Australian Society of Exploration Geophysicists

DECEMBER 2023 • ISSUE 227
ABN 71 000 876 040 ISSN 1443-2471

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FRONT COVER

Rebecca Latto (on right) who completed her Masters thesis at the University of Tasmania in 2023. See *Education matters* in this issue for more information.

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

ISSN: 1443-2471 eISSN: 1836-084X

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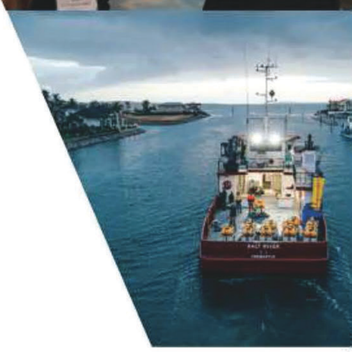

Editor's desk

Change is underway in *Preview* land.

The ASEG Federal Executive, supported by the ASEG Publications Committee, has decided to resume responsibility for production of *Preview*. The ASEG will be entirely responsible for the content and design of the magazine from January 2024. The design of the magazine has, for the past five years, been constrained by the rather rigid formatting requirements of a production system set up for journals by Taylor and Francis (T&F). A change to self-production will eventually allow us to move to a more dynamic layout and offer more interesting possibilities to advertisers. A digital version of the magazine will continue to be published on the ASEG website and, at this stage, T&F will continue to allocate DOIs to individual articles and publish them on their website. This is primarily so that institutional sales that currently pair *Preview* and *Exploration geophysics* can be honoured. Hard copies of the magazine will now be printed and distributed by the ASEG within Australia. This change should result in a significant improvement in delivery times for all Australian subscribers.

It is the ASEG's hopeful expectation that most of the cost of production, including print and distribution, will eventually be covered by income from advertisers. Many of you will be aware that our advertising base fell away when we moved from CSIRO Publishing to Taylor and Francis. We think that this was partly because the T&F advertising team, which is based in the United States of America, did not have a good understanding of our industry, and was not prepared to put time and effort into getting to know individual players. We are hoping that by resuming control of production, including advertising, we will be able to rebuild our advertising base to the point where *Preview* is a going, and growing, concern.

As this issue of *Preview* will be the last issue produced by T&F, I would like to thank the T&F production team for individually doing their best to produce *Preview* under what were sometimes difficult circumstances (COVID, remember that?!), and sometimes a difficult and demanding Editor. All the very best for your own futures and for us, the *Preview* Editorial team and our loyal readers, it is onwards and upwards!

This Christmas issue of *Preview* features an article by Ken Witherly. The article entitled "What lies beneath revisited – supergene enrichment and conductivity" builds on a talk he gave to AEGC in Perth in 2019, and on talks he gave to a number of ASEG branches when he was in Australia at the end of last year. Ken enjoins us to think outside the box – always important in exploration! This issue also features, as we have come to expect at this time of year, summaries of theses completed in geophysics in Australia in 2023 (*Education matters*). As Marina Pervukhina says, this compendium is noteworthy in that we received contributions from nineteen students. That number suggests that there is still a significant number of postgraduate students in geophysics in Australia. Some of these students have participated in one of the CAGE field camps (CAGE 2023 is reported on in this issue). This popularity of these camps also suggests that student interest in geophysics is alive and well – so maybe it is not all doom and gloom out there!

In other news and commentary, in this issue of *Preview* David Denham (*Canberra observed*) reflects on the latest data from the UNEP that suggests that the chances of limiting global warming to 2.0°C by 2050 are close to zero. He also takes a look at the latest figures on exploration investment in the Resources and Energy Quarterly for 2023. Mike Hatch (*Environmental geophysics*) has prevailed on Dave Allen to give us a lesson on the use of microwaves for communication in geophysics. Terry Harvey (*Mineral geophysics*) reminds us of the dos and don'ts of follow-up geophysical surveys. Mick Micenko (*Seismic window*) is intrigued by LinkedIn commentary on split spread seismic data acquisition. Tim Keeping (*Data trends*), updates us on big data and machine learning, and Ian James (*Webwaves*) muses on what we can learn from the Optus outage.

Enjoy, and on behalf of the *Preview* Editorial Team, a safe and happy festive season to you all!

Lisa Worrall
Preview Editor
previeweditor@aseg.org.au

President's piece

Eric Battig

As we prepare to draw the curtains on 2023, I am amazed at how quickly this year has passed by. Outside of the sphere of the ASEG, the year has been marred by conflict and ensuing humanitarian crises abroad, and domestically we went to our first referendum in almost 25 years. My thoughts are with any of our readers who have had their lives, or those of loved ones, impacted by these events.

Reflecting on 2023 through the lens of the ASEG, there have been a number of significant events through the year, and we have made material progress against a number of strategic priorities that we established at the beginning of the year.

We will be moving *Preview* to self-production in 2024. There has been acknowledgement from both ASEG and Taylor & Francis (T&F) that, as T&F is a commercial publisher specialising in scientific journals, their workflows are not suited to a magazine such as *Preview*. This general mismatch between the publisher and magazine style has unfortunately often resulted in many frustrations for ASEG volunteers.

Self-production will mean that our volunteers are in control, with potential for improved income through advertising, and the possibility of more dynamic content as well as content delivery via phone apps etc. The experience gained by the ASEG in self-production will also serve us well as we continue to look at how to improve the impact of our publications. This includes ongoing concerted efforts to improve the appeal of our flagship scientific publication, *Exploration Geophysics* (*EG*), as we seek to prioritise the value and relevance of *EG* for ASEG Members.

We set out to revitalise our publications at the start of the year, and our Publications Committee are working tirelessly and are performing an amazing collaborative effort with T&F to bring this to fruition. However, to truly make this a sustainable success story will require extra help, especially in the advertising space. Please reach out to Steve Hearn (publications@aseg.org.au) or Lisa Worrall (previeweditor@aseg.org.au) if you are keen to help.

A further milestone for our publications and web team has been the self-publication of *Extended Abstracts* for the 2021 and 2023 AEGC and AEM 2023. It's a moment our authors and readers have no doubt been waiting for, and the process has provided useful knowledge to our team, including in the practices of digital workflow and formal DOI allocation.

I have just come back from MAG 23, which once again delivered an engaging programme with invited talks spanning regional targeting, case studies and petrophysics. We had over 20% participation from students and early career professionals, and the organising committee did a tremendous job in bringing these groups together. A special mention should go to Richard Lilley and NexUS in that regard. The opportunity MAG 23 offered for engagement between students, early career professionals and the more experienced professionals in the room was refreshing. While this event can't single-handedly turn the tide of the decline in geophysical professionals, one couldn't help but feel a sense of optimism about the sustainability of our industry. I hope that MAG 23 will serve as a model for future ASEG events.

Staying on the Society's aims of growing geophysical capabilities and content delivery, I am pleased to report that significant progress is being made on preparations for DISCOVER 2024. We have engaged our PCO and are finalising dates and venue selection. You will be sent further information, including key dates (abstract submissions *etc.*) before the end of the year.

It is likely that as you read this column you will have already taken advantage of our Early Bird offer to renew your membership for 2024. If you have, thank you for your ongoing support. Renewals are still very much open, and we also encourage prospective members to take the plunge and apply for ASEG Membership today – the membership forms are available online and are reprinted at the end of every issue of *Preview*. I am confident that, together, 2024 will be even bigger than 2023.

Finally, with the end of the year only days away, I hope you are all about to settle into a well-earned break with family and friends. I know I am.

As always, please reach out to me with any thoughts, comments or feedback.

Eric Battig
ASEG President
president@aseg.org.au

Executive brief

The Federal Executive of the ASEG (FedEx) is the governing body of the ASEG. It meets once a month, via teleconference, to see to the administration of the Society. This brief reports on these monthly meetings. We hope you find these short updates valuable. If there is more that you would like to read about on a regular basis, please contact Asmita on fedsec@aseg.org.au.

Finances

The financial report presented to the November FedEx meeting reported to 31 October 2023. The October 2023 operating income was $31 263, which included "Meeting/Events" (Wine Sales) of $21 045 and MAG 23 conference registration of $8596. The October 2023 operating expenses were $28 380, which included CAGE 23 expenses of $5579, MAG 23 expenses of $6273 and the monthly TAS Management Fee of $9135. For the month of October 2023, the ASEG was running at a profit of $2883, and the YTD loss was $7468.

	October 2023	YTD
Total Income	$31 263	$327 901
Total Expense	$28 380	$335 369
Net Profit	$2883	-$7 468
Net Assets		$987 603

Membership

On 3 November 2023 the ASEG had 844 Members, compared with 828 at the start of last month and 794 at this time last year. We welcomed seven new members in October and seventeen new Members in November. Our Corporate Plus Members are **Velseis** and **Total Seismic**. Our Corporate Members are **HiSeis**, **Transparent Earth Geophysics**, **Santos**, **Southern Geoscience Consultants, SkyTEM Australia, DUG Technology** and **Seismic Asia Pacific Pty Ltd**. We would like to ask Corporate Members, who are yet to renew their membership, to please consider renewal, as your support is appreciated. Welcome to all our new Members, and thanks to all our renewed Members, Corporate Plus and Corporate Members, and local sponsors of our local Branches for their continued support in 2023.

Events

All upcoming events are listed in *Preview* and the ASEG Newsletter, and on the ASEG website. Please keep an eye on the notifications via emails regarding events held by local state branches. There are also some excellent webinars coming up, and links to the past webinars are available in the ASEG website on our YouTube channel https://www.youtube.com/@ASEGVideos/videos.

Great feedback was received on CAGE 2023 from participants, and our heartiest thanks go to the organisers, who put in a lot of effort to make the event successful. We also extend our thanks to the CAGE 2023 sponsors **BHP, AuScope, Rio, CSIRO, Teck and GBG Group** and to others who provided in-kind sponsorship. MAG 23 took place on 15 November and a big thanks go to the WA Branch for organising that event.

Communications

There are many avenues to stay connected with ASEG including *Preview* magazine, the ASEG Newsletter, the ASEG website, and via various social media such as LinkedIn, Twitter and Facebook. There have been continuously increasing Facebook and LinkedIn views in the recent months. Top posts have been ASEG's announcement on the inaugural DISCOVER conference on Facebook, and the CAGE 2023 update on LinkedIn. Great to see that people are watching ASEG YouTube videos. "Interpretating aeromagnetic data to aid mapping undercover and structural analysis of the Tanami" was the most watched YouTube video in October. Please consider using social media to promote ASEG events and publications.

Wish you all a Merry Christmas and a very happy and prosperous new year.

Please contact me for more information about any of the above.

Asmita Mahanta
ASEG Secretary
fedsec@aseg.org.au

Free subscription to *Preview* online

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

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

Welcome to new Members

The ASEG extends a warm welcome to 24 new Members approved by the Federal Executive at its October and November 2023 meetings (see table).

First name	Last name	Organisation	State	Country	Membership type
Ariha	Agrawal	University of Melbourne	Vic	Australia	Student
Sophie	Allen	Monash University	Vic	Australia	Student
Fernanda	Alvarado-Neves	Monash University	Vic	Australia	Student
Vinicius	Antunes Ferreira da Silva	The University of Western Australia	WA	Australia	Student
Jye	Blackman	The University of New England	NSW	Australia	Student
Christian	Centellas Asllani	Curtin University	WA	Australia	Student
Kevin	Cherogony	University of Western Australia	WA	Australia	Student
Leander	Erbe King	Curtin University	WA	Australia	Student
Bemsen	Ikumbur	Benue State Polytechnic Ug	BENUE	Nigeria	Associate
Maggie	Li	University of Adelaide	SA	Australia	Student
Toon	Lim	Seequent	WA	Australia	Active
Xulu	Lin	CSIRO	Qld	Australia	Associate
Matthew	Little	Resource Potentials	WA	Australia	Active
Jessica	Latimer	The University of Melbourne	Vic	Australia	Active
Jack	Muller	James Cook University	Qld	Australia	Student
Ratna	Putri Natari	The Australian National University	ACT	Australia	Student
Gabriela	de Oliveira	University of Western Australia	WA	Australia	Student
Kehinde	Oyewo	Indian University- School of Business Management and Administration.	OYO	Nigeria	Associate
Rakshith Vamsi	Ravichander	The Australian National University	ACT	Australia	Student
Mick	Small	Devil Resources Ltd	WA	Australia	Active
Ingrid	Smith	The Australian National University	ACT	Australia	Student
Erin	Tuohino	University of Adelaide	SA	Australia	Student
Jason	Valuri	Orica Digital Solutions	WA	Australia	Active
Gaston Ronald	Yupa Paredes	Terra Resources	WA	Australia	Active

Participants in CAGE 2023.

ASEG Honours and Awards: Call for nominations

It's never too soon to nominate someone for a prestigious ASEG award! The awards committee welcomes all nominations and is here to help answer any questions. The committee does not nominate or 'back' nominations, we rely on you, all ASEG Members including State and Federal executives to nominate people you consider deserving of these awards. And we encourage self-nomination, the work you do could be confidential, bespoke, and hard to understand … so self-nominate!

The 2024 award recipients will be announced at the inaugural DISCOVER 2024 ASEG Conference in Hobart in October 2024.

