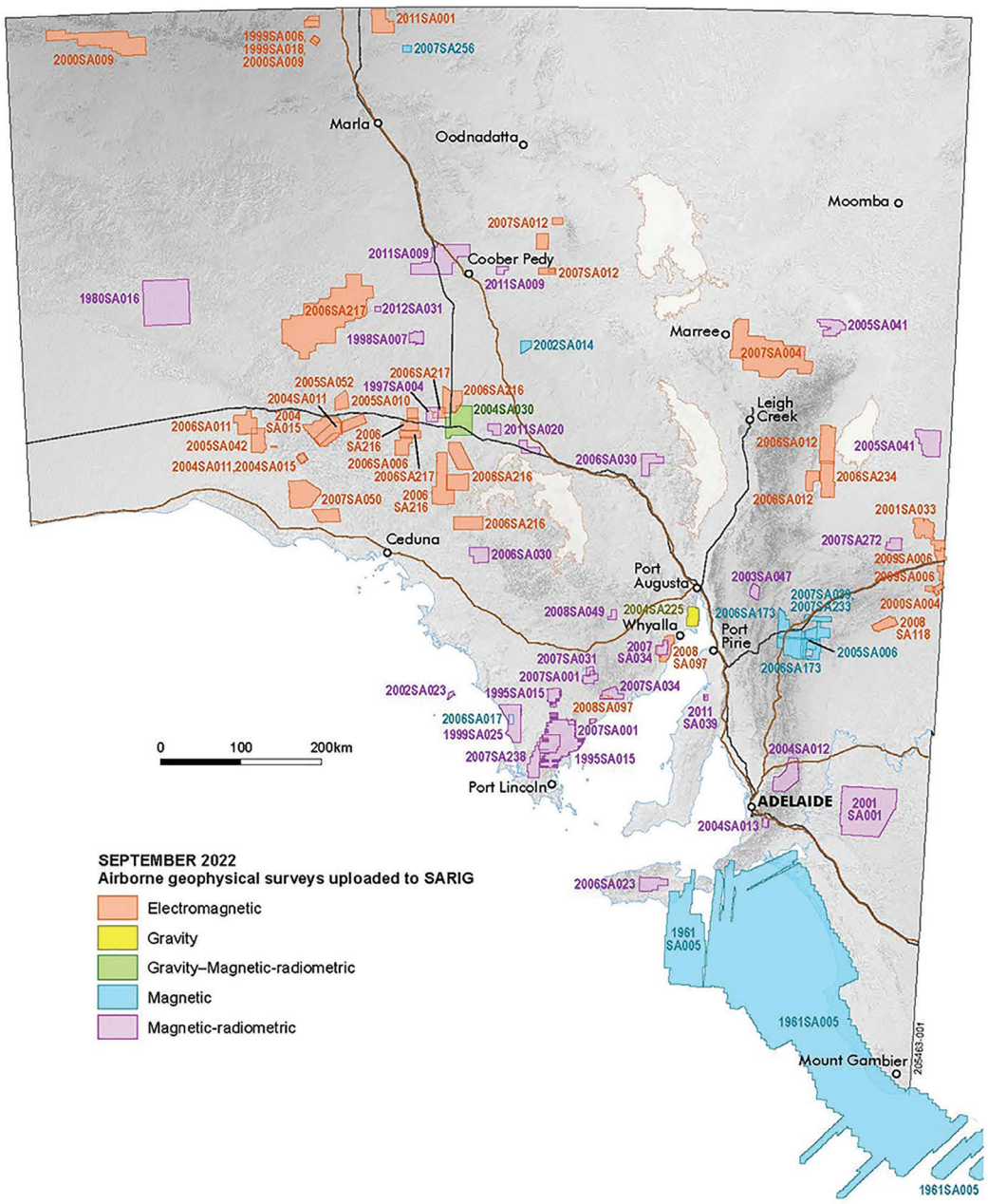

Figure 1. *Geophysical survey data released in September 2022.*

Is there a future for geophysics in Australia?

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Over the months of writing this article (on-and-off of course, I'm not that slow a typist) it went through several different versions. The emphasis changed from reviewing the general state of the geophysical industry, to the state of geophysics education in Australia, to the status of the ASEG itself. Eventually (and perhaps to get it off my desk once and for all) I decided to go with the rather hyperbolic subject and title of "Is there a future for geophysics in Australia?"

What's written here should not be seen as criticism (although perhaps that interpretation is unavoidable) instead I see it as a call to arms to try and rejuvenate what I, and many others, see as a steady (although perhaps now precipitous) decline in Australian geophysics before it is too late - although the reader could be forgiven for thinking that that moment may have already passed.

A wise colleague often reminded me to consider "what does success look like?" If we don't have a clear picture of what we are attempting to achieve, then how do we know if we achieve it? With geophysics, some obvious areas to assess are the commercial health of the industry - are geophysical companies healthy? Do we see new companies enter the market or just companies leaving it? We can also look at the professional society - are membership numbers increasing (or at least stable), are meetings healthily attended? Does the society play an active role in promoting our field? Finally, and in my view, we should remember the wise words of Whitney Houston "I believe the children are our future. Teach them well and let them lead the way".

Table 1. A summary of geophysics teaching in Australia. Reproduced from Selway, K., 2021. Geophysics education in Australia – AEGC wrap up and updated survey results: *Preview*, **214**, 37-38.

		Undergraduate			Postgraduate (coursework)		Trends	
State	Institution	Geophysics major (or equivalent)	Number of stand-alone geophysics subjects	Subjects with geophysics components	Named Masters degree	Any postgraduate geophysics teaching	Recent changes (positive/ negative)	Planned changes (positive/ negative)
ACT	*ANU*		5	4				
NSW	*Macquarie*		1	1				
	UNSW		1	3				
	U of Sydney		0	2				
	U of Wollongong		0	3				
	U of New England		1	0				
Qld	*James Cook U.*		0	2				
	QUT		1	1				
	U of Queensland		0	1				
SA	*Flinders*		0	2				
	U of Adelaide		3	2				
Tas	*U of Tasmania*		0	4				
Vic	*Monash*		1	3				
	U of Melbourne		1	0				
	Federation U.		1	1				
WA	*Curtin*		12					
	UWA		0	2				

We should look to the future, primarily the next generation of geophysicists. Do we have a healthy student population across Australia? Do opportunities exist for those both inside and outside the profession to learn more about it?

Back in the August 2021 issue of *Preview* the then ASEG Education Committee Chair, Kate Selway, summarised the state of geophysics education in Australia (which was further updated in the October 2021 issue). With her permission I have included this summary again as Table 1. At first glance the number of red cells in this table is discouraging. Generally speaking, people who refer to themselves as geophysicists tend to have a degree in geophysics, if we look at this table, we see only three undergraduate courses with a geophysics major, and only the one named Master's degree. Of the three undergraduate courses named, only one contained more than five stand-alone geophysics subjects. Perhaps even more discouraging is the "recent changes" column, with all the recent changes being negative (although there were two institutions who claimed that the future was positive).

The recent dire state of earth sciences in general (and not just in Australia) was considered worthy of an editorial in the September 2021 issue of *Nature*. After listing the numerous institutions that have cut back or culled earth sciences completely, the Editor issues a call to arms: "As the climate crisis rages on, human populations continue to grow and Earth's resources dwindle, it is imperative to have more geoscientists willing and able to mitigate, research and act." Unfortunately, Australia does not appear to be addressing this imperative.

Curtin University has long been the most successful Australian university in terms of producing geophysics graduates. Figure 1e shows the number of students enrolled in the undergraduate programme at Curtin over the last 25 years. From 1995 until the early 2010s student numbers were relatively consistent varying between 80 to over 100 (with a small dip around 2003). It is no secret that earth science enrolments tend to track the fortunes of the resource industry, and the Figures 1a to d are included to give an indication of industry health over those years. From these graphs the collapse of the oil industry around 2015 is immediately recognisable, with the oil price and exploration spending dropping precipitously. However, when we look at the mineral industry the picture is very different, with pricing remaining stable and exploration spending (of which geophysics is a key component) continuing to climb. Unfortunately, this did not result in an increase in geophysics student numbers at Curtin, and they have now reached the level where geophysics teaching is "under review". Referring back to Table 1, teaching at Curtin represents 12 of the 27 (44%) stand-alone geophysics subjects at Australian universities. One can only assume, that if the geophysics course at Curtin was to suffer cuts, this would effectively represent the end of in-depth geophysics education in Australia.

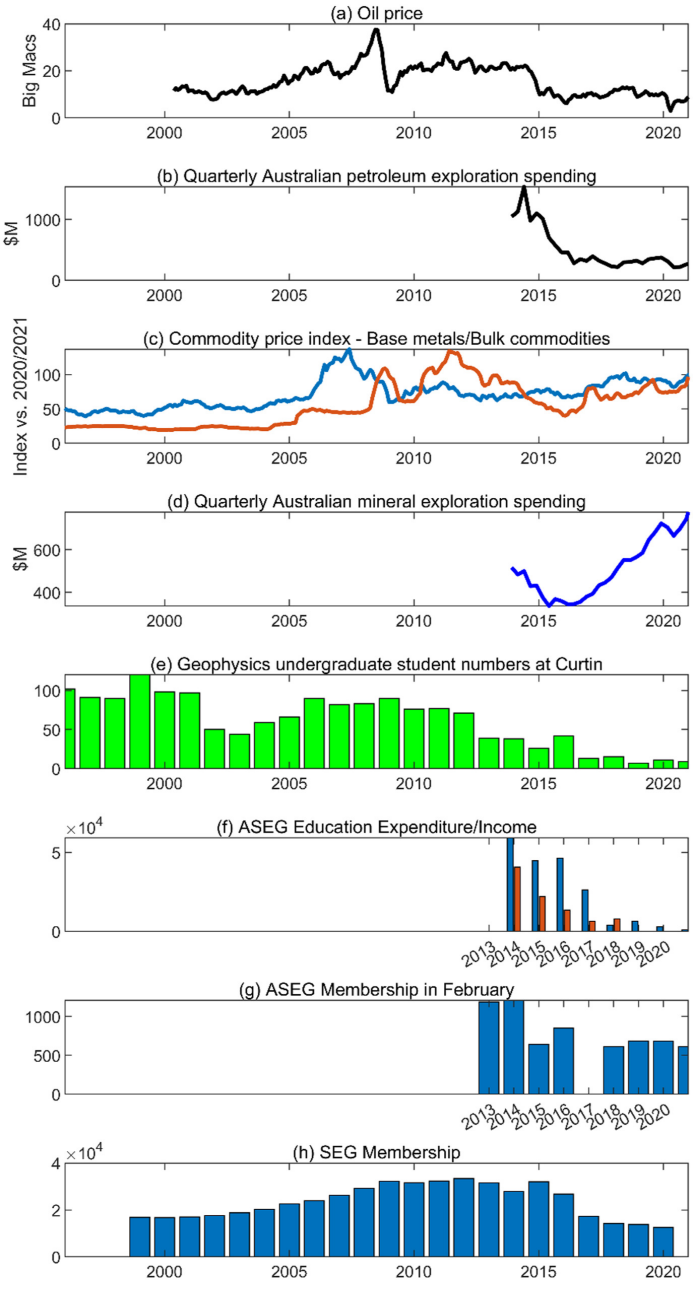

Figure 1. *Illustrative graphs of the state of the resource industry.*

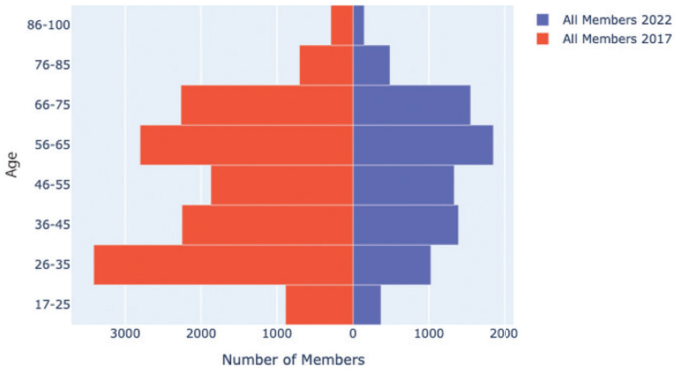

Figure 2. *Distribution of SEG Members, the drop in the younger age groups between 2017 and 2022 was a result of free student membership ending in 2018 (the ASEG currently offers free membership for students). Reproduced from Shragge, J., 2022. A university perspective on the future of applied geophysics: The Leading Edge,* **41**, *162-163.*

Given that the future (and present) of geophysics education in universities looks bleak, what of the ASEG, Australia's professional geophysical society? Figure 1g shows ASEG membership levels from 2013 to 2021, with numbers declining by more than 50%, a problem not just confined to the ASEG, as the SEG membership numbers also declined (Figure 1h).

I do not have access to the demographic figures for the ASEG, but those for the SEG have been published recently (Figure 2). If nothing else in this article causes alarm, then surely this graph should, the age bracket with the largest number of members is 56-65, i.e., almost at retirement, with those in the 26-35 bracket being significantly lower.

If geophysics is to stand a chance of remaining healthy in Australia, particularly in the case of further disinterest from universities, then the strength of the professional society is key. Unfortunately, as I've shown, membership numbers are declining. The 2018 - 23 ASEG strategic plan listed three "measures of success" – support of key activities, identifying and helping deliver geophysics education, and being a preferred source of advice. Although these aims clearly have merit, I believe that encouraging ASEG membership should be key, if not the key, objective of the Society. Clearly a larger membership base would help achieve the measures detailed in the corporate plan, e.g., the larger the number of Members, the better attended our meetings and conferences. I would suggest that the future of geophysics depends on having people who call themselves geophysicists, and the health of our profession would directly flow from this.

How to boost membership is a topic for a wider conversation, but I believe seemingly radical ideas such as making membership free should be considered. Figure 3 shows membership income and expenditure on administration. In 2021 administration spend was higher than all the membership income, nearing $100 000. From a very superficial point of view, one might interpret this as meaning that the organisation solely exists to be administered.