The ASEG Awards can be found on the internet and are summarised below:

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 over many years. Dr Philip Schmidt, Dr Malcolm Cattach and Dr Brian Spies are recent recipients.

Honorary Membership - for distinguished contributions by a Member to the profession of exploration geophysics and to the ASEG over many years. Dr Ted Tyne, Dr Andrew Mutton and Henk Van Paridon are recent recipients.

Grahame Sands Award - for innovation in applied geophysics through a significant practical development in the field of instrumentation, data acquisition, interpretation or theory. Dr Lesley Wyborn, Andrew Duncan and Greg Street are recent recipients.

Lindsay Ingall Memorial Award - for the promotion of geophysics to the wider community. Dough Morrison, Dr David Isles and Dr Leigh Rankin are recent recipients.

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. Dr Janelle Simpson, Dr Stanislav Glubokovskikh and Regis Neroni are recent recipients.

ASEG Service Awards - for distinguished service by a Member over many years to ASEG Branch activities, Federal or State committees, publications, conferences, or other Society activities. Dr Kate Brand, Danny Burns and Marina Costelloe are recent recipients.

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

Nomination Procedure

Any Member of the Society may submit nominations for an award. These nominations are to be supported by a seconder, and in the case of the Lindsay Ingall Memorial Award by at least four geoscientists who are Members of an Australian geoscience body (*e.g.*, ASEG, GSA, AusIMM, AIG, PESA, or similar). The Honours and Awards committee don't nominate people for awards, you do, so please I encourage you and your network to nominate someone you think is worthy of an award.

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

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

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

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

Marina Costelloe
ASEG Honours and Awards Committee Chair
awards@aseg.org.au

Richard Lane Scholarship 2024

Richard Lane (1962-2021)

An ASEG Scholarship has been established to support geophysics Honours and Masters students and to commemorate the life and work of ASEG Gold Medal recipient Richard Lane. The scholarship is open to all BSc (Hons) and MSc geophysics students at an Australian University and consists of a grant of $5000 to the best ranked student for the current year. Ranking will be based on a 200 word discussion, overview of a geophysics project and on an academic transcript. For 2024 we acknowledge and thank Jayson Meyers and Resource Potentials Pty Ltd for the initial concept and ongoing donation.

All Honours (BSc) and Masters (MSc) students with focus predominantly in exploration geophysics are invited to apply. The closing date will be in April 2024 and the application details and form are at www.aseg.org.au/foundation/richard_lane

The scholarship is an annual event and donations to support the continuation of this scholarship are sought from institutions, companies and individuals. Information on donations via the ASEG Research Foundation can be found at www.aseg.org.au/foundation/donate Please mark donation specifically "Richard Lane Scholarship"

ASEG branch news

Victoria

Yes, I am a Trekkie. Don't get me wrong, I love everything about the entire sci-fi genre, but the universe Gene Roddenberry created is unmatched in its imagination. Who can forget the ultimate sacrifice Captain James T Kirk made to save the crew of the USS Enterprise, on multiple occasions? Or the time when Data sacrificed his android existence to save the life of his captain, Jean Luc Picard? There have been many heart-wrenching scenes for Star Trek fans the world over. There happens to be a devastating line from one of the franchises' later movies that continues to haunt me every single time I hear it repeated. It is a line from a piece of work written by American poet and short story writer Delmore Schwartz. In the movie, *Star Trek – Generations*, Malcolm McDowell's character, Soran, delivers one of the movie's most unnerving scenes…*They say time is the fire in which we burn*. Wow. Deep. Heavy. Right now, as President of the Victorian chapter of the ASEG, I feel my time is up, but a little more later on in the piece.

In Branch news, Victorian Members were treated to a special technical presentation by **Scott Robson**, Exploration Manager of Battery Minerals Ltd, at The Kelvin Club on the night of 11 October. Scott's talk titled "Victorian intrusion-related gold, not to be taken for granite", gave members insight into the exploration progress of several projects associated the White Rabbit diorite intrusion, an event that appears to be coeval with emplacement of the Stawell Granite. Battery Minerals Ltd has an exciting pipeline of projects with drill-ready targets along the prospective suture zone between the Delamerian and Lachlan Fold Belts in the Stavely-Stawell fold belt. We wish Scott and his company every success.

Our last technical meeting for 2023 was staged on 15 November, and we had the pleasure of hosting **Shaye Fraser** (PhD candidate in Geospatial Science at RMIT University) at The Kelvin Club. And of course, with the festive season rapidly approaching, our annual year-end joint ASEG-PESA-SPE Christmas luncheon was held on 5 December at Henry and The Fox in the CBD. **Dr Andrew Long** (Chief geoscientist, PGS) was our guest speaker. Given the title of his talk "The Karma Sutra of seismic", I was expecting nothing short of polemic controversy and some NSFW seismic sections to boot - and I wasn't disappointed 😊. Please keep your eye out on various ASEG social media platforms for information about upcoming events.

Now, back to ummm…burning time in a fire. I have given this quite a lot of thought recently. It has been an honour and pleasure serving the Victorian Branch of the ASEG since 2017, first as Secretary and then as President since 2020. Right now, though, I am completely burnt to a crisp. While I am still enjoying my tenure as President, I believe that now is the time for change. I will be stepping down as President at years' end. I feel the Committee needs a fresh injection of younger, more energetic individuals to help steer our great branch through the mid-2020s. It will be an exciting new chapter for the Victorian Branch, I'm sure of it. Let's see what 2024 will bring.

One final time, thank you to all our Members for your unwavering support this year. I've had a fantastic time catching up with most of you at our numerous events throughout the year. Please have a safe and enjoyable festive season and an excellent New Year's Eve. Catch you guys on the flip side.

Thong Huynh
vicpresident@aseg.org.au

Scott Robson presenting to the Victoria Branch of the ASEG

Western Australia

The Western Australian Branch of the ASEG hosted a technical night talk on 26 October as part of its monthly technical talk series. The guest on this night was **Dr Mick Micenko,** who is an Honorary Member of the ASEG and is well known for his regular column *Seismic Window* in *Preview* magazine. Mick started his working career acquiring gravity, magnetic and IP data across Australia for mining companies, before moving into the oil industry working the Eromanga Basin with Delhi Petroleum. He has a wealth of experience in a variety of basins in Australia, NZ, India, SE Asia, Africa and the USA and became a well-respected seismic interpretation consultant. He has worked for numerous companies and taught the seismic interpretation course at Curtin University for many years.

Mick gave an interesting talk, which was entitled "High density 3D seismic acquisition: An illustrated example from onshore India" about the world class Mangala oil field which was discovered in Rajasthan in 2005. Even though the field had 3D seismic coverage the crest of the structure was poorly imaged and an experimental 2D seismic line was recorded across the crest in 2004. This test line confirmed the benefits of using closer spaced source and receiver points and led to a high-density 3D survey being recorded across the field commencing in August 2006. Severe flooding in Rajasthan delayed recording for several months, and the 120 km^2 survey was eventually completed in May 2007. Development drilling began in 2008. The HD3D was acquired with

Mick Micenko delivering his inspiring talk

Ruth Murdie presenting to the WA audience.

short station intervals with source and receiver spacing of 10 m. The vibrator frequency range was increased using a single vibrator and effectively point receivers. This resulted in a 20 Hz gain in bandwidth and improved signal-noise. The resulting seismic data had improved imaging of the shallow section which led to better depth migration and enhanced resolution of the structural complexities within the reservoir allowing more optimal positioning of the development wells. The field began production in 2008 with oil initially being trucked until a heated pipeline was built to transport the oil 600 km to the coast.

The technical night talk for the month of November was given by **Dr Ruth Murdie**, who is the Manager of the Earth Imaging and Observation Group at GSWA. Ruth started at GSWA ten years ago as a 3D modeller and has been involved in most of the organisation's seismology projects. Before joining GSWA, Ruth spent some time at St Ives gold mine in the Eastern Goldfields as the exploration geophysicist. She has also worked at the Comprehensive Nuclear-Test-Ban Treaty Organisation in Vienna and was a lecturer in geophysics at Keele University, UK.

Ruth's talk was entitled "Shake, rattle and roll on. Seismology at GSWA" and gave the audience an overview of seismological projects that have been carried out as part of the operational research at GSWA for the past ten years. These projects have, to date, been quite low-key, concentrating on imaging specific geological targets such as the Capricorn Orogen, the Albany-Fraser Orogen, the SE margin of the Yilgarn Craton, the Canning Basin and the area between the Western Australian Craton and the North Australia Craton. These studies have been carried out in conjunction with geological mapping, active seismic and MT. GSWA is now conducting longer-term projects in conjunction with GA, such as baseline monitoring in the Canning Basin, seismicity of the Goldfields Region and more detailed monitoring of the SW Seismic Zone. The biggest project, known as WA Array, is the complete coverage of Western Australia with passive seismic stations at 40 km spacing. This project continues the work started in other parts of the country under the EFTF as AusArray. This is a ten-year programme with a specific list of products, a tight timeframe and big ambitions.

Emad Hemyari
WA Branch Communications Officer
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Australian Capital Territory

The ACT Branch hosted a breakfast with **Dr Phil Schmidt**, the ASEG Gold

Members of the ACT ASEG Branch at breakfast with Phil Schmidt. Left to right: ***Yvette Poudjom Djomani, Marina Costelloe, Phil Wynne, Wenping Jiang, Jackie Hope, Phil Schmidt*** *and* ***Janice Schmidt****.*

Branch news

Medal winner in 2023 on 9 November at Blackstone Café. Phil and his wife Janice were in Canberra for the 50th anniversary of the ANU Research School of Earth Sciences.

On 23 November, we hosted a talk by **Jared Peacock** from USGS and **Karl Kappler** from the DIAS Geophysical and Space Science Institute. The talk was titled "An interactive workflow for MT data using open-source packages and HPC". Jared and Karl presented a workflow for MT data that demonstrated how to use existing open-source software packages to go from raw data to a 3D resistivity model. This workflow increases the capacity of MT data to be used for open science following FAIR principles.

Wenping Jiang
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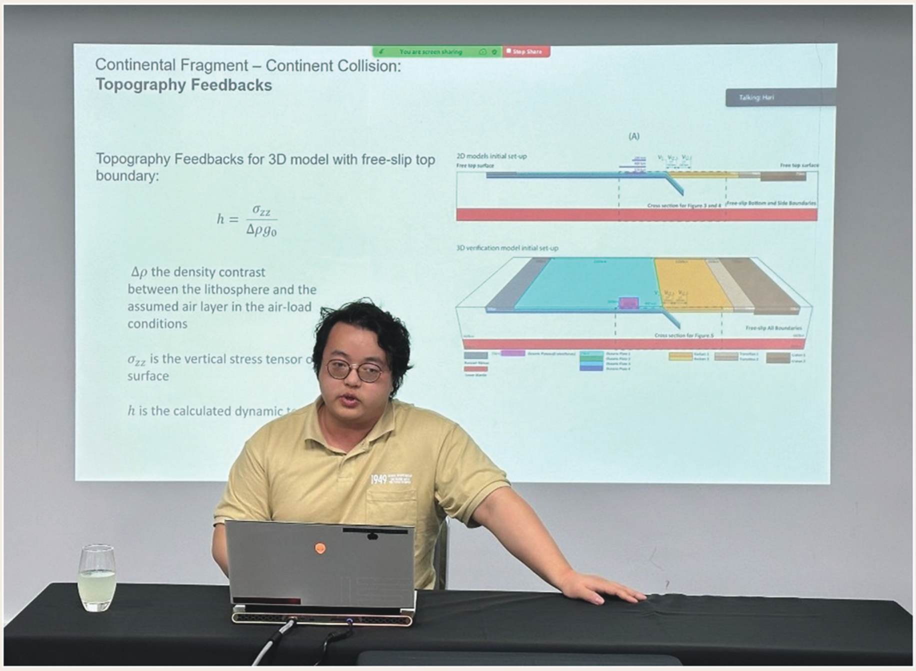
James explaining the "Geophysics in the Park" to the NSW Branch.

New South Wales

In September, **Dr James Daniell,** Senior Geophysicist at Fender Geophysics, presented a talk entitled "Geophysics in the Park": How can industry support geophysics education?". Geophysics in the Park, organised by Fender Geophysics, had its inaugural session in Trunks Park, Cremorne. The attendees were primarily students who deployed, acquired, and processed electrical resistivity imaging and seismic refraction. James' presentation gave the geophysics community some helpful insight into a great idea, and there was some noteworthy discussion on ideas in the future to foster students and the community's interest in geophysics.



Peigen discussing topography feedbacks with the NSW Branch.

In October, **Peigen Luo**, a PhD candidate at The University of New South Wales (UNSW), presented a talk entitled "Continental fragment collision in subduction and the dramatic uplift acceleration in the eastern Anatolian Region". Peigen's presentation provided a deep dive into the dynamic interactions of continental fragments and subduction processes, enriched by his advanced 3D numerical modelling results, vividly depicting subduction in action. His detailed models illuminated the causes of uplift and deformation in the Central Taurides, offering a new understanding of geological evolution influenced by continental fragment collision.