Although not directly comparable, many sports organisations, for example, have larger memberships than ASEG but get by solely with voluntary or casual administrators. For those sceptical of the effects of free membership one only has

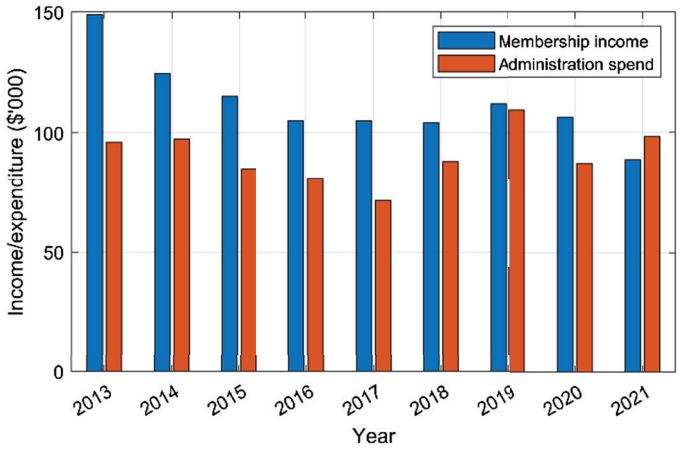

Figure 3. *ASEG annual membership income and administration spend.*

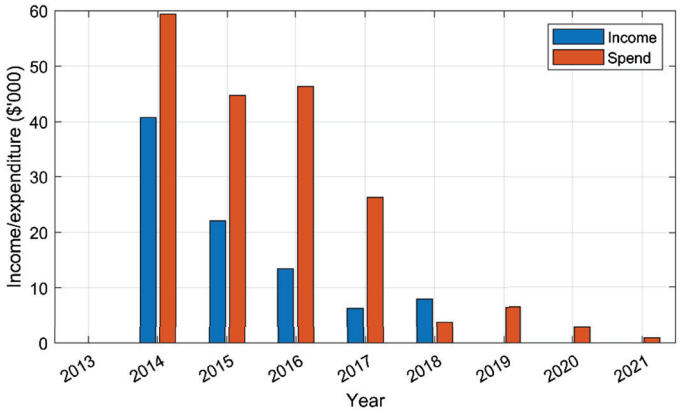

Figure 4. *ASEG income and expenditure on education.*

to look at the effect of the abolition of free membership for students by the SEG in 2018 on their membership demographics (Figure 2). Another alternative is to merge with another Australian geoscience society, or to become an overseas chapter of a large international society such as the EAGE or the SEG. Doing so would immediately enlarge the membership base and help promote the Society. Clearly, there is no simple answer to the decline in Member numbers, but I feel that seemingly radical solutions should not be discarded because that's the way we've always done it.

Again, with the decline in university education it is likely that the importance of the ASEG for educating the next generation of geophysicists will increase. However, looking at the ASEG's expenditure on education (Figure 4), we see that the ASEG spends almost nothing on education (and this decline existed before the impact of COVID). The upcoming "Camp for Applied Geophysics Excellence", which offers 20-25 students and early career professionals a week of geophysical field work in South Australia, is clearly a positive move, but alone is unlikely to produce the next generation of geophysicists.

By this stage you, the reader, have perhaps become dispirited by the picture I have painted, an almost vanished university education sector and a professional society apparently in decline. One would think that our industry was centred around obsolete technology such as overhead projectors and phone books. The reality is, however, that the industry is in rude health and that the demand for geophysics and geophysicists is only increasing, particularly as resources become harder to find. This decline is reflected across the resource industry as a whole, with problems attracting the next generation of geoscientific personnel. Arguably this is a result of the perception that the industry, and its allied fields such as geophysics, are part of the climate change problem rather than its solution. This is beginning to be addressed in various advertising campaigns (BHP's "Our products help build a better, clearer future" and BP's "Reimagining energy") and even corporate names (Total became TotalEnergies to reflect its desire to "contribute to the sustainable development of the planet facing the climate challenge").

Unfortunately, I cannot claim to have all the answers, nor can I assure the reader that the situation is salvageable. The chance to increase undergraduate student numbers indirectly by increasing the profile and attractiveness of the profession, as well as directly by providing scholarships, for example, and to save some courses may have already gone, but the fight is still well worth taking up. What remains is the need for a clear acknowledgement that geophysics in Australia, despite the apparent state of the commercial industry, is in trouble and urgent action is required to attempt to save it. Clearly ASEG should be at the centre of these efforts, if only as the only significant geophysical representative body remaining. Australia has a wealth of experienced geophysicists, and the Society has significant cash reserves, we should leverage these resources before it is too late…

Acknowledgements

I would like to thank Denis Sweeny, Kate Selway, Lisa Worrall, Megan Nightingale, Nick Josephs and Sean Strong, amongst others, for interesting discussion on this topic.

Tim Dean is a Specialist Project Geoscientist for Anglo American. Prior to joining Anglo American he was a Research Fellow within the Department of Exploration Geophysics at Curtin University. This followed an extensive career at Schlumberger/WesternGeco/Western Geophysical in a variety of roles including marine and land field operations, software development, and research located in Saudi Arabia, England, Norway and Australia. Following his final position within Schlumberger as Principal Research Geophysicist at the Schlumberger Fibre-Optic Technology Centre Tim joined HawkEye Technology (a division of Sony) as a Project Advisor for the introduction of goal-line technology into the UEFA Champions League. He also conducted research into the use of sensors within sports as diverse as cricket, AFL, and volleyball. Tim has an Honours degree in geophysics from Curtin University and a PhD in physics from the University of New South Wales. His research interests include land acquisition, particularly vibroseis sources, land data processing, and distributed fibre-optic sensing.

Canberra observed

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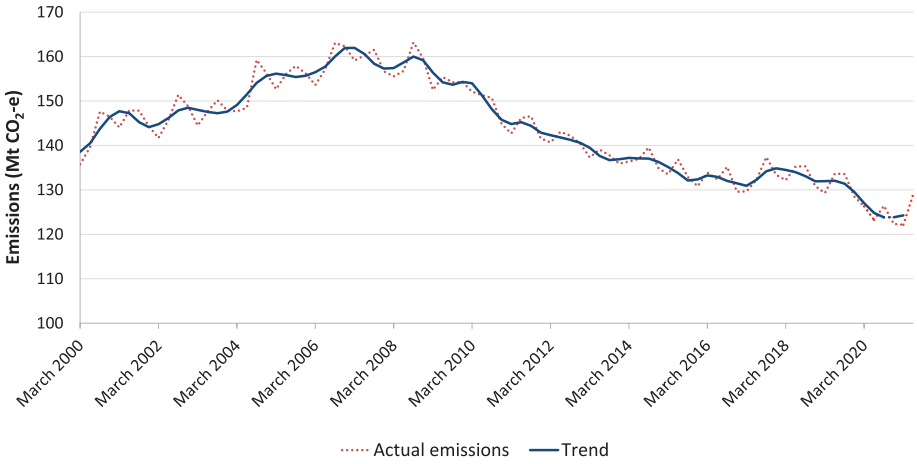

Figure 1. *Quarterly emissions of Australia's greenhouse gasses from Australia's National Greenhouse Gas Inventory. Source: https://www.dcceew.gov.au/climate-change/publications/national-greenhouse-gas-inventory-quarterly-update-march-2021.*

Climate Change Bill passes both Houses of Parliament -a pause in the climate wars?

On 8 September 2022 both Houses of Parliament passed the Climate Change Bill 2022. It was approved in the Senate by 86 votes to 50 with the help of the Greens, Jacqui Lambie Network and independent senator David Pocock.

The emissions reduction target, to cut greenhouse gas emissions to 43% of 2005 levels by 2030, *en route* to net zero by 2050 is now a legal obligation.

What happens next?

1. The Bill requires the Government to provide annual reports tracking progress towards the goal, and ensure future targets go further.
2. A technical and design paper on the setting of baselines, use of offsets and how to tailor treatment for emissions-intensive and trade-exposed businesses. This was open for consultation until the end of September 2022.
3. The Government has also proposed requiring the country's highest polluters to shrink emissions by up to 6% per year under the strengthened centrepiece of its commitment to reduce emissions by 43% this decade.
4. The Government will release a more detailed design proposal for the safeguard mechanism for feedback later this year.
5. The reforms are slated to take effect from July 2023.

How hard will it be to reach the target?

It won't be easy. Even though emissions have been reduced by 20% from the 2005 level (see Figure 1), they rose quite steeply in 2021, and the Government won't be able to use the land-use sector, which has been used earlier.

At present, it appears that the electricity sector, which provides energy for our national power grid, will meet its target, but transport, construction and the other sectors could find their targets hard to meet.

Furthermore, several climate experts argue that 43% falls short of the level of ambition (see Liam Mannix, *Sydney Morning Herald*, 9 August 22).

We should remember that Australia's contribution to global emissions is very small.

In 2020 global emissions totalled 34.8 billion tonnes, of which China contributed 10.7 Bt, the US 4.7 bt and Australia 0.4 Bt (https://ourworldindata.org/co2-dataset-sources). On a per capita basis, Australia is near the top of the table with an annual total of 15.4 t. US has 14.2 t, China 7.4 t and India only 1.9 t.

Australia can and should do better.

Meanwhile support for fossil fuels increases

Support from governments for fossil fuels almost doubled in 2021, slowing progress toward international climate goals, according to a new analysis from OECD and IEA. (https://www.oecd.org/fossil-fuels/).

The OECD and IEA have consistently called for the phasing out of inefficient fossil fuel support and the re-direction of public funding toward the development of low-carbon alternatives, alongside improvements in energy security and energy efficiency. This is not happening.

Figure 2 shows the results of the analysis. The estimates cover 51 major economies, spanning the OECD, G20 and 33 other major energy producing and consuming economies representing around 85% of the world's total energy supply.

As the IEA Executive Director Fatih Birol said:

"Fossil fuel subsidies are a roadblock to a more sustainable future, but the difficulty that governments face in removing them is underscored at times of high and volatile fuel prices. A surge in investment in clean energy technologies and infrastructure is the only lasting solution to today's global energy crisis and the best way to reduce the exposure of consumers to high fuel costs."

Quite right.

Offshore petroleum exploration: ten areas up for offer

The release of offshore areas for petroleum exploration, controlled by the Australian Government, continues as though nothing has changed in a race to produce locally more oil and gas, rather than reduce emissions.

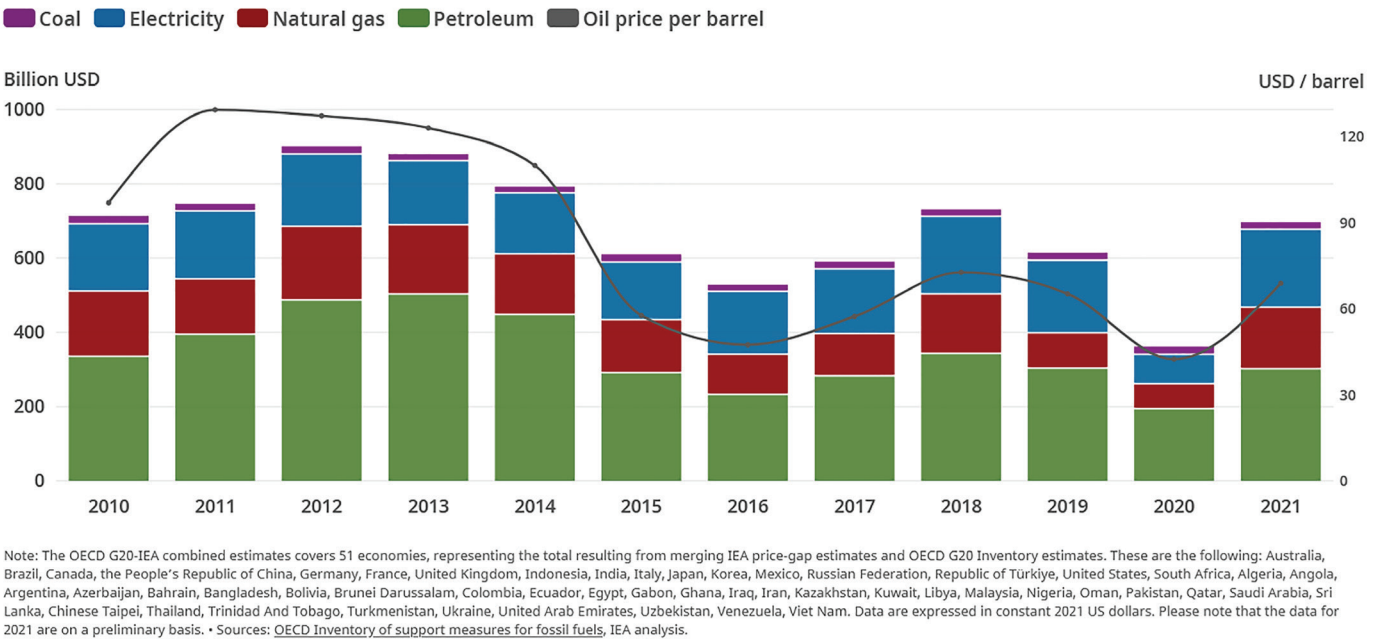

Figure 2. *Fossil fuel support from the G20-IEA estimates from 51 economies. Source: https://www.oecd.org/fossil-fuels/*

The ten areas are:

- Bonaparte Basin | Vulcan Sub-Basin AC22-1
- Browse Basin | Caswell Sub-Basin AC22-2 and W 22-2
- Bonaparte Basin | Malita Graben NT22-1 and W22-1
- Browse Basin | Barcoo Sub-Basin W22-3
- Northern Carnarvon Basin | Dampier Sub-Basin W22-4 and W22-5
- Northern Carnarvon Basin | Exmouth Sub-Basin W22-6
- Gippsland Basin | Basin V22-1

The increase in the oil price to about $US100/bl because of the war in Ukraine is obviously a driver for these policies. We note that Woodside Energy had a profit of $2.37 billion (B) in the last year. And that it sponsored the Midwinter Ball this year in the Parliament. Money talks.

Five areas for carbon capture and storage to be approved

In August 2022, Minister for Resources and Northern Australia Madeleine King announced that greenhouse gas storage permits have been awarded to two areas offshore of the Northern Territory and Western Australia (https://www.industry.gov.au/data-and-publications/2021-offshore-greenhouse-gas-storage-acreage-release). The permits are for a joint venture between INPEX, Woodside Energy and Total Energies for area G-7-AP over GHG21-1 in the Bonaparte Basin, and for Woodside Energy for area G-8-AP over GHG21-3 in the Browse Basin.

Minister King soon expects to finalise the awards for all five new offshore greenhouse gas storage permits under the 2021 offshore Greenhouse Gas Storage Acreage Release. She said that she would announce the release of a 2022 offshore greenhouse gas storage acreage later this year.

What financial arrangements are in place and how the success of each project will be judged are not clear, but it would be encouraging if at least one of these projects was successful.

In the meantime, the Greens, Senator Pocock and the Teals will be pushing the Albanese government to prevent any new coal mines or any expansion of current mines. Once again money talks.

The market capital of Yancoal on the ASX has risen from $3.1B in September 2021 to $9.1B in September 2022 and Whitehaven's from $2.9B to $8.4B over the same period.

It will be interesting to see how the Government handles the emission targets. On the one hand we have a legislated target, and on the other there is commercial pressure to produce more coal and gas regardless of the greenhouse gas emissions.

Mineral exploration investment continues to grow

The Australian Bureau of Statistics released the exploration investment results for the June 2022 quarter in August 2022 (https://www.abs.gov.au/statistics/industry/mining/mineral-and-petroleum-exploration-australia/latest-release).

The new data have been incorporated into Figure 3. Essentially the minerals industry is just powering ahead, and the petroleum sector seems to be in the doldrums.

The original series shows how strong the trends are:

- Total investment rose by $198.3 million (M) to $1053.6M;
- Investment in existing deposits rose by $145.7M to $740.7M and
- In new deposits it rose by $52.6M to $312.9M

Iron ore recorded the largest rise, up $61.5M to $201.0M. However, gold at $420M still dominates and coal is in third place at $61M.

Petroleum in the doldrums

Meanwhile, the petroleum sector was very disappointing. Total expenditure,

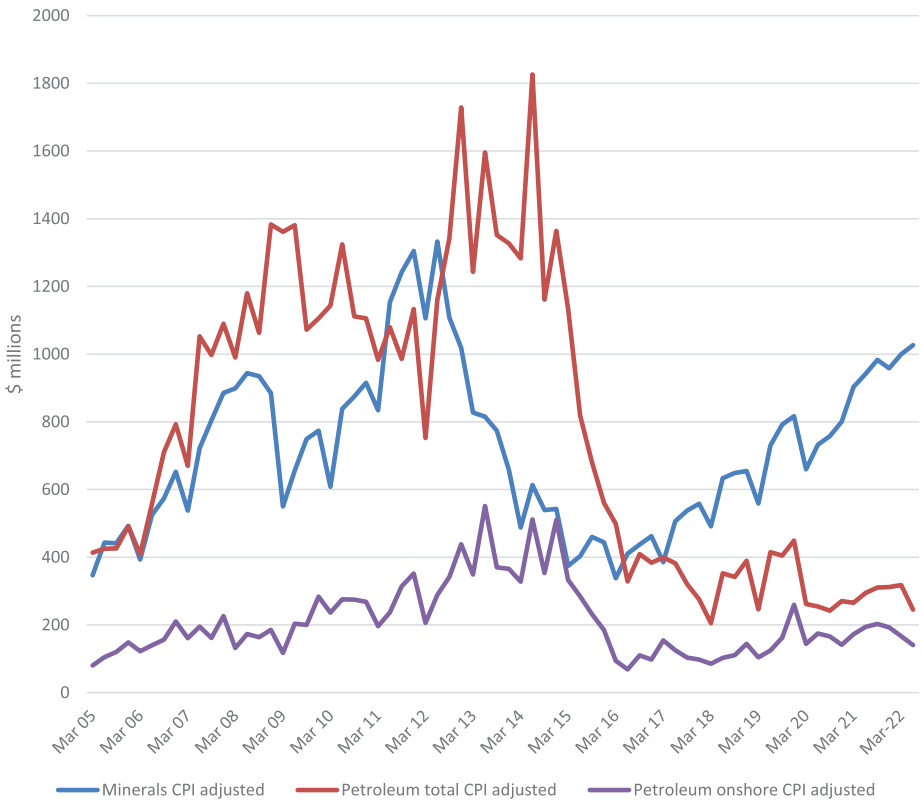

Figure 3. *Quarterly petroleum and mineral exploration investment 2005-2022. Source: https://www.abs.gov.au/statistics/industry/mining/mineral-and-petroleum-exploration-australia/latest-release.*

seasonally adjusted, fell by $66.9M to $245.3M from the last quarter. Onshore, seasonally adjusted expenditure fell by $23.4M to $140.3M, and offshore, seasonally adjusted also fell by $43.5M to $105.0M. The only increase was in production lease areas where the increase was a measly rise of just $3.1M to $96.1M.

Gone are the days when billions of dollars were invested annually. It will have to improve soon.

More resource companies now in the top 150 of ASX

It is worth noting that although there has been some rationalisation within the larger companies, e.g., Oil Search merging with Santos, and Woodside taking over BHP's petroleum interests, there are now many more resource companies in the top 150 of the ASX than ever before.

Back in 2000 there were 16 companies. Now there are 26 and many of the newcomers are hunting for lithium and iron ore. A very healthy situation for geophysicists.

Education matters

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Passionate about mineral exploration

In this issue of *Preview* we continue a series of interviews on educational needs in the field of geoscience with leaders working in government and industry. Our special guest today is Dr Sandra Occhipinti, Research Director in Mineral Resources Business Unit at CSIRO.

MP: Can you please say a few words about yourself? Why did you decide to become a geoscientist?

SO: For me, it was just a lucky accident. I had intended to study English literature and drama at university. I spent high school doing science, but I always kept up with drama as well, and I enjoyed it. But when I considered my preferences to go to University I put science first because I had been doing science for so long and the teacher helping with my enrolment was upset that I was planning to put English first. A few months later I found out that I got my first preference – Monash Science.

"It is the richness of storytelling in geoscience that I really enjoy"

I did not know whether to be happy that I got my first preference or to be sad because I was not going to be doing what I wanted. In any case, I decided to stick it out. I went to Monash University to sign up for my course, and I think I chose geology because the person I spoke with was a geologist. It was simply because of this face-to-face interaction… I think I was lucky because geology is magical; it has something other sciences do not have. Even then, people sometimes described it as not a real science, you know, even before the sit-com, *Big Bang Theory*. It is the richness of storytelling in geoscience that I really enjoy. We never know all the answers, which made me realise that I needed to learn more and more about it as I progressed through my career.

MP: And now, you are in a very senior position as a Research Program Director in the Mineral Resources Business Unit in CSIRO. So, please tell readers a little bit more about your journey.

Dr Sandra Occhipinti with colleagues in the field

SO: I have been quite lucky. I never stayed at a job long enough to get bored, or to not enjoy the work I was doing. I always left a workplace happy, having learned something, and then looked at an opportunity as another step. Every time I left something, I stepped up. Some say that if women stay in one place, they more easily go to the top. I have never believed that would be the case for me. I have always got to the point where I sort of thought: "I have learned enough here now, and I have to go to where I need to make a change." I think that in terms of getting into this position, it came because of the previous changes I had made. Having had a background in government, academia, and industry – all very deliberate changes made by me. To sum up, after completing my undergrad and Masters at Monash University, I went to work for seven years for the Geological Survey of Western Australia, and then decided to go back to university and do my PhD. And at that point, I realised that I needed to learn something about economic geology, I had not thought very much about that before then, and that is when this journey to CSIRO really began —getting this research piece under my belt and that journey of the application of geoscience to benefit back into the economy.

I received my PhD from Curtin University. At the time Curtin had a small geology department. It was a great culture. I had my first son when I was doing my PhD.

After my PhD I went to work for Fugro Airborne Surveys, taking my first steps into the minerals industry. That is where I learned how to complete geological interpretations from geophysical data. And it was like a baptism of fire, I would have to say. It was a great culture, great environmental work, and really close teams. We could walk into the rooms where geophysicists were and get help whenever we needed it. I learned how to play around with the data a little bit. It was great. After a couple of years I had the opportunity to work for AngloGold Ashanti as a project generation geologist in their global group. Much earlier on in my career, I thought that would be my final destination – it was what I always aimed to do. I stayed with AngloGold Ashanti for about six years, and then I moved across to UWA as a mineral systems geologist and stayed there for five years. Having already reached that lofty goal of project generation, I

realised how much I didn't know. Going back into the university system was part of my learning journey to learn much more about mineral systems. My current position as Research Director, at CSIRO Minerals, is really about leadership. It has provided an opportunity to help set the direction of new exploration technologies to develop for the future. I am quite passionate about that. I am really passionate about mineral exploration in the mineral industry; I just love it.

MP: From your point of view, how can we attract the best young people to geoscience?

SO: I did not even know what geology was when I signed up for it. For me, it was a lucky accident, really, getting into geology. Recently, I have met other people who did the same. They fell into it in a similar way. They were at uni, had to pick up an extra course, and they did geology and stayed in it. One of the difficulties now, of course, is that we don't always have face-to-face interaction with someone when we enrol. Our kids hardly have this face-to-face interaction with anybody. My eldest son recently applied to go to university online. There was no one for him to speak to and I think that is killing courses. It is the major barrier for us in geoscience. It was never the most popular course. We are not even exposing people to it, even at that enrolment stage. We blame other factors, but that point of enrolment is a really important moment. I think it is one of the barriers. I was not exposed to geoscience at school. I was brought up on a farm, so I had geology around me… I did geography in high school, and that was as close as I got to geology. We do talk about exposing kids to geoscience at school, which I think is important, but if we think about when we were at school, not all of us did geoscience.

The issue for people now, for kids now, and for the general population now, is the exposure that they get to industry connected to geoscience is mostly negative. People might not be attracted to the fly-in-fly-out lifestyle in the minerals and the oil and gas industries. It does not matter if you say to kids that we still need gas, that we are still driving our cars. Many people do not want to join this industry because they simply don't want to become polluters. Children often have higher aspirations, and we should not be trying to push back on them. We should encourage them, and instead should be confirming that: "We need these high aspirations, we need to change, and we need you to come to the industry and make these changes." As a community, we are changing our message; but perhaps we should have changed our message five or ten years ago.

"We need these high aspirations, we need to change, and we need you to come to the industry and make these changes"

To mitigate climate change, we actually need the minerals industry, and we need the industry that has traditionally been oil and gas to focus on hydrogen. And that is the message that we have to get out. But we do not want to use it as a greenwashing message. We actually need to illustrate what we are doing. It is what we are trying to do at CSIRO. There has been a major pivot, working on technologies and methodologies to enable a Clean Energy transition, and many companies are doing this as well. Of course, we can also help with mineral carbonation - locking carbon in rock, rather than releasing it into the atmosphere.

MP: My next question is what do government organisations like CSIRO expect from tertiary education in today's rapidly changing mineral resources and energy landscape?

SO: I can't speak for everyone. But I expect to see graduates who are willing to continue their learning journey with us – in CSIRO. We increasingly look for people with multidisciplinary skills who are willing to work on problems we face in geoscience. It's no good having the best geophysicist in the country working with you if they are unable or unwilling to focus on the problems at hand. People who understand that there is a whole lot out there to learn, understand that their skills can continually be 'refreshed'. It can be a bit frightening for some, but what I am seeing is an eagerness to be agile and to flex a little when required. I also expect graduates to be able to work as part of a team, to encourage those around them, but to be brave enough to 'call something out' when it doesn't sit right.

"We increasingly look for people with multidisciplinary skills"

MP: How do you see your "fresh blood," new recruits?

SO: We're all about building diverse and inclusive teams to drive invention and innovation. People who can maintain that 'child like' eagerness of adventure and learning without encumbrances of 'pre-conceived' ideas or assumptions are who we need.

MP: What has changed in the recruitment process in the last twenty years? In the last ten years?

SO: I think the focus on diversity has driven some change. The knowledge that breaking down the possibilities of sub-conscious or implicit bias in interview panels has helped our recruitment strategy while I've been at CSIRO at least. Twenty years or so ago I sat on one interview panel that questioned a woman's ability (who was younger than I am now) to do the job because of the 'assumption' that she might have elderly parents to look after. Needless to say I flipped my lid. The men on the panel had never met her, did not know her…but they made assumptions about her. Of course, this is probably still happening now, but I hope it's not as prevalent. I often wonder what assumptions people made about me when I walked out of an interview.

In the last ten years? I'm not sure on this. I think that we might have been more focussed on getting the "best/most accomplished" person into a position, without focussing as much on how they might gel in a team etc.

MP: Should we expect evolution or revolution in tertiary education to ensure a smooth and efficient transition to clean energy?

SO: Mmm – it should simply be an evolution. However, I imagine in some quarters asking universities to change their content to support educating students so they are ready to enable the energy transition might be difficult for a number of reasons, including the nature and structure of tenured staffing arrangements at universities.

MP: What role does digitalisation play in the clean energy transition?

SO: Digitisation enables decision support tools to help guide exploration and mining processes. It will play an enormous role in the clean energy transition. I would say that we better need easy to access, downloadable data and content from government servers/ websites as a starter, so that they can be used without good internet connectivity. Other support tools, like ones that aid

in consistent fast downhole logging, fast easily updatable 3D interpolations or models etc are also required. Apart from this, ways of confidently identifying mineralogy in the field, directing the next part of an exploration programme "on the fly", using ML to move away from grid sampling etc. Digitisation will also help with sorting of ores, translating data from sorting systems into processing plants and information the processing part of an operation.