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

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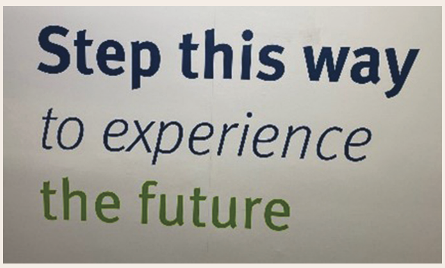
Queensland

The itinerant Queensland Branch continued its wandering with the October technical meeting taking place at the "Cross River Rail Experience Centre" in central Brisbane. The centre is an exhibition space whose subject is the new, 10.2 km rail line (with 5.9 km in tunnels) that runs under central Brisbane. The centre is certainly not afraid of over-selling itself (see signage below)…



The centre consists of a number of interesting exhibitions, including a virtual reality tour of the new underground stations (comment from one user "I kept on seeing the same people over-and-over again"), which were enjoyed by the assembled local ASEG Members (only soft-drinks in hand this time though).

We then adjourned to a side-room at the centre for an update on the construction from one of the project engineers and an ASEG promotion presentation from local President and international Tiktok star **Nick Josephs** (albeit somewhat preaching to the converted in this case).

The main event of the evening was a presentation from **Dr Kelsey Lowe**,

Queensland ASEG Members enjoying the Cross River Rail Experience Centre and yes, that is **Shaun Strong** *in his customary subdued attire.*

Local geophysics doyen Nick Josephs exhorts those present to join the ASEG…

Wayne Stasinowsky *enjoying the VR railway station experience.*

Queensland Branch President, and co-founder of defunct social networking site MySpace, Nick Josephs, thanks Dr Kelsey Lowe for her presentation (photo taken prior to the admission that her speaker gift had been left in his car…).

Branch news

Principal Program Officer at the (deep breath) Queensland Department of Treaty, Aboriginal Torres Strait Islander Partnerships, Communities and the Arts on "Geophysics meets Archaeology". Fears of another Great Schism of the order of that in 1054 turned out to be unfounded and an extremely interesting presentation showed that there are many underutilised (and underfunded…) areas where geophysics can be applied.

Coming up, the search for a home continues, with the local branch off to 'Club Yeronga' (formerly the Yeronga RSL) for a talk by **Dr Gerrit Olivier** from Fleet Space on ambient seismic noise tomography. Planning is also 'well underway' for the local branch Christmas party.

Will the Queensland Branch hold an event at the same venue twice? Will this columnist ever include news on events he didn't personally attend? Will Shaun Strong attend two events in a row? Will we ever manage to wipe that smile off Nick Josephs face? Find out in the next exciting instalment of Queensland Branch news.

Tim Dean
qldsecretary@aseg.org.au

South Australia and Northern Territory

The SA-NT Branch of the ASEG held our annual Melbourne Cup Luncheon on Tuesday 7 November. The event was attended by 36 of our Members, friends and colleagues resulting in a great day catching up with old friends in the beautiful surrounds of Adelaide Oval.

ASEG SA-NT Branch Melbourne Cup event

As usual, **Neil Gibbins** from Vintage Energy brought his wealth of knowledge and enthusiasm to MC the event. He ensured that everything ran smoothly, and that the Calcutta Sweep was completed before the race began. I would also like to say a big thank you to Adelaide Oval for providing the venue and such excellent food and service throughout the event.

Have a safe and relaxing Christmas break from the SA-NT committee, we look forward to seeing you at some of our future ASEG events in 2024.

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**, **BHP**, **Vintage Energy**, the **Department for Energy and Mining**, **Zonge**, **Santos and Heathgate**.

Paul Soeffky
sa-ntpresident@aseg.org.au

Tasmania

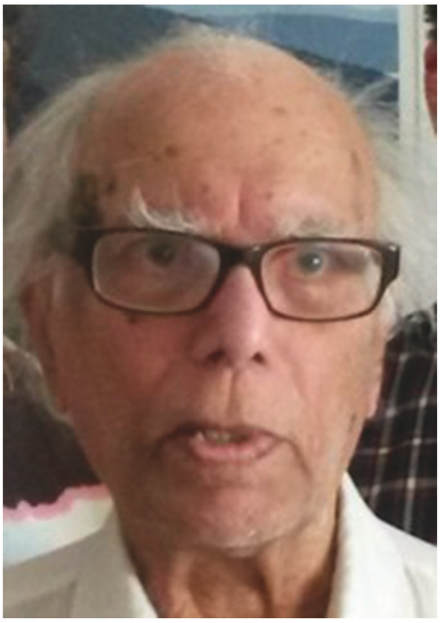
Meeting notices, details about venues and relevant contact details can be found on the Tasmanian Branch page on the ASEG website. As always, we encourage Members to keep an eye on the seminar/webinar programme at the University of Tasmania / CODES, which routinely includes presentations of a geophysical and computational nature as well as on a broad range of earth sciences topics.

Tjaart de Wit
taspresident@aseg.org.au

ASEG national calendar

Date	Branch	Event	Presenter	Time	Venue
ASEG Branches hold face-to face meetings and webinars. Registration for webinars is open to Members and non-members alike, and corporate partners and sponsors of state branches are acknowledged before each session. Recorded webinars are uploaded to the ASEG's website (https://www.aseg.org.au/aseg-videos), as well as to the ASEG's YouTube channel (https://bit.ly/2ZNglaZ). Please monitor the Events page on the ASEG website for the latest information about events.					
5 Dec	Vic	Joint ASEG-PESA-SPE Christmas lunch	Andrew Long	1200	Henry and The Fox, Melbourne
6 Dec	WA	Christmas Party		1730	Leederville Sporting Club, West Leederville, Perth

Vale: Professor Emeritus Dattatray Parasnis 1927–2023



Datta Parasnis

Datta, as he was commonly called, came to Sweden in the 1950s after university studies in Bombay and Cambridge. He began his career as a geophysicist at AB Elektriks Malmletning in Stockholm. There he met his future wife, Helena Nyström from Finland. In 1960, they moved to Boliden, where he was employed as a research physicist.

Datta continued his university studies, now in Uppsala, where he became a leading teacher and researcher in solid earth physics. With his studies in geoelectrical methods, he came to further develop a strong Swedish prospecting technical research tradition, which resulted in a large number of scientific publications.

It was therefore unsurprising that in 1974 he was called to a professorship in prospecting geophysics at Luleå Institute of Technology and thus contributed to its mining profile. Datta was elected in 1976 to the Royal Academy of Engineering Sciences (IVA).

Besides many journal articles, Datta wrote several books. He had great success with *Principles of Applied Geophysics*, which was updated and printed in several editions and used as a textbook in many countries. Datta was widely known, but you still couldn't help but be surprised when, for example, in the jungles of Central America you met geoscientists who knew him well.

Datta was heavily involved in skills building at universities in developing countries and contributed to the establishment of geophysical departments. He supervised many PhD students. They were often given a great deal of freedom in their research, something that contributed to them gaining a strong independence for the benefit of their careers.

Dattatray Parasnis had a strong scientific position with his successful research, was rewarded with a number of awards and was a very good ambassador for Luleå University of Technology. Many of us miss him.

Professor Emeritus Dattatray Parasnis, Luleå, passed away on 16 June 2023 at the age of 96. Next of kin are his children Irawati, Ravindra and Amalendu with their families.

Sten-Åke Elming, Eric Forssberg, Lennart Elfgren and Thorkild Maack Rasmussen,

Luleå University of Technology, Sweden

Originally Published by Lulea University of Technology, Sweden 19 July 2023 https://www.ltu.se/org/sbn/Minnesord-Professor-emeritus-Dattatray-Parasnis-1.231289?l=en)

Further reflections from Ted Tyne

The passing of Professor D S Parasnis, an icon of applied geophysics developments in the Swedish exploration industry and at Luleå University of Technology, is a reminder of Sweden's leadership together with Canada and the US in the early development of geophysical exploration methods in Scandinavia and the Americas.

Professor Parasnis was widely recognised for his influence on developments in Swedish applied geophysics as well as his teaching and leading research publications on potential field and electrical and electromagnetic methods. Indeed, this recognition extended to practising Australian geophysicists from the 1960s and over the early decades of the ASEG. His seminal early textbook *Principles of Applied Geophysics* updated and republished in four editions from 1962 to 1986, was used as a primary reference textbook in Australian university undergraduate courses in geophysics and exploration geoscience over this period.

In my postgraduate years in the early 1970s at the University of NSW, School of Applied Geology, under Assoc. Professor Laric Hawkins, Dr Bob Whiteley and Dr Ifti Qureshi, D. S. Parasnis' principles and practices in electrical and electromagnetic geophysics were an important foundation in the many case-history electrical geophysical survey articles published in *Geophysical Case Study of the Woodlawn Orebody, NSW Australia*, Ed. R. J. Whiteley, Pergamon Press 1981, and in *The Geophysics of the Elura Orebody*, Ed. D. W. Emerson, ASEG Bulletin Vol 11, No.4.

Professor Parasnis was also a friend and colleague of Dr Ifti Qureshi, from their postgraduate years in the United Kingdom and that friendship and their exchanges contributed to the teaching of geophysics at UNSW. It was through this link that I was introduced to Professor Parasnis who was appointed as an external examiner of my own PhD Thesis in 1987. It was indeed a privilege to receive valuable guidance, suggestions and generous commendations from Professor Parasnis on my own exploration geophysics research.

Condolences from the ASEG to the family of Professor Parasnis and to his many friends and colleagues.

Ted Tyne
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News

CAGE 2023: A practical geophysics experience

CAGE 2023 participants.

On the lands of the Wajuk and Nyaki Nyaki people in Western Australia, CAGE 2023 unfolded over seven days, bringing together 25 students and early-career geoscientists for hands-on experience in collecting, modelling, and interpreting geophysical data.

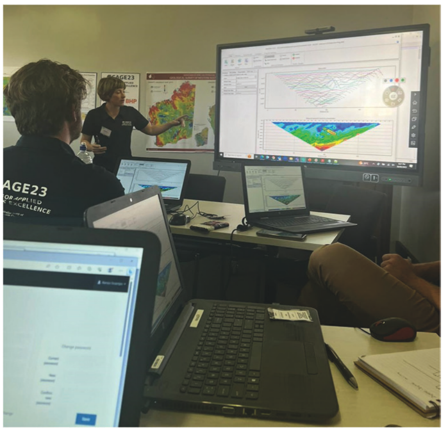
Led by experts like Dr Teagan Blaikie, Ian James, Dr Kate Selway, Dr James Reid, Mike Whitford, Dr Anne Tomlinson, Dr Sasha Aivazpourporgou, Mikayla Sambrooks and Peter Eccleston, participants collected ground magnetics, seismic refraction, moving-loop electromagnetics, and resistivity data at the Forrestania EM test range. They combined their results with existing geophysical and geological data and petrophysical constraints to develop their own ideas for nickel exploration strategies. Attendees were housed at IGO Ltd's camp for the geophysical acquisition component of CAGE.

CAGE moved to nearby Hyden for the processing and modelling sessions, and from there visited the cultural and geological landmark of wave rock. This 2.7 Ga granite outcrop was a tangible reminder of the Archean Yilgarn Craton rocks that were being imaged geophysically and also provided a spectactular backgrop for the CAGE 2023 group photo!

As the attendees processed and analysed their data, they could see how different field practices could lead to better and worse data quality. They considered data quality, ran inversions and forward models, and grappled with non-uniqueness. In teams, they presented exploration recommendations, mirroring real-world scenarios. Thanks to software sponsors including Mira Geoscience, Seequent, Geometrics Inc., ElectroMagnetic Imaging Technology, and Scientific Computing Applications, they were exposed to state of the art industry software for data processing and modelling.

Interspersed with the technical programme were sessions that provided valuable industry insights, with talks on opportunities and graduate programmes by various sponsors and volunteers, and invaluable networking opportunities.

CAGE 2023's success owes much to ASEG volunteers, financial sponsors, including BHP, AuScope, CSIRO, Rio Tinto, Geoscience Australia, GBG Group, and Teck Resources Limited, and in-kind supporters, including Southern Geoscience Consultants, IGO Ltd, Seequent, Vox Geophysics, Moombarriga Geoscience, Mira Geoscience, Newcrest Mining, Geometrics Inc., GBG Group, Geological Survey of Queensland, ElectroMagnetic Imaging Technology Pty Ltd, Terra Resources Pty Ltd, National Exploration Under Cover School, AirGeoX and Scientific Computing Applications, who generously provided demonstrators, equipment, and software.



Dr Kate Selway, Vox Geophysics, demonstrates to students the usage of Res2DInv – with licences generously donated by Seequent.

CAGE addresses the gap between theoretical education and real-world applications. With a decline in field geophysics teaching in Australian universities, CAGE is becoming invaluable for emerging geoscientists, offering practical training from data collection to geological interpretations.

The impact of CAGE goes beyond seven days, fostering a community of knowledgeable geoscientists. Follow the ASEG on social media for announcements about CAGE 2024.

Dr Kate Brand and Dr Kate Selway
continuingeducation@aseg.org.au

Geoscience Australia: News

Recent highlights of Geoscience Australia's geophysical programmes, as conducted under the Australian Government's Exploring for the Future (EFTF) project, and in collaboration with our State and Territory survey partners, are summarised below. Details of all current and recently completed programmes and survey locations can be found in Figure 1 and the tables that follow this section.