MP: What kind of education is required to guarantee efficient digitalisation of the mineral resources sector?

SO: Simply a little bit of data science, GIS literate graduates, and exposure to coding. However, the ability to work with other specialists and explain what they need might be enough. We can't all be experts on everything.

MP: Sandi, you are very passionate about your role. Would you recommend this career path to young women?

"People who can maintain that 'child like' eagerness of adventure and learning without encumbrances of 'pre-conceived' ideas or assumptions are who we need"

SO: There have been times when I questioned, "Why would anyone do this?" I remember somebody asking once: "You know, Sandi, would you recommend this job for young women? What would you say to them now?" And I said: "Well, if they really loved it, I would say go for it. But if they did not, I would not recommend them to go into this business". And he was shocked, and I said: "Look at me, I am surrounded by men all the time, and it is really very tough at times." I think it is getting better. We see around us at CSIRO that the number of people coming to our workplace is much more diverse than ten or twenty years ago. Focussing on diversity and changing our recruitment methods helps. In the Discovery Program, we always choose the best candidate, we have not had to use positive discrimination, but we changed the way we recruit, the way recruiting panels are developed, and we get 50:50 men and women through at the moment. It is incredible. And the other thing too, which I have noticed, which is really great, is that the diversity in ethnicity has really picked up as well. So, we just need to ensure that those people who are still in the minority in our group feel supported and that we foster a very inclusive culture within the team.

Inaugural Camp for Applied Geophysics Excellence (CAGE)

CAGE22

CAMP FOR APPLIED GEOPHYSICS EXCELLENCE

The ASEG is supporting the inaugural Camp for Applied Geophysics Excellence (CAGE). The camp will be held from September 23 to 30, so hopefully by the time you are reading this issue of *Preview* you are also seeing some of the highlights on ASEG social media.

The camp was motivated by the recent losses in geophysics teaching in Australian universities and the knowledge that many students are not being exposed to a broad range of geophysics techniques in the field. There were more than 70 applications for the 25 places we had available, which highlights the current demand for this kind of geophysical training. The attendees will collect magnetic, seismic, resistivity and nanoTEM data, process and invert all the datasets, and produce an integrated interpretation. We will focus on developing their understanding of field techniques, safety and risk, and the concepts of data quality, uncertainty, and linking geophysical observations to rock properties.

As well as the ASEG, the Platinum Sponsors of CAGE are AuScope, NExUS and BHP. Geoscience Australia is a Bronze Sponsor, and Southern Geoscience Consultants, Zonge, GHD, Newcrest, Mira, Seequent, EnviroCopper, The University of Adelaide, MinEx CRC, and a very hard-working team of volunteers are providing in-kind support. We look forward to updating you on how it all went in the next issue of *Preview*!

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CAGE 2022 sponsors, who are acknowledged with thanks:

Australian Society of Exploration Geophysicists

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Environmental geophysics

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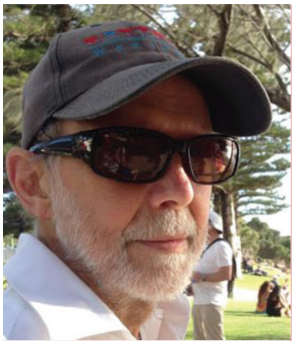
Welcome readers to this issue's column on geophysics applied to the environment. We are now on Scenes 5 and 6 of the reminiscences by Niels Christensen on his career at Aarhus University and that group's progress into and through electrical geophysics starting in the 1970s through to the 1990s and beyond. There are no "geophysical war stories" *per se* in these, although there is mention of the stress and exhaustion involved in setting up a conference. I completely sympathise, as would many of you who have done similar. Also, for those of us who are looking to educate the next crop of geophysicists – some of the references that Niels mentions here may be useful. Over to Niels…

Pivotal moments: Seven scenes from a geophysics adventure



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Scene 5: An international breakthrough

… in which a group of Danes make their presence felt on the North American continent, in Europe and Australia, and invite people to come to beautiful Aarhus.

In 1993 I participated in my first SAGEEP conference which was held in San Diego, California. The conference focused primarily on near-surface geophysics, which up to that point in time had been treated as a somewhat suspicious snotty-nosed upstart at most geophysics conferences, e.g. SEG and EAGE, where the main emphasis was - and still is - on the deeper parts of the Earth, in particular seismic methods used in the oil and gas industry. It was a kind of revelation for me that many other geophysicists in the world were engaged in the same subjects as I was. It made me feel part of community, where I could be one of the pioneers in a new research field. I had found a professional home.

I totally enjoyed the conference, and my American network of geophysicists was renewed and extended. As the conference went on, I could see that what we did in Aarhus was in no way inferior to what was presented at the conference, and I was itching to present our work in a community like SAGEEP. I knew it would be well received. The SAGEEP conference is an annual event, and when I returned home, I started to infuse colleagues and PhD students with my own enthusiasm. It was a bit of an uphill battle to make people understand (" … but it is so far away! … ") that we should all go to the 1994 conference in Boston. SAGEEP was THE place to present our work. I managed to twist enough arms (in *I Ching* it says: Perseverance is recommendable) so that quite a few colleagues, PhD and Masters students accompanied me to the Boston conference. It turned out that we did 7% of all presentations at the conference, among them were these:

- Niels B. Christensen and Kurt Sørensen. Integrated use of electromagnetic methods for hydrogeological investigations.
- Esben Auken, Niels B. Christensen, Kurt Sørensen, and Flemming Effersø. Large scale hydrogeological investigation in the Beder area - a case study.
- Kurt Sørensen. Pulled array continuous electrical profiling.
- Kurt Sørensen. The Ellog auger drilling method.
- Peter M. Duch and Kurt Sørensen. When Is 1D 2D? Interpretation of geoelectrical sections.

I'm listing the presentations here because they show what subjects we were actually working on at the time; subjects that came to characterise our efforts and approaches in the years to come. The conference became a decisive moment where our research group opened up towards the international community of near-surface geophysicists, in particular the Americans. Our presentations made quite a few people talk about those guys from Aarhus, and who were they actually - and, anyway, how did you pronounce Aarhus? Over the coming years, SAGEEP became the most important international forum where we presented our work, and our network expanded, especially in the US. The Boston conference became the pivotal moment that came to define our international orientation: We became known and appreciated internationally, and, internally, amongst ourselves, it changed our perception of who we were. I was no longer the only person who wanted to present internationally. At the 1995 SAGEEP conference in Keystone, Colorado, a group of people

decided to start a new journal, the *Journal of Environmental and Engineering Geophysics*. There was a bit of panic to get it to take off as soon as possible, and Allan Witten, the newly appointed editor of the journal, invited everyone to contribute to the first issue. Now, manuscripts are not often something you just have lying ready in a desk drawer, but for once it was actually the case for me. A few months before, over some of the last hectic days of my visit to Australia, I had finished a manuscript draft on approximate inversion of transient data, so that came out in Volume 0, page 1, of the JEEG.

In 1995, in Torino, Italy, the first European near-surface geophysics conference took place, and we were there from the beginning. I was there with two female PhD students, and several of the southern-European professors asked me how I had managed to acquire an 'entourage' like that. At that point in time, two thirds of the PhD students at our section were female, but south of the Alps they apparently became an 'entourage'. We laughed a bit about that, the PhD students and I. In the afternoons, after the conference, we - as would a lot of other people - went to one of the many cafés on one of the main walking streets in Torino and had cocktails and watched the people promenading in the street in their best clothes, just as they in turn were watching us. Not a bad lifestyle! And the two PhD students went to town and bought Italian clothes and turned up on the last day of the conference in "women-on-their-way-forward" garb: a stylish skirt and a jacket to match - which did not go unnoticed …

In 1996 I returned to Berkeley, this time for six months, and worked on making an approximate inversion of TEM data with 2D models functioning properly. During that time period I visited Doug Oldenburg at the University of British Columbia in Vancouver for a couple of days. Later, two of my PhD students: Anders Vest Christiansen and Ingelise Møller spent some months there as part of their PhD studies.

In 1997, Kurt Sørensen and I arranged the European near-surface geophysics conference in Aarhus in The Concert Hall. We received many comments that this was one of the best and most beautiful places people had been to for a conference. I think that every university professor should try to arrange a conference. It is a good experience, but also one that should not be enjoyed too often. On the opening of the first day of the conference, after all of the stress of getting everything arranged, I managed miraculously to give a very short welcome address. I went to sit down among the audience while the Chair of the European section made a longer welcome speech, I fell asleep in ten seconds, totally exhausted after months of stressful efforts. Now, indisputably, we had become a player on the international scene!

One more thing came out of my Australian visit with James Macnae at Macquarie University in 1995 (see Scene 4). In the same way as my visit to Berkeley in 1987 (see Scene 1) opened my North-American network, my visit to Jim Macnae opened the door to Australia, both for me and other researchers at our department and for my PhD student Rasmus Tøllbøl who spent some months in Melbourne with Jim Macnae in 2004-05. In 2002 I was invited to come and work with Fugro Airborne Services in Perth for two months helping them develop a fast approximate 2D inversion method for airborne TEM methods. We succeeded, and we continued working together in 2003, and I was back again in 2004 to further develop the methodology. I really liked Perth and I got long service leave from Aarhus University, moved to Fremantle for two years and worked for CSIRO Petroleum in Perth. At the AEM conference in Finland in 2008 Ken Lawrie contacted me wishing to discuss collaboration plans, and during 2009-2019 I worked with Ken Lawrie and his groundwater group at Geoscience Australia, Canberra, through collaboration agreements between Geoscience Australia and Aarhus University, spending 2-5 months in Australia every year.

SCENE 6: Teaching 1984 - 2011

… in which teaching activities - and their importance in the bigger picture - are presented.

In 1984 I became an assistant professor and, shortly after, I started to teach a course in environmental/near-surface geophysics. At first, I used a fairly newly developed compendium for post-education of geologists in geophysical methods. The compendium was initiated by The Nature Agency under the Ministry of Environment (both Danish government agencies), and I had been part of group of contributors. However, there was precious little material already published that addressed the curriculum of the course at the appropriate academic level, and very soon I started to write my own lecture notes. The course was compulsory for students who wished to become geophysicists, but was also aimed at hydrogeologists and geologists. Increasingly geophysical methods were applied, contributing information in many contexts: mapping of raw materials, addressing water issues, and for geotechnical purposes. Very likely, future (hydro)geologists, whether employed privately or in public institutions, would be presented with geophysical results in their work, and it was important that they acquired a basic understanding of the value and limitations of geophysical methods so that they would be able to use geophysical results in a constructive way. Most of the physics and mathematics describing electric and electromagnetic methods is quite complicated and requires a lot of effort to be properly understood, so my ambition was to make a course that would teach the students about EM methods without having to delve deeply into the mathematics. However, at the same time, the ambition was to convey a good understanding of the principal issues of applied geophysics, experimental sciences in general, and the physical and geological interpretations of its results.

The course was offered to third-year students, and after a few years, half of the students of that year would enrol in the course. The course was coupled with a field course in the autumn when the fields were harvested and accessible and still not too wet (Figure 1). All of the students had already been on a compulsory field course for first-year students so there was some basic knowledge to build on to provide a more advanced field course. During this time, it was recognised that the education of well-trained university graduates (up to Masters and PhD level) in near-surface geophysics was one of the three "legs" that supported the national programme to map all of the important aquifers in Denmark. The other two being support from public authorities, i.e. managers of county and municipal water supplies, as well as a base of private contractors with the skills and ability to carry out the work.

Following the introduction of the transient electromagnetic method in Denmark, it's potential in hydrogeophysical investigations very quickly became apparent, and together with local authorities: Aarhus County and the Municipal Water of Aarhus,

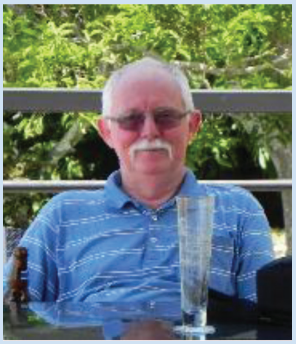
Figure 1. *Field work at the camp: Setting up the TEM instrument and making sure all the pieces are there (photo courtesy: Anders Vest Christiansen).*

more and more local investigations took place. Only rarely was the transient instrument on the shelf in the instrument room. The need to perform TEM measurements grew very quickly, and private companies - some of them newly started as spin-offs from the collaboration between public authorities and the University - adopted the method and offered it commercially. A total of nine instruments (!) were acquired in Denmark, which must be the world record in the category "density of ground-based TEM instruments in one country". This was made possible by the steady stream of newly educated Masters and PhD students who had specialised in the method, making themselves available to be hired by the private companies. A typical story for such a student was to take the third-year course in near-surface geophysics, including the field course, work as a student employee for the county or a private company during their study, and write their theses about the TEM method, having already obtained a promise to be hired after they finished. Several were actually employed before they finished. Without any top-down organisation and strategy, it was no problem for the students to gain practical experience during their studies and there was also no problem with "academic unemployment". All the activities were also "relevant for society" and contributed to "economic growth" to a degree that everyone with similar ambitions today looks back at that time with envy. Most of my time at the university I would have five to seven Masters students and two to three PhD students, which of course could be quite a challenge for a person with the ambition to always have an open door. I'm sure this is not possible at today's universities with all the administrative burdens, registration of activities, and writing of applications for research money now put on the shoulders of the academic staff. In total, I supervised 40 Masters and 11 PhD students during the years 1986-2011.

In the mid-1990s, I taught a course in Advanced Electromagnetic Methods, starting out in a seminar-like way with contributions from all participants: students, PhD students and staff, and then evolving into a more standard form. The course was primarily aimed at PhD students, but was also attended by ambitious Masters students. It was a no holds barred course, especially in the mathematical-physical foundation of electromagnetic methods. In the same way as for the third-year course in near-surface geophysics, I produced lecture notes for parts of the curriculum and a collection of assignments (with solutions). In some years there were too few students to run the course, but from the late 90s and in the 00s, there were typically four to seven participants every year.

In the late 1990s more and more foreign students came to our department to study and, consequently, all the lecture notes, assignments and solutions were translated into English, with the lectures conducted in English as well. Most of the material - substantially edited, extended and updated - is now collected in a book that is available to all students in the department. I always liked teaching and most years, beside the lectures, I also ran what we at European universities called the "exercise" part of a course, basically where problems were given to students to work out with the help of an instructor. I often ran these instead of having a student do the work. It is my opinion that there is - at least - as much learning potential in the exercise classes as in the lectures, and I wanted to make sure that all the important points from the lectures were mentioned in the exercise classes. I was also one of the instructors at the field courses, mostly with the transient method. I liked being with the students, and again, the learning potential - and the potential for fooling around and having fun and good laughs - is huge when you are walking around in the field.

Minerals geophysics



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Drill-hole logging

As an adjunct to a recent drilling programme we undertook extensive geophysical drill-hole logging, and I thought I'd share some of the practicalities of such an endeavour.

The principal aim of the drill-hole logging was to assemble a database of petrophysical properties of the principal rock types and mineralisation styles. This knowledge was expected to benefit future exploration programmes through selection of more appropriate geophysical techniques and survey parameters and a more informed interpretation of results. Specifically, a better understanding of petrophysical properties could improve geophysical modelling and constrained inversion of geophysical survey results. Our database could have been assembled from measurements on selected drill-core samples, but we opted for a drill-hole geophysical logging programme to generate systematic data unbiased by sample selection. With such detail, we reasoned it should be possible to recognise subtle trends in data properties within particular rock units, which in a best-case scenario might be related to mineralising processes.

To generate a comprehensive petro-physical database, we selected a suite of geophysical logging techniques comprising magnetic susceptibility, density, inductive conductivity, IP-resistivity, spectral gamma-ray and seismic velocity, plus acoustic and optical televiewers for structural information. There are some excellent sites on the net with information on geophysical drill-hole logging, some sponsored by geophysical logging companies and down-hole sonde manufacturers, and some linked to universities and professional associations. PetroWiki (Society of Petroleum Engineers), for instance, is a good site for the fundamentals of geophysical logging; not unexpectedly, it does have an oil and gas bias. Table 1 provides a summary of the operational parameters for each logging technique. Some concern was expressed about the use of a radioactive source in the density tool; strict radiation handling protocols were enforced and the risk of block sterilisation around a stranded probe was deemed acceptably small.

The diamond drill-holes selected for geophysical logging ranged in depth from 400 m to over 1800 m. Most drill-holes were logged with the drill-rig off-site. However, in several instances, a drill rig remained on-site with rods in-hole covering zones of caving to ensure logging access to the deeper sections of the drill-hole. The logging itself was all carried out open-hole. Drill-hole inclinations were typically quite steep, although at their deepest, some drill-holes flattened to less than 30^0, limiting the depth to which the probe could be lowered.

To expedite survey conduct, we supplied the logging crew with a comprehensive suite of information on each drill-hole including collar location, total depth, drillers' surveys, in-hole location of major fault zones and zones of poor rock quality, details of any surface casing and stranded in-hole casing, and, for the acoustic and optical televiewers and sonic logging tools which employ centralising spacers, depths of hole diameter changes. Drillers were requested to flush drill-holes on completion to remove grease, etc., but this wasn't always successful; in several instances rigs had to be recalled to site to undertake further cleaning. Drill-hole water turbidity prevented the successful application of the optical televiewer in most drill-holes.

Finally, did everything run smoothly? For the most part, yes, but in the last phase of the programme, while in-filling missing coverage, we did lose one probe, jammed in a drill-hole. As luck would have it, the drill-pad was small and uneven, requiring a track-mounted rig for safe access. Unfortunately, this rig had moved off-site, so an attempt at probe recovery was not immediately possible. Given that a track-mounted rig would have to be specifically sourced and brought back on site, recovery was deemed economically unviable at this time. And, no, it was not the radioactive probe!

Table 1. Geophysical logging operating parameters.

Geophysical method	Sonde type	Petro-physical parameter	Radioactive source	Spacer	Dry hole	Wet hole	Steel casing	PVC casing	Comments
Gravity	Sidewall gamma density	Density	Yes	Caliper	Yes	Yes	Yes*	Yes	*Dimished sensitivity
Magnetics	Magnetic susceptibility	Magnetic susceptibility	No	No	Yes	Yes	No	Yes	
Radioactivity	Gamma-ray and spectral gamma-ray	Natural radioactivity	No	No	Yes	Yes	Yes*	Yes	*Dimished sensitivity
Resistivity	Dual guarded resistivity	Electical resistivity	No	No	No	Yes	No	Yes*	*Must be slotted
IP-Resistivity	Dual spacing IP	IP effect and resistivity	No	No	No	Yes	No	Yes*	*Must be slotted
Electro-magnetics	EM induction conductivity	Electical conductivity	No	No	Yes	Yes	No	Yes	
Seismics	Full waveform sonic	Seismic velocity	No	Sprung spacers	No	Yes	Yes*	Yes**	*"Cement log" only **Diminished sensitivity
Geology and structure	Optical tele-viewer	Colour	No	Sprung spacers	Yes	Yes*	No	No	*Clean water
Geology and structure	Sonic tele-viewer	Seismic impedance	No	Sprung spacers	No	Yes	No	Yes*	*Limited sensitivity

Seismic window

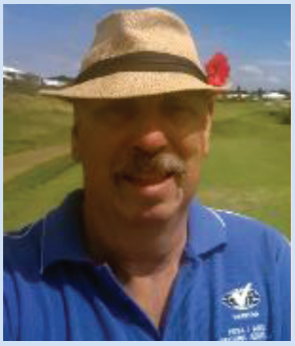

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Figure 1. *Seismic amplitude map extracted along an unconformity surface. Stars are hydrocarbon discoveries, circle are dry holes and "?" is an undrilled amplitude.*

The subtle trap – a case study

For a seismic interpreter unconformities are hard, but they are also useful in setting up subtle and not so subtle hydrocarbon traps. The following example from a well-explored area shows an undrilled amplitude anomaly in an area where several amplitude related discoveries have already been made (Figure 1). Three wells drilled where there were no amplitude anomalies were dry holes. The amplitude supported prospect looks attractive, but is undrilled because it is complicated, and complicated means risky.

Figure 2 is a strike line that runs SW-NE along the prospect area. It shows an unconformity that truncates a series of dipping reflectors, one of which has significantly higher amplitude than the others. It has been interpreted as a hydrocarbon filled reservoir.

There are several elements to the trap and they all have to be working for the prospect to work. It is obvious that the overlying shale (A) can provide the top seal in a simple structural trap, but in this case a thin transgressive sand could create leak points. Fortunately, the transgressive sand is not present or very thin in surrounding wells.

The reservoir section (B) immediately overlies a bland, low amplitude section (C) interpreted to be a shaley siltstone seal rock. In a truncation trap such as this, a base seal is required to prevent hydrocarbons leaking up-dip from the trap, although in the two sections shown here (Figures 2 and 3) this base seal is down dip of the sub-cropping edge. But that may not be the case everywhere.

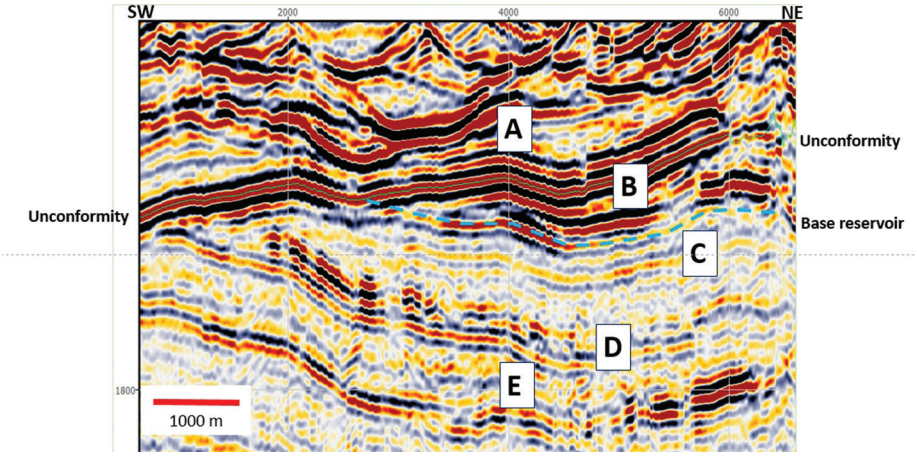


Figure 2. *Strike line along a fault terrace. A is the top seal shale, B is the sub-cropping reservoir, C is an interpreted shale, D Is a low amplitude sand and E is a thick regional shale.*

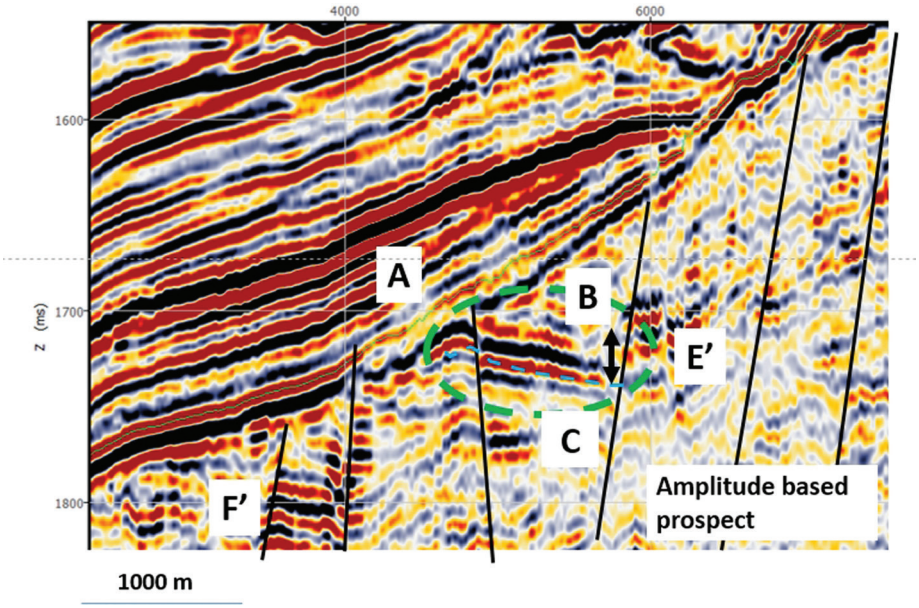
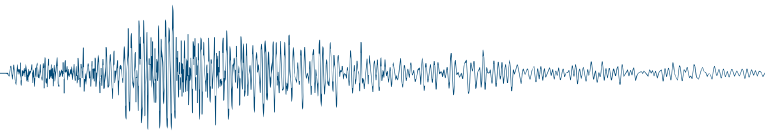


Figure 3. *A NW-SE dip line across the amplitude anomaly. The reservoir section B sub-crops the unconformity which is overlain by the top seal (A). The shale section C provides a base seal. Cross fault seal to the east is provided by the deeper shales in the foot wall and seal to the west is provided by down thrown younger shales. Structural dip to the west and north provide closure.*



Because this prospect is on a fault terrace, it also needs a cross fault seal. This is not difficult to the east because the large fault throws position the reservoir rocks in the hanging wall against the uplifted older shales (E').

Structural dip to the north provides closure in that direction, so this leaves the fault seal to the west. The western fault has a throw down to the west, which places younger possibly poor seal sediments against the reservoir section. However, the structural dip of the unconformity is down to the west along the western edge of the prospect (F'), so any hydrocarbons escaping to the west would be captured and fed back into the reservoir.

The amplitude supported prospect looks attractive with all the different trap elements considered, so what could go wrong? It all hinges on the presence or absence of the transgressive sand. This could make or break the trap, but the low chance of success given to this prospect is, I believe, because it is too complicated and difficult to understand.

Where is it? That's a secret, but if you can guess I'm told the acreage is for sale. Good luck.

Henderson byte: Are coronal mass ejections harmful to humans?

Coronal mass ejections (CMEs), as distinct from ordinary solar flares, are large clouds of magnetised gas or plasma erupting from the Sun's corona. Their appearance on the Sun, and how they differ from solar flares, is graphically shown in www.NASA.gov videos.

Generally, solar flares overwhelm the Earth's magnetosphere and cause magnetic storms that disrupt radio and electrical transmissions and knock out power stations and now, the internet. CMEs have a more powerful effect, and their possible impact on humans is particularly concerning with astronauts now in space and on the Moon. Consequently, there is an urgent need to be able to forecast their arrival, and as a result a new science of space weather is emerging, but that is a topic for another time.

A recent example of the damage that can be caused by CMEs was that attributed to the destruction of 40 Starlink satellites launched by SpaceX at beginning of February, 2022, when a CME produced extra drag in Earth's upper atmosphere causing them to burn up. Recent studies suggest that the storm that caused the Starlink disaster was only a relatively minor one.

Usually, some warning of a CME is a solar flare arriving at Earth one – two days after the eruption. However, it has been observed that some CMEs erupt with no visible warning. These are called "Stealth CMEs".

One researcher working on ways to predict CMEs is Jennifer O'Kane who, when at the Defence Science and Technology Laboratory in UK, used NASA's STEREO satellite (launched in 2006) explicitly to study CMEs. Its "stereo" ability enables a triangulation of the points of origin of CMEs on the Sun, which helped to convince O'Kane that some were erupting with no visible warning. In 2020, when at University College London, O'Kane used STEREO images to detect ultra-faint magnetic structures at the origin of stealth CMEs. She and others postulated that some different physics is involved in launching stealth CMEs. O'Kane has now joined a team of researchers in the International Space Science Institute in Switzerland who are studying this very question.