Forbes-Dubbo and Yathong airborne electromagnetic surveys (AEM) and Yathong airborne magnetic and radiometric (AMR) survey.

Geoscience Australia (GA), in collaboration with the New South Wales (NSW) Government's Geological Survey of NSW, recently completed the acquisition of over 15 000 line-km of airborne AEM data over four blocks within the Cobar-Yathong areas of NSW (Figure 2). This survey was fully funded by the Government of NSW. Additionally, acquisition of the Yathong region airborne magnetic and radiometric (AMR) survey (Figure 2) is nearly complete. Acquisition is along east–west lines spaced 200 m apart and north–south lines spaced 2 km apart.

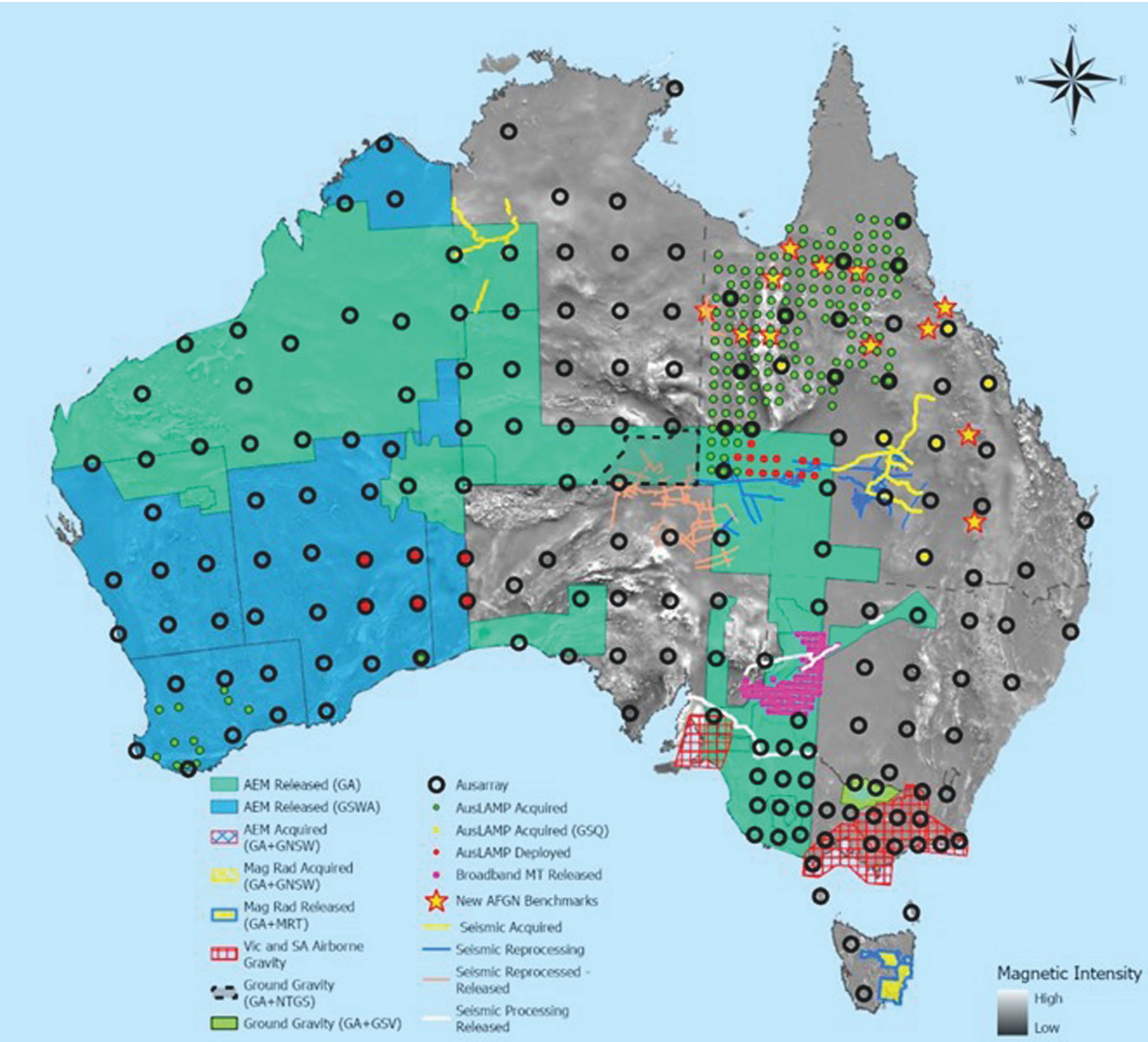


Figure 1. *2021-2023 geophysical surveys – in progress, released or for release by Geoscience Australia as part of EFTF, and in collaboration with State and Territory agencies. Projects that are partially or wholly funded by state government agencies are identified by the bracketed contributors. Background image of national magnetics compilation (first vertical derivative of the reduced to pole magnetics), Geoscience Australia, 2019 (see http://pid.geoscience.gov.au/dataset/ga/144725).*

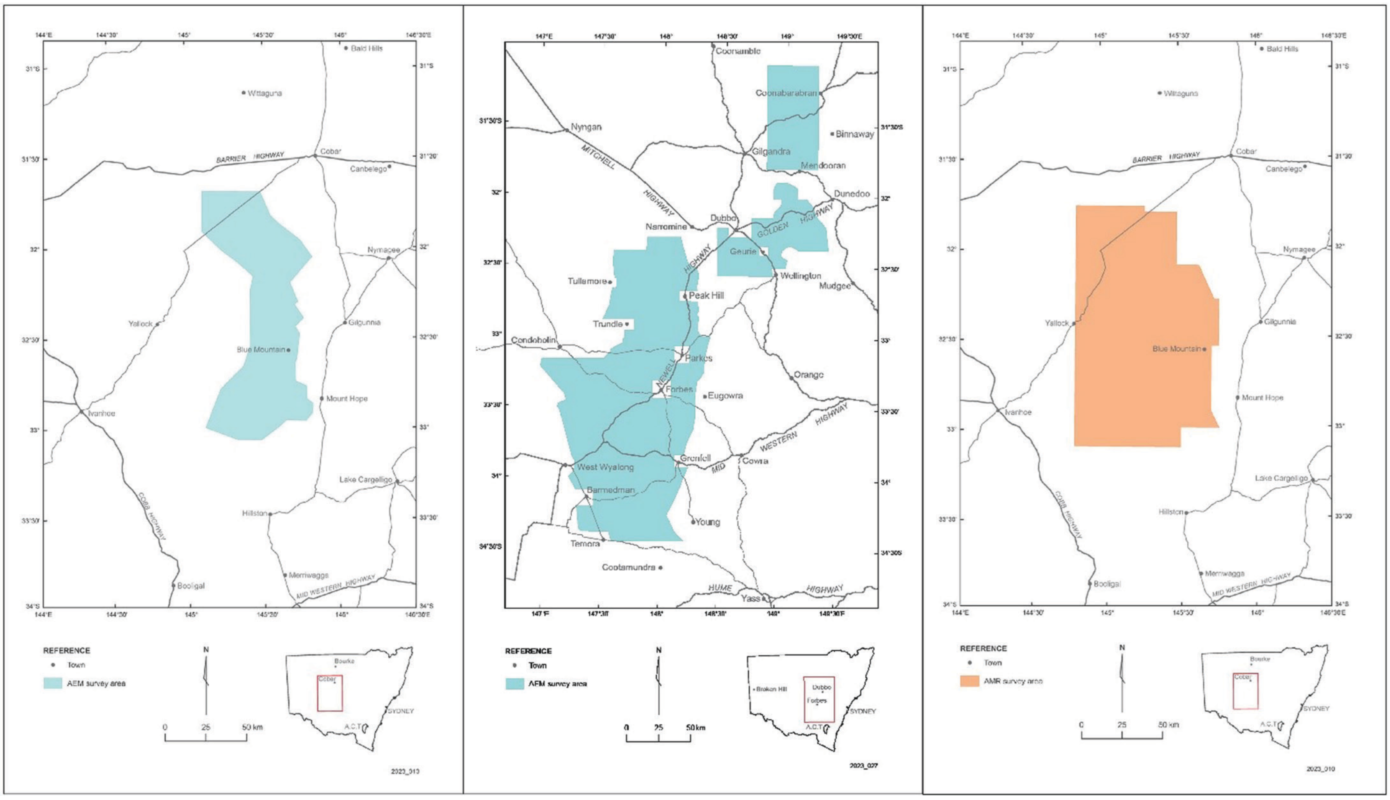


Figure 2. *Location of the Yathong (left) and Forbes-Dubbo (centre) AEM surveys, and the Yathong Airborne Magnetic and Radiometric Survey (right).*

These surveys are currently undergoing quality assurance and quality control checks prior to a release of the data by the end of 2023. For further information on these surveys, please contact Astrid Carlton, Senior Geophysicist - Geological Survey of NSW, at astrid.carlton@regional.nsw.gov.au

NTGS Pedirka ground gravity survey

Geoscience Australia (GA), in collaboration with the Northern Territory (NT) Government's Geological Survey (NTGS), have recently acquired ground gravity in the southeast corner of the NT adjacent to the Queensland and South Australian borders. This survey was fully funded by the Northern Territory Government and was helicopter assisted. Gravity data was acquired on a 4 x 4 km grid over an area of 61 370 km^2, with infill in selected areas at 2 km spacing. Approximately 13 000 gravity stations were acquired. The data are currently undergoing quality assurance and quality control checks prior to a release by the end of 2023. For further information on these surveys, please contact Tania Dhu, Senior Geophysicist – Northern Territory Geological Survey, at Tania.Dhu@nt.gov.au

GSV Shepparton Numurkah ground gravity survey.

Geoscience Australia in collaboration with the Geological Survey of Victoria (GSV), have started acquisition on the Shepparton Numurkah ground gravity survey in central north Victoria. This survey is fully funded by the Government of Victoria survey and is infilling the existing ground gravity network at approximately 500 m spacing along existing public roads and tracks. As part of this survey previous survey nodes and base stations have been included to assist merging of the new gravity stations with existing gravity data. This survey is currently approaching 50% completion, with acquisition expected to continue into 2024.

For further information on this survey please contact Suzanne Haydon at Suzanne.Haydon@ecodev.vic.gov.au.

Northwest Northern Territory seismic data

The Birrindudu Basin is a frontier basin, highly prospective yet underexplored for mineral and energy resources. While it contains Proterozoic rocks, similar in age to those which are prospective for mineral and energy commodities in the McArthur Basin, South Nicholson region and Mount Isa Province to the east, it remains comparatively poorly understood. The Northwest Northern Territory (NWNT, L214) Seismic Survey was designed to correlate well characterised areas of the basin with adjacent gravity lows to the west and to the complex geology of the Tanami Region to the south, in order to better characterise the regional crustal architecture and identify concealed sedimentary basins to better understand the energy, minerals and groundwater potential across the region. This survey was co-funded by the Northern Territory Government. Four lines of deep crustal seismic data were collected in August and September 2023 comprising a total of 900 line-km. The seismic data will be processed starting in November and field data will be released in late 2023. The processed data will be publicly available in the second quarter of 2024.

For further information on the Northwest Northern Territory Seismic Survey and the Officer-Musgrave-Birrindudu Project, please contact Paul Henson Director – Onshore Energy Systems Section, at Paul.Henson@ga.gov.au.

Donna Cathro
Geoscience Australia
Donna.Cathro@ga.gov.au

Figure 3. *Vibroseis trucks operating at night on the Northwest Northern Territory seismic survey. Data was collected at night to allow the cleanest possible data collection with the least amount of wind and traffic noise.*

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 13 September 2023)

The survey details are provided for information only, and on the understanding that the Australian Government is not providing advice. Further information about these surveys is available from Adam Bailey Adam.Bailey@ga.gov.au (02) 6249 5813 or Donna Cathro Donna.Cathro@ga.gov.au (02) 6249 9298 at Geoscience Australia.

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Line spacing Terrain clearance Line direction	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Eastern Tasmania	MRT	GA	MAGSPEC	Mar 2022	57 000	200 m	11 600	Jun 2022	Sep 2022	See Figure 1 in previous section (GA news)	Dec 2022 - http://pid.geoscience.gov.au/dataset/ga/147455

TBA, to be advised.

Table 2. Ground and airborne gravity surveys

Survey name	Client	Project management	Contractor	Start survey	Line km/ no. of stations	Line spacing/ station spacing	Area (km²)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Melbourne, Eastern Victoria, South Australia	AusScope GSV DEL WP	GA	Sander Geophysics	TBA	137 000	0.5–5 km	146 000	Expected Jun 2023	~ Oct 2023	See Figure 1 in previous section (GA news)	Late 2023
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)	Dec 2022 http://pid.geoscience.gov.au/dataset/ga/147481
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	Oct 2022 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	Oct 2022 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	Oct 2022 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)	Nov 2022 https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/147265
SE Lachlan	GSNSW/ GSV	GA	Atlas Geophysics	May 2019	303.5 km with 762 stations	3 regional traverses	Traverses	Jun 2019	Jul 2019	See Figure 1 in previous section (GA news)	Set for incorporation into the national database in 2023

TBA, to be advised

Table 3. Airborne electromagnetic surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km^2)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Western Resources Corridor	GA/ GSWA	GA	Xcalibur Multiphysics	May 2022	~ 38 000	20 km	760 000	Oct 2022	Dec 2022	See Figure 1 in previous section (GA news)	Mar 2023 https://dx.doi.org/10.26186/147688
Musgraves	GA	GA	Xcalibur Multiphysics	Jun 2022	~ 22 000	1 – 5 km	~ 100 000	Aug 2022	Dec 2022	See Figure 1 in previous section (GA news)	Mar 2023 https://dx.doi.org/10.26186/147688
Upper Darling River	GA	GA	SkyTEM	Mar 2022	25 000	.25 – 5 km	14 509 line km	Jun 2022	Oct 2022	See Figure 1 in previous section (GA news)	Oct 2022 http://pid.geoscience.gov.au/dataset/ga/147267
Darling-Curnamona-Delamerian	GA	GA	SkyTEM	Jun 2022	14 500	1 – 10 km	25 000 line km	Oct 2022	Dec 2022	See Figure 1 in previous section (GA news)	Feb 2023 https://dx.doi.org/10.26186/147585

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/ WA	Exploring for the Future – AusLAMP	500 deployed 2016-23	50 km	Long period MT	The survey covers areas of NT, Qld and WA. Data acquired 2016-19 and related model released 2020. Data package: http://pid.geoscience.gov.au/dataset/ga/134997 Model: http://pid.geoscience.gov.au/dataset/ga/145233 Queensland model update and data release: https://dx.doi.org/10.26186/148633 Data acquired 2020–23.
AusLAMP NSW	GSNSW/ GA	NSW	AusLAMP NSW	~300 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 deployed 2023	25-12.5 km	Audio and broadband MT	This survey will extend the University of Adelaide-AuScope Curnamona Cube MT survey from the Curnamona Province into the Delamerian Orogen. Data was released in May 2023, https://doi.org/10.26186/147904. and related model published Aug 2023: https://dx.doi.org/10.26186/148623
AusLAMP Qld	GSQ/GA	Qld	AusLAMP Qld	6 deployed 2023	200+ km	Long period MT	Adding to the coverage in Queensland undertaken as a part of EFTF. Ultimate coverage planned at 50 km spacing.

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
Darling – Curnamona – Delamerian	GA	SA, NSW, VIC	Darling – Curnamona – Delamerian deep crustal reflection survey	~1275	10	10/40	20	2D deep/ crustal high resolution vibroseis seismic survey.	This survey will create an image of important crustal boundaries including the structure of the Delamerian margin, which runs through NSW, SA and Vic, separating older rocks of the Gawler Craton and Curnamona Province from younger rocks of the Lachlan Fold Belt (Tasmanides). Acquisition commenced in Jun 2022 and concluded in Aug. Data processing is complete and the data are available for download at https://pid.geoscience.gov.au/dataset/ga/147423.
Central Australian basins	GA	Qld/ SA	Shallow legacy data	~2100	Varies	Varies	3-20 sec	2D shallow & deep legacy data, explosive, vibroseis	GA commissioned reprocessing of selected legacy 2D seismic data in Qld and SA, as part of Exploring for the Future, Australia's Future Energy Resources Project. Reprocessing of these data is complete and the data package will be released in early 2024.

(*Continued*)

Table 5. Seismic reflection surveys (*Continued*)

Location	Client	State	Survey name	Line km	Geophone interval	VP/SP interval	Record length	Technique	Comments
Adavale Basin	GA	Qld	Deep and shallow legacy data		2350	Varies	3-20 sec	2D shallow & deep legacy data, explosive, vibroseis	GA commissioned reprocessing of selected legacy 2D seismic data in the Adavale Basin, Queensland Australia, Data driven Discoveries Initiative. Reprocessing of the legacy data is complete and the data package will be released in the second half of 2023.
Adavale Basin	GA	Qld	Adavale 2D deep crustal seismic survey	1715	10	40	20 sec	2D Deep Crustal/ high resolution vibroseis seismic survey	The Adavale deep crustal seismic survey can be combined with the recently released reprocessed seismic data to provide an important modern basin-scale seismic dataset for the Adavale Basin which will facilitate better understanding of the extent of salt bodies within the basin that may be able to store hydrogen, while also improving our understanding of the structural controls and potential for other resources in the basin. Processing of these data are underway, with the data expected for release Q2 2024
Northwest Northern Territory	GA/NTGS	NT	Northwest Northern Territory deep crustal seismic survey	900	10	40	20 sec	2D deep crustal/ high resolution vibroseis seismic survey	The Northwest Northern Territory (NWNT, L214) Seismic Survey was designed to correlate well-characterised areas of the basin with adjacent gravity lows to the west and to the complex geology of the Tanami Region to the south, in order to better characterise the regional crustal architecture and identify concealed sedimentary basins to better understand the energy, minerals and groundwater potential across the region. Acquisition is complete and raw data for this survey will be released in early 2024.

Table 6. Passive seismic surveys

Location	Client	State	Survey name	Total number of stations deployed	Spacing	Technique	Comments
Australia	GA	Various	AusArray	149 temporal seismic stations	~200 km spacing	Broad-band ~18 months of observations	The survey covers all of Australia to establish a 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 was completed in June 2023. Data will be acquired over 12-18 months.
Northern Australia	GA	Qld/NT	AusArray	247 broad-band seismic stations	50 km	Broad-band 1-2 years observations	The survey covers the area between Tanami, Tennant Creek, Uluru and the WA border. The first public data release of the transportable array was in 2020. 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
AusARRAY Victoria Collaborative Project	GA/GSV	Vic	AusArray Victoria	21 temporary seismic stations	~100 km	Broad-band ~12-18 months of observations	Data acquired from the movable array sites will add to the scientific understanding of the Earth's lithosphere on the national and regional scale. Phase 1 of the deployment (~100 km) was undertaken in Mar 2023.

Table 7. Survey technical requirements

Survey type	Author	Contributors	GA Release
Magnetics, radiometrics and horizontal magnetic gradiometry	James Goodwin	Brian Minty, Ross Brodie, Mark Baigent, Yvette PoudjomDjomani, Matt Hutchens with acknowledgements to Peter Milligan, Laz Katona and Mike Barlow	Mar 2023 http://pid.geoscience.gov.au/dataset/ga/147457

Geological Survey of South Australia: The nuts and bolts of a major gravity upload

The Geological Survey of South Australia (GSSA) is proud to say that all public-domain ground gravity surveys conducted in South Australia are available to the public via SARIG. That is, all the ones we're aware of. We're also aware that not all surveys are visible online in the spatial layer on SARIG. This is an issue that GSSA geophysicists are rectifying as a matter of priority, as we recognise this is a primary way to discover new surveys. It will also lead to a new state gravity grid product (tentatively scheduled for early 2024).

The process of identifying, cleaning, formatting, compiling metadata, uploading, and releasing ground gravity surveys is a broadly linear process, with complexities each step of the way.

Identifying files associated with ground gravity surveys is relatively straightforward. South Australian Government company reporting officers keep detailed records of all data submitted as part of annual technical reports, including all geophysical data. These records allow the GSSA geophysicists to easily compile a list of files that require upload to SARIG. The data files are automatically attached to openfile envelopes after a five-year confidentiality period, but are not automatically added to the spatial layers online. Complexities can arise if a portion of a survey is missing. The company reporting officers are authorised to contact exploration companies directly and can usually track down missing information.

"Cleaning" a ground gravity survey usually involves a quick check of the data file(s) to ensure that there are no formatting issues. The majority of survey data files are fine, but occasionally an asterisk or column formatting issue will sneak in. We identify the issue and modify a copy of the file accordingly. We never alter the original company data; we create copies and work on those. There is always a backup.

We create a shapefile of the survey and view the field data spatially. Here we undertake QA/QC work and ensure that the survey has been acquired over the correct tenement(s), and compare nearby elevation and observed gravity values from overlapping and adjacent surveys. *i.e.*, we check that the survey "fits in." Each survey in the database has an export quality flag associated with it. The majority of surveys get this tick, allowing the data to be automatically harvested. The very few surveys without the export quality tick are still available via company reports, but are not visible on the spatial layer on SARIG.

In rare instances we need to back-calculate observed gravity from Bouguer Anomalies (and elevations). This is a last resort, only occurring if a request for the full data from the exploration company fails. In these rare situations we have in-house spreadsheets to calculate the "original" data, and we clearly state if survey data has been back-calculated in our database.

Formatting the files is arguably the most time-consuming step. In order to upload ground gravity data to the gravity module in the SA Geodata database, we need to upload a minimum of eight columns of data per survey (not including survey metadata). These fields are a point number (of no more than eight digits), easting and northing and zone (or latitude and longitude), three heights (AHD and both ausgeoid09 and ausgeoid2020 ellipsoidal heights), the observed gravity, and a grid flag (indicating if the point is to be included in the state grid product. Y = yes, include in the grid, N = no, do not include in the grid). The database will use this information to calculate the Free-Air and Bouguer Anomalies (both slab and spherical cap Bouguer Anomalies are calculated). Not all survey data come with all three heights, and we usually need to calculate one or two of them. For this we regularly utilise the free online calculators available on the Geoscience Australia website.

We also need to remove repeat observations. The architects of the gravity module built the database so it won't accept two gravity values at the same point within the same survey. Generally this is a simple step of filtering a "station type" field and removing repeated points, but occasionally this isn't an option and we need to look at repeated point numbers, or matching easting/northing combinations.

Once the data has been whittled down to the essential information, we compile as much of the survey metadata as possible (including but not limited to: Survey name, start and end dates, number of stations acquired (with and without repeats), survey company, for whom the survey was acquired, gravity serial numbers, the Exploration Licence number(s) on which the survey was conducted, gravity meter details, base station and survey tie details, DGPS and elevation info, gravity datum, geodetic datum, confidentiality status.

The survey is given a unique survey code, usually in the form YYYYAXX, where YYYY is the year, A is the letter A, and XX is the n^{th} survey for that year that we've processed. In surveys prior to around 1990, the "A" would be replaced by a B or E or I (or other letters) depending on the nature of the survey. The codes with an "E" letter are interpreted as scientific notation numbers in some software packages, and so we no longer use this naming system and just use an "A". The metadata is loaded into the gravity module, followed by the field data. The database will reject the data if values within the upload file fall outside allowable parameters. As an example, a positive latitude value cannot be uploaded.

Once the survey is loaded, we commence work on the next survey. However, we are currently managing many surveys in batches. We have constructed a simple dashboard to allow us to compile all surveys requiring upload, and then we can clean all the files at once, format them at once, *etc*. At the time of writing we are 59.04% through the process of uploading 176 surveys.

The story doesn't end there. Once the surveys are on SA Geodata, they still need to be loaded to the spatial layer on SARIG. This is a partially automated process, with aspects of the process requiring manual intervention. First, the data is automatically harvested into a corporate data layer and becomes available for internal government use. This occurs automatically every month but can be pushed through upon request. Next, we need to notify our GIS experts that the corporate layer needs to be added to SARIG – to update the current gravity station layer. This isn't automatic and is undertaken on an as-needs basis. The spatial data is made SARIG-friendly and the SARIG team is alerted to the update. The layer is first added to a test instance of SARIG (UAT; User Acceptance Testing) to ensure everything is in order, before an ok is given and the test layer is replicated in production. The move is not a push, rather it is a pull, with SA Government IT external to the GSSA managing the process. Finally, the SARIG server must be restarted for the changes to flow through to production.

It can therefore take over a month from identifying a file for upload, to the points of that survey being made visible on SARIG. As indicated, we are currently working through uploading a batch of surveys. We anticipate these will be available in early 2024, before they are added to a new state grid product. Stay tuned!

Figure 1 (not included): a photograph of the author, staring at a screen full of letters and numbers, looking for a misplaced comma.

Ngaityalya

(Kaurna, thank you)

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Henderson Byte: Superconductors – some new developments

A superconductor is a material that conducts direct current with no electrical resistance. This lack of resistance supports very high currents without loss, and makes superconductors very attractive for use in power transmission. Also, the persistence of current in a closed loop can be used in various applications to make large permanent magnets. For example, today's Magnetic Resonance Imaging (MRI) machines use superconductor magnets to achieve a magnetic field strength 30 000 times stronger than the Earth's field. Superconductors also make for highly efficient electronics with extremely high levels of performance.

An important feature of superconductors, which confirms the existence of the state, is that they expel the magnetic field from within the material and also do not allow the magnetic field to penetrate. This phenomenon in superconductors is called the Meissner effect**.** This makes them powerful electromagnets, some with the ability to levitate trains. Superconducting circuits are also a promising technology for quantum computing because they can be used as qubits, the basic units of quantum processors.

However, until recently, the ultra-low temperatures (close to absolute zero, 0 Kelvin) and ultra-high pressures (>10^4 bar) necessary to achieve the superconducting state makes it inconvenient to implement. An ideal superconductor would be at room temperature and pressure. If such a superconductor could be economically mass-produced, it could revolutionise electronics. Despite decades of intense research efforts, such a state is yet to be realised.