The frequency of coronal ejections is not strictly related to solar 11-year cycles. Large coronal mass ejections occur on average a few times a day at solar maximum, down to one every few days at solar minimum. One-third of CMEs are estimated to be stealthy in the cycle minimum, and even more in the cycle maximum. More on this topic is available at https://en.wikipedia.org/wiki/Coronal_mass_ejection

Researchers have observed that solar storms with their associated strong magnetic fields disrupt the navigation of pigeons and other birds and insects, and we know that changing magnetic fields alter human brain wave patterns (see Henderson, *Preview* **210**). By analysing the records of deaths in 263 US cities, Dr Vieira of Harvard University and her colleagues found that an excess of persons die of heart attacks in years of high solar activity (Science of the Total Environment, doi.org/h2dg). To better understand why, Dr Viera's team examined the ECGs of the hearts of 800 men in the US during intense magnetic disturbances and found that they exhibited stress (*New Scientist*, 25 June 2022). In years of strong activity this can amount to thousands of extra deaths. This research is ongoing.

Incidentally, the next maximum in the solar cycle is just three years away!

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Data trends

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ASEG GDF3?

I was discussing my Tech Standards woes with a colleague who replied "pretend you are developing GDF3, what would it look like?"

For the uninitiated, the ASEG GDF2 standard includes multiple ASCII files:

- .dat (data) is a fixed width text file with columns of data where each line is a sample location
- .dfn (definition) defines the .dat fixed widths and what sits inside them
- .des (description) is a (tiny) report
- .prj (projection) defines the data/projection used
- .ddf is essentially the .dfn rearranged into a monolithic list for machine reading

The .dat and .dfn files are the bare minimum, and we need to encourage (or enforce) greater use of the other files. This requires the ASEG to publish such recommendations, and would tie in with the idea that the ASEG should host a GDF2 checking website.

What do I like about GDF2? It does not mandate column names and therefore has been used for almost all types ground and airborne geophysical surveys, as well as in Kim Frankcombe's adaptation for electrical surveys (ESF). What we need now (GDF3) is a set of predictable data names without too much interference.

Machine consumable

People want data to work out of the box. GDF2 already has aliases for base data:

- X (including datum and projection)
- Y (including datum and projection)
- Fiducial
- Line Number
- Flight Number
- Date

At least one additional alias is required for potential field data to be immediately usable:

- Line Type (flight or tie)

Line direction information is sometimes in the .des file but not in a form predictable for parsers, and often there is no .des file to parse.

Aliases

Set names do not come out of devices or surveyors and even units can depend on the device. Aliases can identify the important columns for automating interoperability for significant data such as "final_mag" or "final K/Th/U". The shorter the better for maximum backwards compatibility.

The examples above show the dominance of airborne mag and rad data, but we need to cater for data from other survey types. What columns are significant for gradiometry? Do we need a column recording instrument direction (NED or END) or a single .des file entry? Should all tensors be present? EM produces numerous "slices" so can we assign an alias to an array?

Such matters are being considered by the ASEG Naming Convention subcommittee and any ideas relating to the evolution of GDF2 are welcome (technicalstandards@aseg.org.au).

Webwaves

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Preview digital library update

In *Preview* **209** I highlighted the creation of the *Preview* digital library and the hosting of the back catalogue of *Preview* on the ASEG website. This was followed in *Preview* **217**, where I completed a similar collection for the historic copies of *Exploration Geophysics* and the ASEG Bulletin. These libraries have continued to grow with new publications as they are released, with the *Exploration Geophysics* collection expanded to include the recent issues of Volume 53. These webpages continue to be very popular with Members: the *Preview* webpages continue to be the most visited pages on the ASEG website, and the *Exploration Geophysics* webpage is the eighth.

Until just this week, the *Preview* collection had a number of missing issues from the early releases, namely *Preview* 2 to *Preview* 14 (1986 - 1988). Following effort on the part of Roger Henderson, our History Committee Chair, Greg Street has given the Society copies of these early issues (many thanks!). Also included were copies of the ASEG Newsletter from 1984 and 1985 (before the Newsletter was renamed *Preview*). These hardcopies have been digitised into single PDF files for each issue, with the front page turned into a JPG file for display on our digital bookcase. Any errors or mistakes are entirely my own, and should be reported so I can rectify them.

Figure 1. *ASEG Newsletter and Preview from 1984 - 1988*

I hope you enjoy reading these historic copies of *Preview* and the ASEG Newsletter, but please don't post $36 for a case of 1983 Vintage Shiraz Cabernet from Penfolds Wines, you will not be receiving it (ASEG Newsletter, October 1985)!

Figure 1 shows the covers of the earliest issues of *Preview*.

Some notes for each year that has been uploaded:

1988: *Preview* **13** and *Preview* **14** were published in February 1988 and April 1988, with a gap in June before the new look *Preview* was published in August 1988 starting with Issue 15. This resulted in five issues of *Preview* in 1988.

1987: The *Preview* collection from 1987 is complete, although our copy of *Preview* **11** is missing some internal pages. This special conference edition featured information on the upcoming Adelaide '88 conference. If anyone has a copy, please get in touch.

1986: While *Preview* **5**, **6**, and **7** have standardised to the August, October and December releases, *Preview* **1** - **4** were released in January, March, April and June resulting in seven issues of *Preview* in its inaugural year of 1986.

1985: Two copies of the pre-*Preview* ASEG Newsletter were provided, covering March and October 1985.

1984: A single issue of the ASEG Newsletter has been provided for August 1984. Any further copies of the ASEG Newsletter from 1985 and earlier will be gratefully received.

If anybody has historic copies of other ASEG publications that are not yet digitised on the ASEG website, please get in contact with me at webmaster@aseg.org.au to facilitate their digitisation and sharing with the geophysical community.

AEM2023

8th International Airborne Electromagnetics Workshop

4–8 September 2023
Fitzroy Island, QLD, Australia

The 8th International Workshop on Airborne Electromagnetics will be held at Fitzroy Island, Queensland Australia, in person between the 4th and 8th September 2023. Fitzroy Island is an unspoilt tropical paradise of rainforest and beaches within the calm sheltered waters of the Great Barrier Reef. The island is a National Park, with walking trails, tropical plants and animals, and abundant marine life.

The Workshop will encompass advances in airborne electromagnetic systems, modelling and interpretation. Case studies covering geotechnical, mining, energy, groundwater and environmental applications will be presented. The event will be a platform to contribute, discuss and learn about airborne electromagnetics and provide a forum for in-depth conversations on the subject area with colleagues from Australia and worldwide.

A four-day program will feature speakers from academia, government and industry, with keynotes delivered by leading experts in their respective streams.

If you would like to keep up to date about the event, please scan the QR code and fill in your details.

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Hydrogen exploration: The next big thing?

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The world is going through strange times. Whilst the global race towards carbon Net-Zero continues, 2022 has seen hydrocarbon commodity prices peak. Hydrogen has emerged as a potential saviour to the world's energy crisis, with increasing resources being dedicated to developing hydrogen technology, infrastructure, and storage capacity. However, the production of hydrogen from water is both costly and extremely energy intensive. The concept of natural hydrogen exploration remains beyond conventional thinking amongst many geoscientists. A key stumbling block remains in finding sources of environmentally friendly, or 'green' hydrogen. This begs the question: can natural hydrogen be explored for and exploited? Recent measurements of H_2-fertile geological regions indicate high natural hydrogen generation at the present day in regions that contain altered basic igneous rocks. In this article, I explore the possibility of applying the well-established 'hydrocarbon kitchen' concept to the exploration of hydrogen as a commercially exploitable resource.

Old fashioned cooking

Traditional thinking by geoscientists exploring for oil and gas is dominated by the well-established concept of the 'petroleum kitchen'. In a successful petroleum kitchen, an organic-rich source rock such as shale, expels hydrocarbons as it is buried and experiences increased pressures and temperatures, i.e., cooked. Buoyant hydrocarbons migrate along carrier beds until they reach an impermeable barrier and accumulate in structural or stratigraphic traps. These traps are targets for hydrocarbon exploration. These processes occur over geological timescales and are predicted in a variety of ways, including using basin modelling. However, most geologists and geoscientists across both academia and industry share the preconception that naturally occurring hydrogen cannot accumulate in geological formations or remain stable for geologically significant periods. This is because hydrogen, as the lightest element, is highly mobile.

A new kitchen

Several lines of recent research indicate that the percolation of meteoric fluids along faults characteristic to fossil arc–continent collision orogens (e.g., New Caledonia) and other hydrogen-rich terranes may play an important role in the formation of hydrogen-rich fluids (Dugamin, Truche and Donzé, 2019; Ulrich *et al*., 2020; Patriat *et al*., 2022) (Figure 1).

Naturally occurring H_2-fertile geological settings include regions of serpentinised mafic rocks (e.g., ophiolites) and regions tapped by faults that act as conduits for mantle-derived hydrogen (e.g., Ellouz *et al*., 2003; Ulrich *et al*., 2020; Lefeuvre *et al*., 2021). In these examples, the process of serpentinisation of mafic rocks produces fluids which are highly enriched in molecular hydrogen. The liberation of hydrogen from serpentinite by percolating groundwater is analogous to the generation of oil and gas from kerogen in the hydrocarbon kitchen. Recent measurements of gas seepages in the ophiolitic rocks of New Caledonia into ultrabasic spring water (pH ~10-11) show that the gases are H_2-N_2-CH_4 mixtures with H_2 contents between 12–34% (Deville *et al.* 2021, Patriat *et al* 2022). Recent investigations of natural hydrogen seeps in the Western Pyrenees, Spain, found that major thrust faults may act as conduits for hydrogen produced by the serpentinisation of mafic mantle rocks at depth (Lefeuvre *et al.* 2021). The ability for hydrogen to migrate along faults is not surprising, but represents the important step of migration. Furthermore, the prospect of meteoric waters percolating through naturally fractured serpentinised rocks raises obvious parallels to hydraulic fracturing. The final step in the hydrogen kitchen is the existence of a trap that can hold hydrogen on timescales suitable for extraction by humans. Clearly, this is different to a trap capable of holding stable hydrocarbons in the traditional hydrocarbon kitchen.

The storage of gaseous hydrogen in salt caverns is already used on an industrial scale (Andersson and Grönkvist 2019). As is well known, salt deposition occurs as water evaporates and thick accumulations characterise salt basins across the world. Subsurface salt bodies may be significant in size and be 10-100s km long and several kilometres high. Hence, it is possible that salt bodies within the vicinity of buried mafic rocks may be charged by hydrogen produced by serpentinisation and delivered by faults. It is exciting that the geological and stratigraphic accumulation of hydrogen, i.e. trap, may be achieved by the

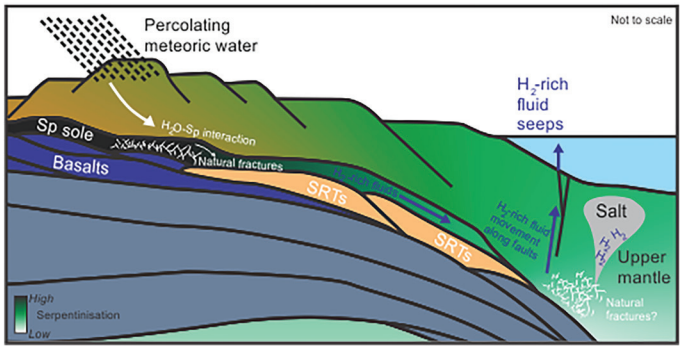

Figure 1. *Conceptual model for possible fluid-rock interactions at the New Caledonia ophiolite. Sp = Serpentenite, SRTs = Subduction-related terranes (e.g., Diabot Terrane at New Caledonia). Interaction between percolating meteoric waters and serpentinised mafic rocks at base of the fossil subduction zone are known to produce H2-rich fluids (Ulrich* et al.*, 2020; Patriat* et al.*, 2022). Movement along natural fractures within serpentinites or faults may provide migration pathways to natural hydrogen seeps at the surface. Modified from Ulrich* et al.*, 2020. A salt diapir is displayed for illustrative purposes only, which may act as a store for naturally produced hydrogen (e.g. Andersson and Grönkvist, 2019; Lefeuvre* et al.*, 2021). Salt structures have been identified in the New Caledonia Basin (e.g., Auzende* et al.*, 2000), thus illustrating the interesting possibility of a meteoric fluid – serpentinite – evaporite hydrogen kitchen in similar geological settings around the world.*

presence of shallow (<10 km) mantle rocks overlaid by multiple doleritic sills and aquifers (Lefeuvre *et al.* 2021), or subsurface salt structures (Andersson and Grönkvist 2019).

The storage of gaseous hydrogen in salt caverns is already used on an industrial scale (Andersson and Grönkvist, 2019). As is well known, salt deposition occurs as water evaporates and thick accumulations characterise salt basins across the world. Subsurface salt bodies may be significant in size and be 10-100's km long and several km high. Hence, it is possible that salt bodies within the vicinity of buried mafic rocks may be charged by hydrogen produced by serpentinisation and delivered by faults (Figure 1). It is exciting that the geological and stratigraphic accumulation of hydrogen, i.e. trap, may be achieved by the presence of shallow (< 10 km) mantle rocks overlaid by multiple doleritic sills and aquifers (Lefeuvre *et al.*, 2021), or subsurface salt structures (Andersson and Grönkvist, 2019).

Clearly, more research is required to improve our understanding of how hydrogen migrates through the subsurface and whether recent generation coupled with short-term migration (compared to geological time scales) can deliver commercially exploitable hydrogen resources. Recent estimates of velocities in generalised sandstones calculated using oil- and gas-water saturation relationships indicate that hydrogen may move vertically at ~4 m/year at the surface and ~2 m/year at a depth of 2 km (Lodhia and Clark, 2022). Whilst these values are a gross simplification, they illustrate the potential timescales of hydrogen migration. Future research should focus on understanding hydrogen gas-water saturation relationships. Application to mafic and other rock properties may help determine the migration pathways of hydrogen using a similar approach to Lodhia and Clark (2022).