In recent decades, researchers have developed a class of so-called high-temperature superconductors**,** defined as materials with a critical temperature, T_c (the temperature below which the material behaves as a superconductor) above 77 K (–196.2 °C), which is the boiling point of liquid nitrogen. They are only 'high-temperature' relative to previously known superconductors, which function at even colder temperatures.

New room-temperature superconductors promise to change that. As the name suggests, room-temperature superconductors don't need special equipment to cool them. Some do need to be pressurised, but only to a level that can be achieved by using strong metallic casings.

In March this year, eleven researchers at the University of Rochester, New York, USA announced in *Nature* a new material that is a superconductor at room temperature. It is a synthesised compound of nitrogen-doped lutetium hydride exhibiting super conductivity at a critical temperature, T_c , of 21°C (294 K). While at room temperature, the pressure required is still high at 10^4 bar, and would restrict the use of this superconductor (see Dasenbrock- Gammon *et al., 2023. Nature,* **615**, 244–250).

However, subsequent published criticism of this research, which claims that it does not present evidence for true superconductivity, has resulted in this paper being retracted from *Nature* in November, 2023.

In June this year, two research teams in China, one led by Jianjun Ying at the University of Science and Technology of China and the other led by Changqing Jin at the Chinese Academy of Sciences, published their work together on the production of a single element superconductor with the highest critical temperature to-date of -237°C (36 K) This was using Scandium (Sc) compressed between two diamonds. While much below room temperature, the T_c is comparable to that of classic multi-element superconductors. However, it is still at a pressure of 10^4 bar. (See *Physical Review Letters,* **130**, 256002*).*

A more recent development in July this year, by Hyun-Tak Kim and colleagues at William and Mary College in Virginia, USA, is the formulation of a multi-element superconductor at room temperature and pressure. The synthesised material, called LK-99, is a modified lead apatite crystal and its resistance is near zero at 30^0 C (See *New Scientist,* 5 August 2023). The conductor exhibits the Meissner effect when a millimetre-sized sample of LK-99 is placed on a magnet. This is illustrated in a still from a video in the above *New Scientist* paper, page 10. Only one edge of LK-99 levitates, due to only that part being superconductive. Two papers, not peer reviewed, reporting this development, are doi.org/kk42 and doi.org/kk43. The latter is by Kim's colleagues at Korea University in South Korea.

While the above development is considered by many to be an important breakthrough in the quest to have easy-to-use superconductors, some are sceptical of the results from LK-99 and claim it is too early to say that the evidence of superconductivity is certain.

Clearly this is a space to be watched!

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Canberra observed

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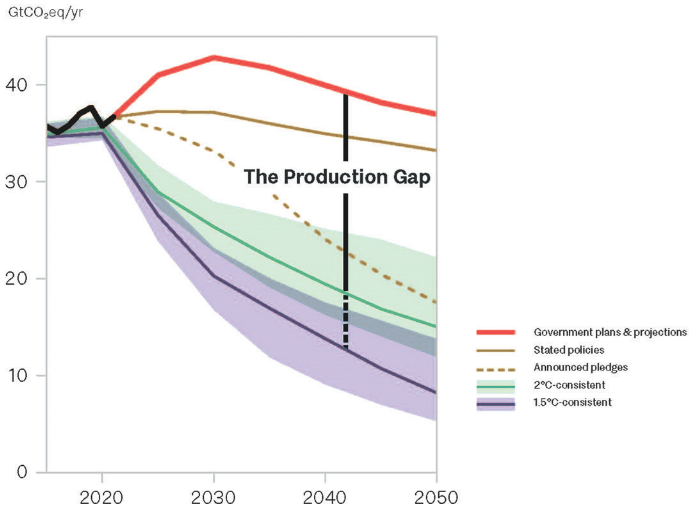

Figure 1. *Global fossil fuel production. Source: https://www.unep.org/resources/production-gap-report-2023*

The chances of limiting global warming to 2.0°C by 2050 are close to zero

The United Nations Environment Programme (UNEP) has produced an annual "Production Gap" report since 2019. These track the discrepancies between governments' planned fossil fuel production and global production levels consistent with limiting warming to 2050. The *Production Gap Report 2023* was released in November 2023 (https://www.unep.org/resources/production-gap-report-2023). It makes grim reading and shows that the top fossil fuel producers plan even more extraction despite climate promises.

This conflicts with government commitments under the Paris Agreement, and clashes with expectations that global demand for coal, oil, and gas will peak within this decade even without new policies.

Figure 1 shows the global production gap and Figure 2 shows the details for coal, oil and gas production.

Globally, Australia is a small contributor

The production, import, export, and net supply for domestic consumption of primary fossil fuels in exajoules (EJ) by country in 2021 is summarised in Table 1.

An exa-joule is one joule x 10 to 18^{th}. Values are rounded to one decimal place. Exports are shown as negative values. The contribution by China dominates.

Meanwhile, Australia's greenhouse gas emissions remain almost unchanged

The results of the December 2022 quarterly update (https://www.dcceew.gov.au/about/news/australias-greenhouse-gas-emissions-dec-2022-quarterly-update) show that emissions were 463.9 million tonnes of CO_2 equivalent in the year to December 2022. This was 0.4% or 2.0 million tonnes lower than the same period in 2021.

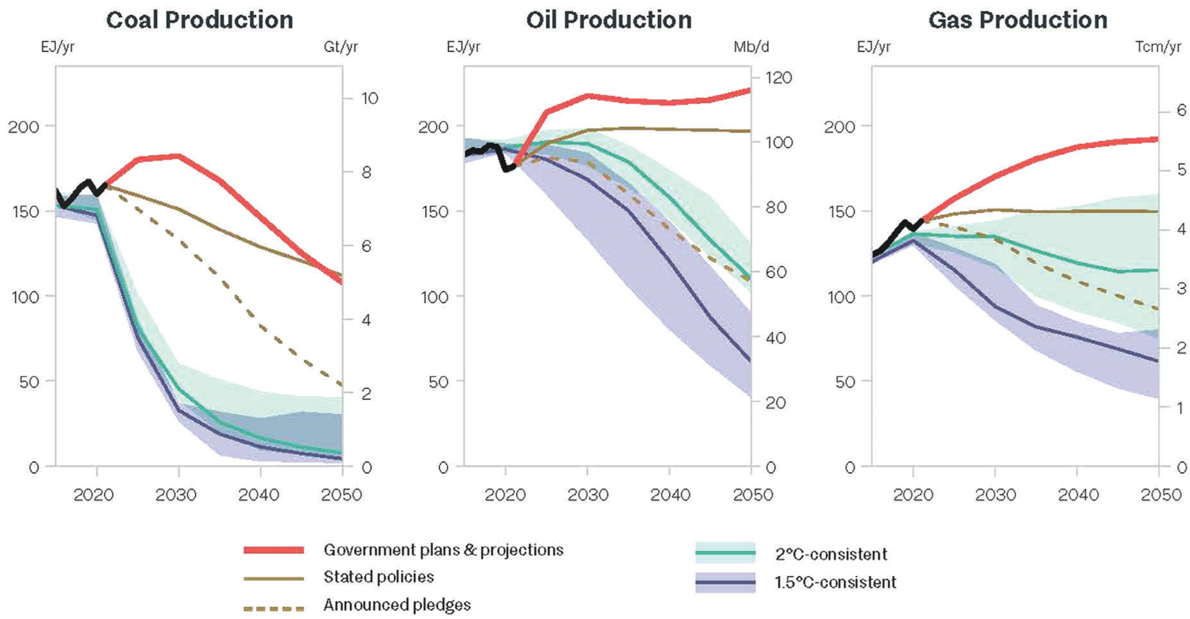

Figure 2. *Government plans and projections for global fossil fuel production https://www.unep.org/resources/production-gap-report-2023. Current plans would lead to an increase in global coal production until 2030, and in global oil and gas production until at least 2050. See the report for details. The legend is the same as for Figure 1.*

Table 1. Production, import, export, and net supply for domestic consumption of primary fossil fuels in exajoules (EJ) by country in 2021. Source: https://www.unep.org/resources/production-gap-report-2023

Country	Production	Import	Export	Net supply for domestic consumption
Australia	17.4	0.7	-14.2	3.8
Brazil	7.8	1.5	-2.7	6.6
Canada	19.4	2.5	-12.2	9.8
Colombia	3.6	0.0	-2.8	0.8
Germany	1.4	7.5	-0.1	8.9
India	15.2	14.7	0.0	29.8
Indonesia	16.0	1.1	-10.9	6.2
Kazakhstan	6.3	0.3	-3.9	2.7
Kuwait	6.3	0.3	-3.9	2.7
Mexico	5.4	2.5	-2.4	5.6
Nigeria	4.4	0.0	-3.5	0.9
Norway	8.3	0.1	-7.4	1.1
China	102.3	33.5	-0.3	135.4
Qatar	9.4	0.0	-6.4	3.0
Russian Federation	60.0	0.9	-24.0	36.9
Saudi Arabia	25.3	0.0	-13.3	11.9
South Africa	5.5	0.5	-1.8	4.2
UAE	9.2	1.2	-5.2	5.2
UK	3.0	3.8	-1.7	5.0
US	75.3	17.4	-16.1	76.5

The trend over the year indicated:

- Reductions in emissions from electricity as renewable energy uptake continues
- Decreased fugitive emissions, reflecting reduced production in coal mining due to the impacts of heavy rainfall events in New South Wales and Queensland
- Decreased emissions from stationary energy (excluding electricity) driven primarily by decreased activity in the manufacturing sector and decreased gas consumption in the residential sector
- Increased transport emissions reflecting the ongoing recovery from COVID related travel restrictions, particularly in domestic aviation
- Increased emissions from agriculture, returning to pre-drought levels because of increases in livestock numbers and crop production.

There's a lot of work to do to make a substantial reduction.

Santos and Beach to develop Moomba carbon capture and storage project

Santos and joint venture partner Beach Energy recently announced a final investment decision to proceed with the A$220 million Moomba carbon capture and storage (CCS) project in South Australia, with startup expected in 2024. Santos has successfully registered the Moomba CCS project with the Clean Energy Regulator. The Regulator's CCS method provides a crediting period of 25 years, over which period the project will qualify for Australian Carbon Credit Units for emissions reduction from Moomba CCS. The plan is to permanently to store 1.7 million tonnes of CO_2 per year in the same reservoirs that used to hold oil and gas. They are hoping for a first injection during 2024 at a cost of US$6-8 per tonne of CO_2.

Whether CCS will make a significant impact to drive down carbon emissions is yet to be determined. The International Energy Agency's (IEA's) Sustainable Development Scenario requires a hundredfold increase in CCS between now and 2050 to achieve the world's climate goals– going from 40 million tonnes of CO_2 stored each year today to 5.6 billion tonnes in just 30 years' time. We are not told how much CO_2 they expect to store over the life of the project, but we look forward to the first results in 2024.

The Resources and Energy Quarterly provides a good summary of the health of our resources industries

The September 2023 Resources and Energy Quarterly is worth a read, even if there are 178 pages (https://www.industry.gov.au/publications/resources-and-energy-quarterly).

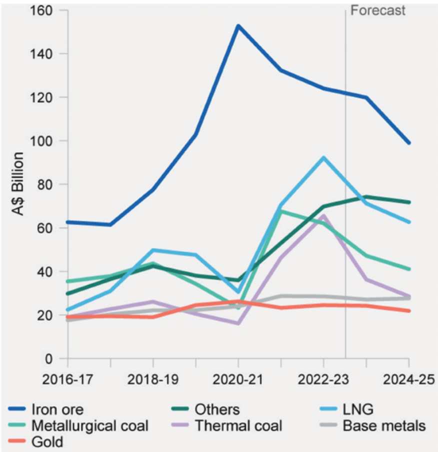

Figure 3. *Australia's resource and energy exports. Source: https://www.industry.gov.au/publications/resources-and-energy-quarterly-september-2023*

The current issue underlines the importance of the sector, which contributes about 14% to Australia's GDP and makes up more than two-thirds of Australia's total merchandise exports. In 2022-23 the commodity export earnings set a record of $467 billion.

When you add on the $1 billion invested each quarter on mineral exploration, it is surprising that the economists are forecasting a significant downturn in future years. Figure 3 summarises the current situation and shows what the economists are forecasting.

It is surprising that that the forecast is for a decline in export values for most of our commodities. It does not appear to consider the value of the battery-building minerals, such as copper and lithium, and you might have expected a larger contribution from the petroleum sector. The levels of exploration expenditure have been so small over the last few years, they can only go up.

In all the volatility of the price of commodities, gold has averaged between USD 1800- USD1900, over the past four years. So, gold continues to shine brightly and provide stability. With good values, gold exporters should be able to make a living!

Education matters

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Dear Readers, with great pleasure and admiration, we extend our warmest congratulations to the brilliant cohort of nineteen PhD, MSc, and Honours students from eleven esteemed Australian Universities on the successful completion of their theses. The culmination of their dedicated efforts and intellectual prowess marks a significant milestone in their academic journey and contributes immensely to the field of exploration geophysics.

In the following pages we invite you to delve into the detailed summaries of these exceptional theses, each a testament to the depth and diversity of research within our community. From innovative approaches to geophysical exploration to groundbreaking discoveries that push the boundaries of our understanding, these students have exemplified the spirit of inquiry and excellence that defines the geophysics field in Australia.

As we celebrate their accomplishments, we also acknowledge the invaluable guidance and support provided by mentors, faculty, and the broader geophysical community. It is through collaboration and shared passion that we continue to advance the frontiers of exploration geophysics.

Join us in recognising these emerging leaders and their contributions to our field. May their achievements inspire future generations of geophysicists, propelling us toward new heights of scientific discovery and technological innovation.

Theses in geophysics completed in 2023 PhD theses

Shubham Agrawal, Australian National University: *Seismicity and structure of the eastern Gawler Craton and Lake Eyre region.*

Kati Thanda-Lake Eyre represents the lowest point and the largest lake (when filled) in Australia. Located northeast of the Gawler Craton, the region is associated with pronounced intraplate seismic activity and thick sedimentary cover, potentially obscuring the elusive boundary between older Proterozoic and younger Phanerozoic eastern Australia. Despite this, the area had limited seismic data coverage due to its remoteness and the harsh arid climate, creating a seismic coverage blind spot in the centre of the Australian continent. To address this, two seismic arrays were deployed from 2018 to 2022 - the Lake Eyre Basin array and AusArray-SA array, which provide the basis for this thesis.

One of aims of this thesis was to understand the seismic signature of sedimentary layers within South Australia using receiver functions. Three-quarters of the Australian continent is covered by a blanket of sedimentary and regolith material and estimates of sedimentary thickness are therefore essential to begin to explore beneath the sedimentary cover. However, active-seismic methods such as reflection imaging can be prohibitively expensive, particularly in remote areas. Therefore, to address these challenges, we utilise seismic stations in South Australia to determine basement depth based on the arrival time of the P-converted-to-S phase at the boundary between the crustal basement and sedimentary strata. By establishing a predictive relationship between Ps arrival time and basement depth using borehole data, we provide a way to obtain an initial estimate using relatively low-cost and portable seismic stations.

Using this shallow structure information, the thesis investigates the Moho topography beneath the region. Many of the recently deployed stations are located on such low-velocity sedimentary basins, leading to high-amplitude reverberations in the receiver function signal. We employ a resonance removal filter to reduce the sediment reverberation effect, facilitating detection of the P-to-S conversion from the Moho, and providing new insights into the crust of an under-explored region of South Australia.

Finally, the thesis focuses on understanding the occurrence of earthquakes in the Lake Eyre region. Intraplate seismicity can pose a significant risk as it is often non-periodic, poorly understood, and sporadically recorded by sparse seismic networks across vast continents. Within Australia, the distribution of intraplate seismicity is non-uniform but instead tends to concentrate along weak zones of increased activity, such as, the eastern margin of the Gawler Craton in South Australia. Over 130 new local events have been recorded that would otherwise have gone undetected by the national network. After relocation, the pattern of earthquakes becomes more spatially defined and appears closely tied to a trans crustal scale fault system at the edge of the Gawler Craton. Interestingly, earthquakes follow the natural spring system in the region associated with the edge of the Great Artesian Basin, indicating a possibility of fluid-assisted hydrofracturing. Thus, this thesis provides new constraints on the crustal structure of a hitherto under-explored region in the heart of the Australian continent and contributes to the ever-increasing global understanding of intraplate earthquakes.

Auby Baban, Edith Cowan University: *Carbon geo-sequestration and enhanced oil recovery in geological formations: Multi-scale analysis.*

Carbon Geo-sequestration (CGS) is a key component of the net-zero approach of achieving the global decarbonisation programme by 2050. When combined with Enhanced Oil Recovery (CGS-EOR), it is an economically appealing technique as it offsets a fraction of the expenses associated with CO_2 extraction. However, despite recent cutting-edge technical research, predicting quantitative CO_2 trapping in geological formations via capillary trapping remains enigmatic. Moreover, physical underpinnings of several aspects of multiphase flow characteristics of CO_2/brine/rock systems, that greatly impact carbon capture and containment security, require further investigations.

Nuclear Magnetic Resonance (NMR) is of particular interest when investigating the petrophysical characteristics of multiphase flow in porous media as it is highly sensitive to pore scale rock-fluid and fluid-fluid. From T_1-T_2 2D images and T_2 relaxation time, conclusions regarding Porosity, Relative permeability, Pore-Size Distribution (PSD), Saturation (S_w) and thus residual CO_2 saturation ($S_{CO2,r}$) can be inferred.

This thesis investigates laboratory core flooding measurements with data collected on water-wet (hydrophilic) and oil-wet (hydrophobic) sandstone and carbonate formation rocks under reservoir conditions. I was specifically focused on the pore-scale (micro-scale) fluid physics in a multiphase flow pore network due to its significant impact on the Darcy-scale (macro-scale) flow functions and, ultimately, on the reservoir-scale CO_2 residual trapping and oil recovery factor. I used the robust *in-situ* NMR T_1-T_2, 2D images to visualise fluid configurations in the pore-space and utilised T_1/T_2 ratios to assess the microscopic wettability of the rock to pore-space fluids subsequent to displacement processes. The T_2 relaxation time was measured to assess the corresponding rock/fluid interplay at the pore level, analyse the trapping behaviour, and demonstrate displacement mechanisms, all of which are directly connected to field flow functions.

In two-phase flow systems, water-wet samples consistently demonstrated greater residual CO_2 trapping than analogous oil-wet cores. Comparable results of CO_2 trapping were observed in the three-phase flow systems, although certain aspects are different, and displacements are significantly complex. Furthermore, the oil recovery factor in oil-wet cores was substantially lower than that of analogue water-wet cores.

Finally, a thorough and self-consistent dataset that significantly impacts the CO_2 storage in saline aquifers and in hydrocarbon reservoirs is the end result, demonstrating how physicochemical characteristics (wettability) adjustment at the pore scale causes large-scale declines in trapping. These significant innovative advancements emphasise the importance of CGS as an integral part of net-zero missions and CO_2-EOR project designs relative to reservoir-scale implementations in terms of budgets, delivery of additional energy resources (more oil recovery), and storage capacity and containment integrity.

Ao Chang, University of Queensland: *Full waveform inversion with random mixing.*

Full waveform inversion (FWI) is a high-resolution velocity modelling technique used to image subsurface geological structures. The velocity profile is one of vital physical information to identify the properties of medium. The conventional ways to conduct FWI can be gradient-based optimisations, Bayesian frameworks, or even evolutionary algorithms based on stochastic theorem. The optimisation methods are usually driven by minimising the misfit between the observed and the simulated waveform data on the current model to update the velocity model iteratively. The common issue of this method is easily being trapped into local minima, highly depending on the quality of an initial model. In order to validate different methods, the easiest way to obtain an initial model is a smoothed version of real velocity model (which is impossible in reality). Speaking of inversion, it always represents the non-unique solutions due to its non-linear and ill-posed problems. Bayesian provides an alternative option to bring uncertainty quantification of inverted models in instead of a "best-fit" solution. But FWI is of complexity and multi-parameters involved, the intensive computation cost becomes an inevitable issue to deal with within the Bayesian framework.

My thesis is aimed to apply a geostatistical algorithm called Random Mixing (RM) for FWI. It takes advantages of spatial correlation of the unknown velocity field represented by variogram and univariate marginal distribution as prior information to guide the inversion, the univariate marginal distribution can be represented by any parametric or non-parametric distribution function. The prior information can be acquired easily according to literature, experimental knowledge or direct observations. Meanwhile, RM allows for uncertainty quantification based on sets of inverted realisations by means of variance. The realisations generated here are possible velocity models of the assumed variogram and marginal distribution, and all observations are reproduced to some accuracy. Thus, a multitude RM running can be regarded as sampling from the random field which is modelling the solution space of the inversion problems. The probability density function for each element can be characterised by calculating and visualising element-by-element moments. The spatial distribution of the mean and standard deviation across a group of realisations are shown as uncertainty within the solution space. Inside the inversion processing, RM reduces the computation cost through reducing the number of forward models running. It is achieved by transforming the objective function into single components and get optimal estimation via Whittaker-Shannon interpolation.

The first model is built up with an added anomaly represented by regular sinus pattern on a homogeneous field to investigate the survey depth and feasibility of the algorithm. Then a spatial random field with an anomaly body is generated and tested for the same purpose. The mean fields of RM realisations are able to deliver good estimates for the velocity. Both of two models illustrate the significance of the accuracy of the spatial characterisation (even though the accurate ones are not possible in real work). So as the further work, well log data is added as linear constraints to estimate the prior information and drive inversion processing with seismic observations together. The virtual well logs are drilled with an equidistance along the survey line where the seismic survey covers. The experimental spatial parametrisations are estimated from well log velocity data samples and fitted into theoretical spatial functions to get best-fit used for the following inversion. Through RM, the linear information can be added on the inversion processing in a straightforward way rather than into the objective function as a regularisation. At the same time, the uncertainty across the realisations can be reduced via being constrained by direct observations. The tests with estimated prior information are implemented on the same previous random model for comparison. The results with combination of both linear and non-linear constraints with estimated prior information can reach to the similar level of results which are inverted by individual seismic observations with accurate prior information. Even without seismic observations, the individual well log data with estimated parametrisations can still lead to satisfying results when the vertical sampling interval could cover the spatial correlation length. Furthermore, an anisotropy multi-layered model with a tilt is generated to test RM for a strong spatial anisotropy. The velocity data returns a velocity distribution reproducing the geometry of the tilted structure with high accuracy, which validate RM's ability for complex geological structures.

Youseph Ibrahim, University of Sydney**:** *Investigating the dynamic drivers shaping fold and thrust belts from plate margins to intracontinental settings.*

This thesis investigates the dynamic processes behind the formation and evolution of fold and thrust belts in conventional plate margin settings and non-conventional intracontinental settings. The main research questions are: (1) How do pressure gradients derived from the thickening or thinning of the crust influence the genesis and evolution of fold and thrust belts? (2) How does the rheology of the lithosphere influence the architecture of an overlying fold and thrust belt? (3) How does structural and thermal inheritance influence the architecture of fold and thrust belts? (4) How can fold and thrust belts form in an intracratonic environment? This thesis consists of three manuscripts that address these questions.

The first manuscript explores how the interplay between tectonics and isostasy influences the first-order development of fold and thrust belts. Numerical experiments highlight the contrasting isostatic response of a ductile hot lithosphere (*e.g.,* hinterland within continental crust) versus a rigid cold lithosphere to the loading of an overlying fold and thrust belt. We find that when isostatic adjustment is facilitated through ductile flow, shortening is localised in narrower regions. This results in a narrow and thick fold and thrust belt with complex internal architectures. When isostatic adjustment is facilitated by lithospheric flexure, fold and thrust belts have greater relief and are laterally extensive, with an internal architecture consisting of structural repeats. The findings are juxtaposed with the Subandean zone, illustrating the different structural patterns observed in the Bolivian and Peruvian regions due to their varying isostatic responses driven by their distinct crustal rheology.

The second manuscript contrasts the formation of fold and thrust belts from the inversion of narrow and wide rifts. Modern geotherms favour narrow rifts, while warmer Archaean and Proterozoic geotherms favour wide rifts. Through numerical experiments, we explore rifting under different geotherms, followed by compression either immediately post-rifting or after a quiescent cooling phase. Narrow rift inversion encourages foreland basin development adjacent to the fold and thrust belt. Extensional faults reactivate at the centre of the model and new faults propagate in the adjacent foreland basins. Wide rift inversion, however, sees broader fault reactivation and a widely distributed fold and thrust belt. In wide rifts, when contraction immediately precedes rifting while the lithosphere is warm, the ductile lower crust and lithospheric mantle thicken homogeneously, resulting in a flat Moho. Thrusting is limited to the top few kilometres of the upper crust. Conversely, the inversion of thermally relaxed wide rifts involves faults that cut across the lithosphere and offset the Moho by 10-30 km, as a result of the embrittlement of the lithosphere. Comparisons are drawn with the Colombian Eastern Cordillera and Centralian Superbasin.

The final manuscript explores the central Australian Alice Springs Orogeny, a unique setting in which an orogeny forms deep within the interior of a craton. We use a combination of fieldwork, geochronology, and numerical modelling to explore the strange occurrence of a high-grade gneiss dome (Entia Dome) adjacent to a series of nappes and duplexes (Arltunga Nappe Complex) within the eastern Arunta region. Structural data show a structural continuity from the Entia Dome to the Ruby Gap Duplex. Geochronology at key sites confirms the exhumation of the dome to be synchronous with deformation in the Ruby Gap duplex and Illogwa shear zone between 340 and 310 Ma. We present a model in which an extensional domain, comprising the Entia Dome, and a contractional domain, that consists of the Arltunga Nappe Complex, are linked by a translational domain containing the Bruna décollement zone and Illogwa shear zone. Our numerical experiments show that high horizontal gravitational stresses, driven by the substantial pressure gradients introduced by the 35 km deep Harts Range rift, lead to the convergent gravitational collapse and inversion of the Harts Range rift. This initiates the exhumation of the Entia Dome and the sliding of cover sequences forming gravity nappes, isoclinal folds and the thrust systems that make up the Arltunga Nappe Complex.