Even though naturally occurring hydrogen is found at surface seeps and within the subsurface, there exists no framework to explore for naturally occurring hydrogen in H_2-rich geological settings. Momentum behind hydrogen exploration is growing, with jurisdictions such as South Australia granting or receiving applications for 18 exploration licenses by six different companies searching for natural hydrogen since February 2021 (Lodhia and Clark, 2022, Peacock, 2022). I believe that future research should focus on the development of a set of standard criteria for hydrogen exploration, e.g., presence of serpentinised mafic rocks, migration pathways and existence of a storage medium. Such criteria may hopefully contribute to the development of the concept of a hydrogen kitchen and commercial hydrogen exploration.

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The conductivity of bornite, **peacock ore**, a copper-iron sulphide

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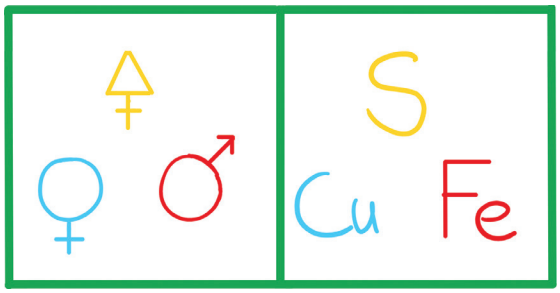

Introduction

Copper is a prominent member of the green metal suite (Cu, Ni, Li, rare earths) essential to the world's embrace of decarbonisation which entails a need for ever more electric cabling. Copper's value has increased substantially (currently ~ $10 000 per tonne) and so has exploration interest in a metal mined for millennia and still keenly sought. In exploration geophysics, applied to copper provinces, the conductivities of copper sulphides are a significant consideration. It is interesting to note that graphite, ironically, is also in demand for green technologies. It sells for ~ $1000 / tonne. Graphite is semi-metal (electronically) and very conductive in concentrated form (see my article in *Preview* **72**).

The three commercially significant Cu sulphides are: chalcopyrite, a primary mineral, lowest grade; chalcocite, highest grade, usually found in secondary enrichments; and bornite (erubescent peacock ore), intermediate grade occurring in both primary and secondary modes. Associated sulphides include digenite and covellite (usually minor constituents of a deposit) and the iron sulphides; pyrite and pyrrhotite. These sulphides are soft (except for pyrite) and form part of the Cu-Fe-S system (Klein & Hurlbut, 1993) as listed in Table 1 and depicted in Figure 1. Bornite seems to have been little studied.

Materials

Attractive types of bornite are shown in Figure 2 where pretty crystal colours and tints are evident. The striking iridescence of some bornite gives it the name of peacock ore. However, most bornite occurs in unappealing, granular, massive forms manifesting dark purplish or black hues. Such were the appearances of the bornites (from Zambia, Mexico and Victoria) available for this study. These samples were checked for softness (Moh's hardness 3) and visually inspected for other sulphides that, when present, were in minor/trace amounts only. The absence of pyrrhotite was attested by low magnetic susceptibilities. Some samples were pyrrhotitic but were discarded from testing as pyrrhotite would have dominated the conductivity measurements. The bornite mineralogy was checked by noting softness and checking the brownish bronze colour of fresh fracture surfaces – a characteristic of bornite. Bornite samples were difficult to obtain. Several samples purporting to be bornite were found on examination to be mainly chalcopyrite, pyrite, and pyrrhotite mixes and, accordingly, discarded.

For interest and for comparison some chalcopyrite samples (pyrrhotite free) were measured and included in the study.

I have already discussed the mesoscale conductivities of chalcocite (*Preview* **212**), pyrite (*Preview* **203**), and pyrrhotite (*Preview* **92**, **188**).

Measurements

Mesoscale electrical conductivities of suitable bornites were measured to show how these compare with other sulphides. Mesoscale means core or hand sample usually comprising crystal or granular aggregates; it is intermediate between the microscale (small single crystal) and the macroscale (regional

Table 1. Some sulphides in the Cu-Fe-S system.

Mineral	Type of conductivity (Shuey, 1975)	Formula (approx.)	Cu	Fe	S	Density g/cc	Magnetic susceptibility	Hardness (Mohs scale)	Electrical conductivity
			← wt. % →				SI x 10^{-10}		
Chalcocite	p type semiconductor	Cu_2S	79.8	0	20.2	5.7	→ 0	3	moderate
Digenite	p type metal	$Cu_{6.9}Fe_{0.1}S_4$	76.6	trace	22.4	5.6	→ 0	3	extremely high
Covellite	p type metal	CuS	66.4	0	33.6	4.7	→ 0	2	extremely high
Bornite	p type semiconductor	Cu_5FeS_4	63.3	11.2	25.5	5.07	~ 55	3	see text
Chalcopyrite	n type semiconductor	$CuFeS_2$	34.6	30.4	35.0	4.2	~ 35	4	high
Pyrite	p,n type semiconductor	FeS_2	0	46.6	53.4	5.02	4	6 1/2	moderate
Pyrrhotite, mon.	low mobility metal	Fe_7S_8	0	60.4	39.6	4.6	35000	4	very high
Pyrrhotite, hex.	low mobility metal	Fe_9S_{10}	0	61.1	38.9	4.7	144	4	very high

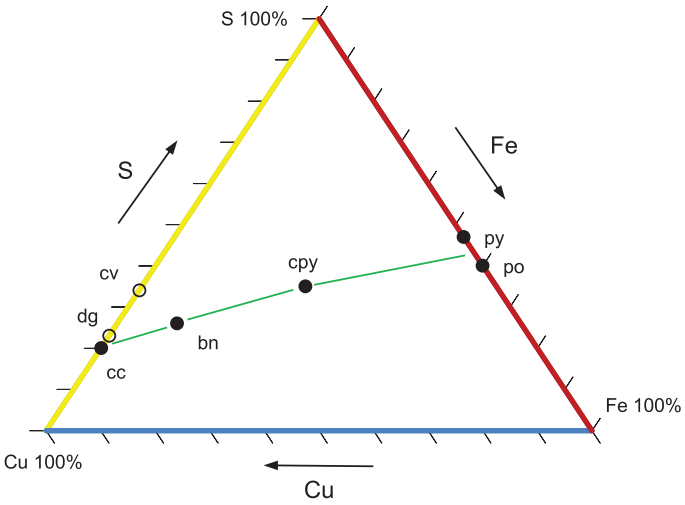

Figure 1. *Mineral compositions in the Cu-Fe-S system (ternary plot, clockwise axes, weight percent proportions Table 1). The Cu minerals are important in copper exploration as they are major ores and are electrically conductive. The Fe minerals are included as they frequently occur with the copper sulphides, and they are electrically conductive too. The native metals, Cu and Fe, usually occur as disseminations or minor masses in host rocks. Their conductivities are of the order of millions S/m; sulphur is an insulator. This ternary plot maps the mineralic combinations of Cu, Fe, S that are of interest in sulphide exploration. This article does not address exploration for the three native elements Cu, Fe, S.*

perspective). Measurement techniques employed in this work have been discussed in previous articles; details will not be repeated here. Ten bornite samples from Zambia, Mexico, and Victoria were tested for density, magnetic susceptibility, and electromagnetic conductivity. The results are presented in Table 2. Measurements on twelve samples of chalcopyrite ores from Mt Isa (Queensland) and Cobar (New South Wales) are also listed.

Discussion

The data listed in Table 2 and plotted in Figure 3 (conductivity vs density) show a range of moderate conductivities for bornite and higher conductivities for chalcopyrite, with each sulphide type confined to separate groups. The two groups show an overall increase in conductivity with density i.e. as sulphide content increases. The scatter of points in each group results from the sulphides' textural variety, e.g. grain size and shape, stringers, lamellae, dendrites, breccia etc. Pyrrhotite's conductivity contributions are regarded as minimal or non-existent as attested by visual (binocular) examinations (none seen), galvanic microprobing (pyrrhotite's very low resistivities were

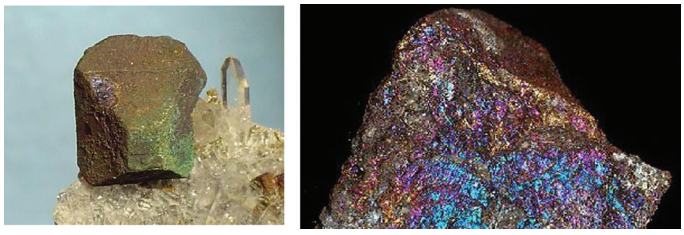

Figure 2. *Slightly iridescent bornite tetragonal crystal ~ 10 cm³ volume (left) and bornite tarnish (right). Bornite is a coppery red/brown colour when fresh, but tarnishes rapidly on exposure -> peacock ore with purple and blue hues predominating, finally turning almost black with prolonged exposure. Most bornite occurs in massive dark aggregates which show a distinctive brown-bronze colour on fresh fractures.*
Source: https://en.wikipedia.org/wiki/File:Bornite-Quartz-135210.jpg / CC BY SA 3.0 https://commons.wikimedia.org/wiki/File:Mineraly.sk_-_bornit.jpg / CC BY 2.0

Table 2. Physical property data for bornite and chalcopyrite.

Sample no.	Bulk density g/cc	Magnetic susceptibility SI x 10^{-5}	EM conductivity S/m
Bornites ◆			
B1	4.85	72	300
B2	4.61	65	234
B3	3.95	34	75
B4	3.40	32	55
B5	4.50	31	515
B6	3.24	14	72
B7	4.52	40	850
B8	3.48	22	71
B9	4.38	41	419
B10	4.08	29	305
Chalcopyrites ◆			
CP1	3.01	50	169
CP2	3.08	63	116
CP3	3.53	42	1003
CP4	3.45	24	710
CP5	3.33	41	522
CP6	3.12	26	244
CP7	3.69	78	1214
CP8	4.09	60	4238
CP9	4.07	48	5530
CP10	3.94	42	929
CP11	3.37	51	879
CP12	2.94	44	218

Notes: Porosities low, not cited; electromagnetic (inductive) conductivities rounded off; measurements deemed accurate to better than 1%; samples B1, B2 from Buchan, Victoria; B3, B4 from Mexico; B5-B10 from Zambia; samples CP1-10 from Mt Isa Block, Qld; CP 11,12 from Cobar Mineral Field, NSW.

The bornite and chalcopyrite mineralisations range from veinlet-disseminated through sem-massive to massive styles and are hosted by felsics or metasediments. Many of the samples are textured so the EM conductivities cited here are the maximum values measured in an induction coil.

not observed) and the low magnetic susceptibilities. Hexagonal pyrrhotite could be present, and not contribute much to the magnetic susceptibility, but this is unlikely as most terrestrial pyrrhotite are intergrowths of the hexagonal and monoclinic varieties (Gould, 1967). The extrapolated bornite trend intersects bornite's density at ~800 S/m; the chalcopyrite trend suggests ~5500 S/m when extrapolated to chalcopyrite's density.

It was difficult to find suitable bornite specimens that are devoid of other sulphides (usually pyrrhotite) so the number of data points is limited. However, it seems reasonable to infer the conductivities, while by no means definitive, are usefully indicative as to the mesoscale conductivities of bornite and chalcopyrite. These can be compared to those for chalcocite, pyrite, pyrrhotite, and graphite in Figure 3.

Some work has been published on single crystal bornite conductivities (Shuey, 1975). Harvey (1928) found a range of 333 – 50 000 S/m for 16 samples from the Harvard University Economic Geology Lab collections. Telkes (1950) measured samples from Bisbee, Arizona – 769 S/m; Butte, Montana – 3226 S/m; Sangenbausen, Germany – 6250 S/m; Silverton, Colorado – 14 286 S/m. Takeno et al (1968) measured low conductivities

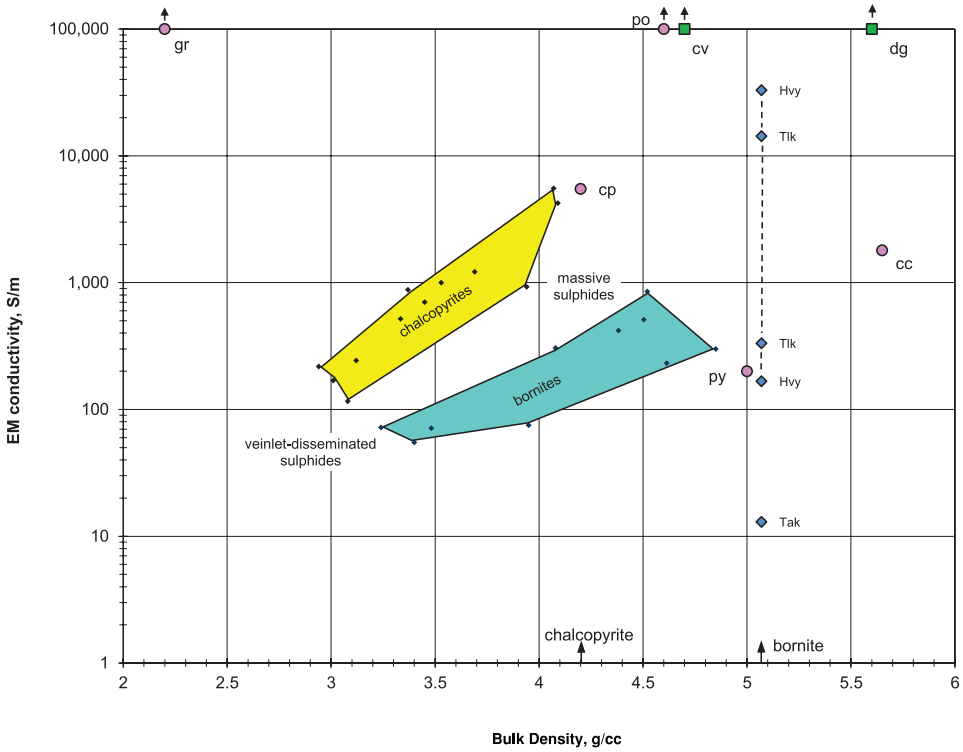

Figure 3. *Cross plot of EM conductivity against bulk density for suites of bornites and chalcopyrite measured (Table 2) at mesoscale. Ranges of microscale single crystal data are included for comparison: Hvy (Harvey, 1928) 16 measurements from unspecified localities; Tlk (Telkes, 1950) four localities; and Tak (Takeno et. al., 1968) nominal measurement; all measured by microgalvanic techniques and cited by Shuey (1975). Nominal values for massive deposits of graphite (gr), pyrrhotite (po), chalcopyrite (cpy), pyrite (py), and chalcocite (cc) are also plotted – these values are based on previous work. The data plot suggests that materials regarded in the field as bornite are less conductive than chalcopyrite, and intermediate between pyrite and chalcocite, ~800 S/m for 100% bornite. Note that the single crystal conductivities of the reference minerals [graphite, pyrrhotite, covellite (cv), digenite(dg)] can be much higher than the massive mineral aggregate values plotted here.*

~13 S/m, for natural and synthetic bornites. These values are plotted on Figure 3, where it is seen that Harvey's lowest conductivity and Telkes' Bisbee sample conductivity are similar to that extrapolated to the massive bornite ore density. Most of the single crystal bornite conductivities have higher or far higher values than those measured in this study; the Takeno *et al.* value is far lower. Shuey (1975) suggests that the low Takeno conductivity may be appropriate for bornite and that very fine included networks of extremely conductive digenite and covellite are responsible for the higher conductivities. These minerals have been apparently observed by others at highest magnification in optical studies of some bornites. Be that as it may, and noting that such considerations and detail are far beyond the scope of this preliminary study, it is clear that this study's multicrystalline bornite samples from three localities manifest conductivities intermediate between chalcopyrite and pyrite and probably below that of chalcocite. These conductivities are considered to be of the order of several hundred S/m for massive bornite sulphides. If Takeno *et al.* are to be believed, the bornites may have incorporated threaded networks of minor or trace amounts of more conductive copper sulphides, but it was not possible to establish or refute that possibility here.

Conclusions

In articles over recent years, I have provided data on the mesoscale conductivities of several members of the important Cu-Fe-S system: previously pyrite, pyrrhotite, chalcocite; now bornite and chalcopyrite. The data and analyses suggest that pyrrhotite is extremely conductive and its pervasive habit will dominate conductivity in sulphide ores, even in small amounts (*e.g.* see my article on Broken Hill galena ore, *Preview* **188**). Pyrite, in aggregated grains and crystals, is not so conductive. The three major sulphide ores of copper, if pyrrhotite-free, are moderately to highly conductive: bornite -> chalcocite -> chalcopyrite. More bornite measurements would be desirable either to corroborate or modify these conclusions. The effects, if any, of other copper sulphides (such as covellite and digenite) on commercial Cu sulphide ores need further investigation.

Acknowledgements

Thanks are due to David Kalnins for suggestions, and for the preparation of the manuscript and figures.

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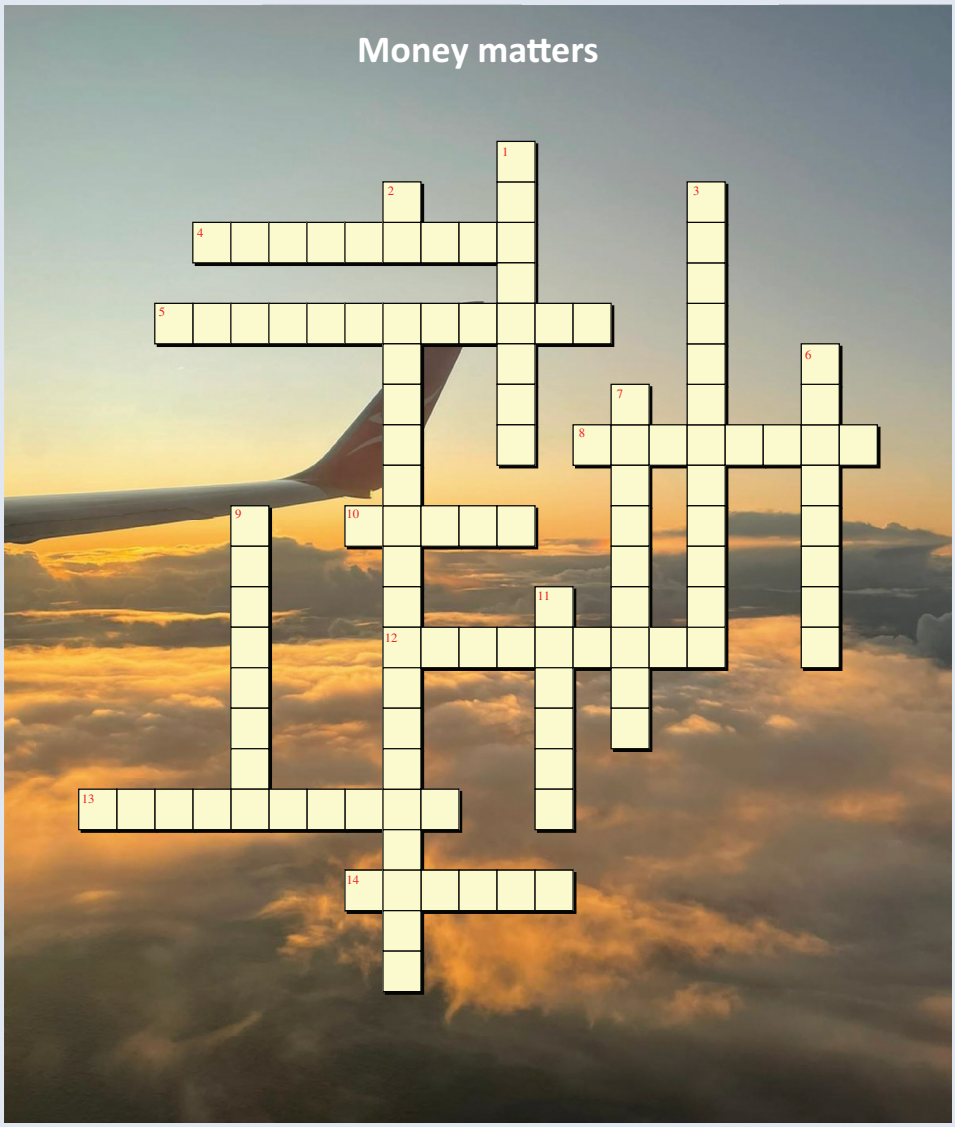
Don Emerson is a geophysical consultant specialising in the physics of minerals and rocks, he also has an interest in ancient and medieval geoscience.

Preview crossword #22



Across	Down
4 The ability to undertake economic transactions with people in other countries free from any restraints imposed by governments or other regulators (4,5)	**1** A lender, whether by making a loan, buying a bond or allowing money owed now to be paid in the future
5 The process of gradually writing off the initial cost of an asset	**2** The total monetary or market value of all the finished goods and services produced within a country's borders (5,8,7)
8 The distribution of a company's earnings to its shareholders	**3** The decrease in monetary value of an asset over time due to use, wear and tear or obsolescence
10 An investment that is made with the intention of reducing the risk of adverse price movements in an asset	**6** A market structure characterised by a single seller or producer that excludes viable competition from providing the same product
12 A general increase in the prices of goods and services in an economy	**7** The efficiency or ease with which an asset or security can be converted into ready cash without affecting its market price
13 A prolonged period of slow economic growth	**9** A country or jurisdiction with very low "effective" rates of taxation for foreign investors (3,5)
14 A market condition where an asset's price rises rapidly, but its intrinsic value remains significantly lower	**11** The tax on goods produced abroad imposed by the government of the country to which they are exported

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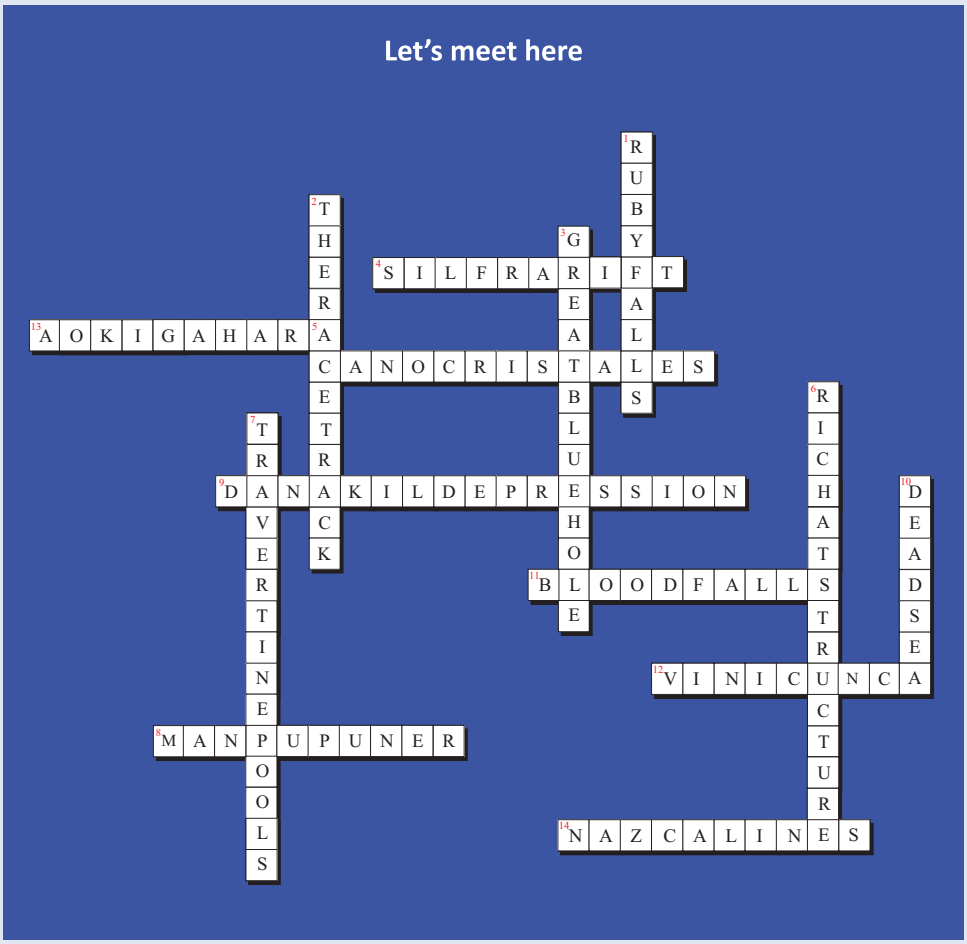
Good luck!

Preview crossword #21 solution



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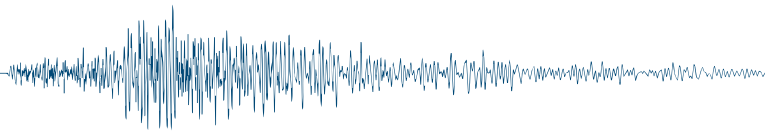

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Organisation		
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E-mail (alternate)		
Mobile	Phone (W)	Phone (H)

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❑	Associate	Please complete all sections
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Seconder			

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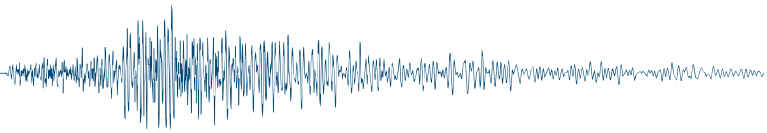

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Department	
Major Subject	Expected Year for completion of studies
Supervisor/Lecturer	Supervisor Signature

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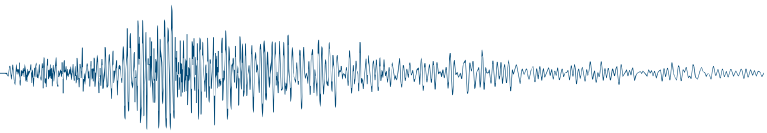

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October	**2022**		
24	Asia Pacific Meeting on Near Surface Geoscience & Engineering https://eage.eventsair.com/5th-asia-pacific-meeting-on-near-surface-geoscience-engineering/abstract-submission	Taipei	Taiwan
26–29	Summit on drone geophysics 2022 https://seg.org/Events/Summit-on-Drone-Geophysics-2022		Virtual
November	**2022**		
9	MAG22 Modern application of geophysics: Mineral case studies https://www.eventbrite.com.au/e/mag22-modern-applications-of-geophysics-mineral-case-studies-tickets-404398866897?aff=ebdssbdestsearch	Perth	Australia
25	Geological Survey of Western Australia Open Day https://www.dmp.wa.gov.au/Geological-Survey/GSWA-Open-Day-29468.aspx	Perth	Australia
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
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
13–18	Australasian Exploration Geoscience Conference (AEGC 2023) https://2023.aegc.com.au/	Brisbane	Australia
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

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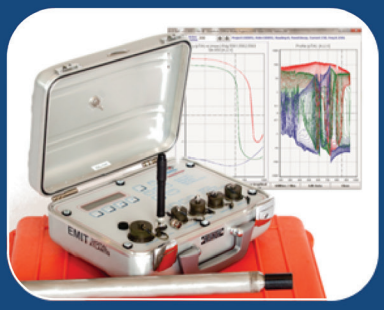

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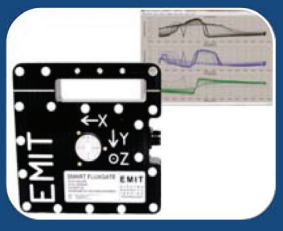

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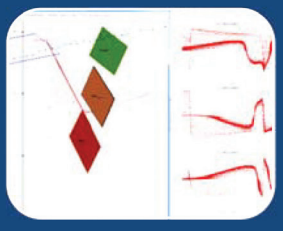

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