This thesis introduces new insights into the role of gravitational forces, lithospheric rheology, and the thermal and structural inheritance of rifts in the evolution of fold and thrust belts. We present the first example of major deformation attributed to contractional gravitational collapse in central Australia and open new dialogues about the tectonic drivers influencing the development and architecture of fold and thrust belts in intracratonic and plate margin settings.

Roman Isaenkov, Curtin University: *Continuous borehole seismic monitoring of carbon dioxide storage.*

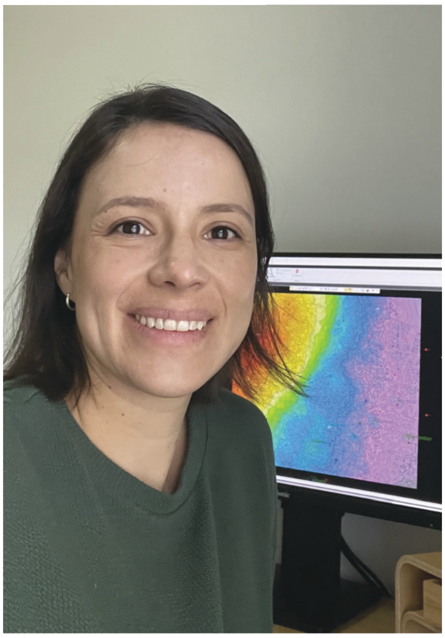
Active time-lapse seismic monitoring technology is essential for carbon storage projects due to its ability to track the CO_2 plume evolution in space and time. The standard industry monitoring approach (known as 4D seismic) is to acquire one 3D seismic survey before injection (baseline) and a series of monitor surveys during and after injection. Assuming that nothing in the subsurface has changed except CO_2 reservoir properties, a comparison of baseline and monitor surveys is supposed to highlight the presence of CO_2. However, such surveys can interfere with other land users and require on-site crew and equipment, which becomes expensive over years or decades of monitoring. These factors limit the frequency of repeat surveys to one or a maximum of two per year – and this may miss critical processes such as CO_2 leakages or fault re-activations.

These limitations may be addressed by a permanent seismic reservoir monitoring (PRM) system with permanent sources and receivers, which can track subsurface changes in near real-time over decades. Permanent sources can be installed on the surface or in shallow boreholes. Permanent receivers can be buried in trenches or also installed inside wells. Borehole installations are often preferred as this approach minimises the influence of weather and variable near-surface on sources and receivers. Permanent installation minimises land access requirements, allows automatisation of the system (crew is not required), and can be frequent (in some cases – daily). However, the main PRM limitation is the high installation cost, as a lot of equipment is required to run the project in the first place.

Permanent monitoring is still in its infancy, and as such, no standard PRM design exists. This is mainly due to the different tasks and different available equipment each project has. As such, there is no standard way to automate data acquisition, storage and processing - each project can have some unique new features. The work of this thesis aimed to develop automated data acquisition, storage, processing and interpretation of PRM data acquired at the CO2CRC Otway Stage 3 project with the main focus on data processing. The work is published in five publications.

The thesis describes the acquisition setup, on-site data storage solution, processing and assessment of PRM's initial repeatability. The initial data processing compresses the data from 1.3 TB/day to 500 MB/day, providing good repeatability over the half-year period. Later, we improved the initial workflow and presented monitoring results and their comparison with high-lateral-resolution 4D VSP data. We detected the CO_2 plume on the second day of injection and monitored its evolution over more than a year of monitoring.

Monica Jimenez, University of Adelaide: *Post-breakup evolution of the Ceduna Sub-basin and understanding of processes that occur on rifted continental margins.*



Understanding the characteristics and evolution of normal growth faults has proved critical for interpreting the geological development of delta systems and the petroleum system of sedimentary basins within passive margins. In general. normal faults control the distribution of sedimentary deposits, the stratigraphic architecture and can provide migration pathways or traps for fluids (*e.g.,* water and hydrocarbons). The interpretation of 3D seismic surveys has permitted a better understanding of fault evolution and control the migration of fluids. However, there are still knowledge gaps regarding the variability of normal growth faults geometrical features (length, strike, dip angle and displacement), fault evolution, changes in the distribution of sediments near the fault planes, and variation in the risk of fault reactivation and their control on magma flow.

This project consists of four chapters that detail the structural complexity of normal growth faults in the Ceduna Sub-basin (Great Australian Bight Basin) and provide a detailed interpretation of the Ceduna 3D MSS seismic survey, an analysis and discussion of the normal growth fault complexity in terms of fault evolution, potential risk of reactivation, and influence the transport of magma. The seismic interpretation used in this study permitted a detail characterisation of 530 normal growth fault segments in terms of displaced sedimentary sequences, length, dip angle, strike, and changes in displacement along the fault plane. This study classifies these faults segments in the Ceduna Sub-basin in three different fault groups related to the displaced sequences and includes three different analyses: (1) Fault kinematic analyses to assess three different evolution styles that include constant growth and reactivation by either dip-linkage or reactivation during the deposition of upper sequences. (2) Assessment of risk of fault reactivation using the fault analysis seal technology to demonstrate that areas of the fault with steep dip angles and oblique strikes from the current maximum horizontal stress are at higher risk of reactivation. (3) Interpretation and statistical lineal alignment prediction to demonstrate the substantial control that normal growth faults have on the geometry and emplacement of eruptive centres magma, flow regions and intrusions.

This is the first study in the Ceduna Sub-basin to include a 3D seismic data that extends 12 030 km^2 to understand the variation in geometrical characteristics and the variability in the fault evolution of normal growth faults, exposing differences in their evolution styles and the importance of the detachment in the fault displacement configuration in delta systems. It established the importance of the changes in the fault roughness in the prediction of fault reactivation where regions of the faults with steeper dip angles and oblique strike orientations are at higher risk of fault reactivation. It also demonstrates that normal growth faults strongly influence the transport and emplacement of magma by stablishing a preferential northwest-southeast alignment between igneous bodies and the fault strike orientations.

Joel Kumwenda, Monash University: *Basement architecture of the North Australian Craton.*

The North Australian Craton is a significant component of the Australian continent, with its basement geology older than 1800 Ma. This basement geology is mostly concealed beneath Paleoproterozoic, Mesoproterozoic, and Cambrian sedimentary and volcanic cover. This thesis focuses on uncovering the hidden basement geology in the interior of the North Australian Craton and how this basement influenced the overlying basin architecture. Using potential field, seismic reflection, and existing isotopic, geochronological, and geochemical data, this study defines the basement crustal structures in the North Australian Craton.

A review of U-Pb inherited zircon ages and Neodymium geochemical data for pre-1800 Ma magmatic rocks provided insights into the nature of the basement of the North Australian Craton. Despite local variations in magmatism, basin systems, and deformation between the blocks, they share similar geologic evolution, magmatic history, and sedimentary provenance, indicating that they were part of a contiguous proto-North Australian Craton prior to the ca 1870-1850 Ma Barramundi Orogeny.

Lineament analysis of gravity and magnetic data reveals the composite nature of the basement in the interior of the North Australian Craton. Five distinct crustal elements are identified: Pine Creek, Arnhem, North Tennant Creek, Tennant Creek, and Tanami-Altjawarra. The Pine Creek, Tennant Creek, and Tanami blocks represent the exposed parts of the Pine Creek, Tennant Creek, and Tanami-Altjawarra, separated by major crustal boundaries interpreted as tectonic sutures. These crustal elements and their boundaries exhibit linear to curvilinear geometry typical of accretionary orogens in modern plate tectonic settings.

Geophysical interpretation and seismic reflection constrained forward gravity and magnetic data modelling shed light on the basement architecture of the Tennant Creek Block at the centre of the North Australian Craton. The forward modelling reveals predominantly WNW-trending faults, defining a half-graben, filled by sedimentary rocks of the *ca* 1840 Ma Ooradidgee Group. The west-northwest-trending structural grain of the basement is not reflected in the overlying younger basins defined by the Tomkinson Creek Group, highlighting the limited involvement of basement structures in the evolution of the overlying basin. This relationship is only evident at a local scale. Comparing the SEEBASE basin architecture of the North Australian Craton with the identified crustal element boundaries suggests that the basement architecture influenced the geometry of the overlying basins.

Overall, this research enhances our understanding of the internal architecture of the North Australian Craton and its tectonic evolution, emphasising the importance of an integrated geophysical and geological approach in deciphering complex basement architecture and its impact on basin development.

Evgenii Sidenko, Curtin University: *Advanced downhole geophysical monitoring of subsurface changes with fibre-optic sensors.*

Distributed Fibre-Optic Sensing is a fast-developing technology and is being actively used in geophysical monitoring applications. The technology is based on continuous measurements along a fibre-optic cable. Distributed temperature sensing (DTS) is used for measuring and monitoring temperature while distributed acoustic sensing (DAS) can record seismic waves/signals that induce axial strain in the cable.

Compared to 4D surface seismic monitoring, repeated Vertical Seismic Profiling (VSP) surveys with DAS receivers reduce the cost and invasiveness of timelapse CO_2 monitoring considerably but have limited spatial coverage around the borehole. This coverage can be extended by interferometric imaging that utilises free-surface multiples. Synthetic and field studies demonstrate that interferometric imaging is a viable method to extend the subsurface image beyond the coverage of standard VSP imaging. Comparison of the standard and engineered fibres shows that both fibres are sensitive to free-surface multiples, but the engineered fibre provides much higher signal to noise ratio, and thus is preferable for interferometric imaging with multiples. The results obtained with the engineered DAS cable show that in the depth range suitable for both methods, the VSP interferometric image of reflectors is comparable to the surface seismic image.

Borehole-based DTS and DAS utilised for continuous monitoring of borehole decommissioning operations reveal an abundance of valuable information about the course of the decommissioning process and the quality of the cement job. DAS has detected vibrational disturbances during the cement's setting up, while DTS was used to assess setting up of the cement and curing times as well as uniformity of cementation from the distribution of temperature along the borehole. Passive DAS data recorded a year later with the same array shows an abundance of seismic events in a wide frequency range from below 1 mHz to over 200 Hz and includes earthquakes, mine blasts, ocean microseisms, and local human activity. The amplitudes of waves from distant seismic events can be used to estimate and monitor physical properties of the media along the entire extent of the well. Spectral analysis of low frequency microseisms shows a strong correlation between passively recorded DAS and local weather observations. Detected peculiar in-hole reverberations are likely caused by crossflows of groundwater behind the intermediate casing, which may indicate imperfections of the cement job. The results demonstrate that downhole fibre-optic array installed in an abandoned well represents an opportunity to establish a permanent facility for continuous recording of passive and active geophysical data and for exploring various applications.

DAS measurements are also sensitive to temperature changes. Laboratory and field tests of DAS sensitivity to changing temperature demonstrate that DAS is sensitive to long-period temperature changes and its response is proportional to the time derivative of temperature. Induced fibre strain is linearly related to slow temperature change and this dependency can be estimated for a particular cable. The results can help compensate for the effect of temperature on low-frequency DAS signal and show that DAS can be used as a distributed temperature sensor if direct temperature measurements are not available.

Most DAS systems are designed to measure signals higher than 1 Hz; however, some DAS systems are sensitive to low-frequency (< 1 Hz) signals such as reservoir pressure variations. During CO_2 injection within the CO2CRC Otway Project, pressure related strain-rate DAS signals were observed in two monitoring wells. These signals are highly correlated with the pressure signals measured by borehole pressure gauges above the perforations in monitoring wells. Analysis of the data shows that DAS is able to detect reservoir pressure variations higher than 10^{-4} psi/s. Analysis of pressure variations and strain calculated from DAS strain rate values allows estimation of the elastic modulus of the reservoir formation. Obtained results show that DAS systems can be utilised not only as seismic sensors, but also as continuous pressure sensors that can help track possible CO_2 leakages into the overburden. In contrast to traditional pressure gauges, DAS is capable of tracking the pressure profile along the entire well. DAS pressure sensing capabilities open up many new applications to complement subsurface reservoir pressure monitoring, CCUS and hydrogeological studies.

Simon Willcocks, University of Adelaide*: Constraining subglacial heat flux in Antarctica from thermal conductivity and subglacial lakes.*

The rate of heat transfer from the solid Earth to the base of ice sheets has a significant influence on the long-term stability of Antarctic glaciers and consequently sea-level. Because it is very difficult in most cases to access the bedrock to determine solid Earth heat loss, we must rely on proxies for the thermal state of the lithosphere such as mantle seismic velocities and Curie depth estimates derived from magnetics. However, these proxies often relate to points deep in the crust/upper mantle and thus miss key aspects of heat transfer in the shallower crust, namely, radioactive heat production and thermal conductivity. My work focused on the latter by collecting some of, if not the first thermal conductivity measurements on Antarctic bedrock and modelling the effects of thermal conductivity both the lateral and vertical transfer of heat. For example, we find that in a subglacial valley, or buried bedrock high, most heat will move through the more conductive bedrock, resulting in heat being moved away from subglacial valleys and into bedrock in regions of geological contacts whereby heat will move into the more conductive of the two mediums. The result is the creation of localised regions where heat flux at the base of the ice sheet can be 80 to 120% of the regional heat flux creating localised regions of elevated/reduced temperature. Using new thermal conductivity measurements combined with a larger global database, I developed a method to predict thermal conductivity from igneous compositions and an empirical relationship with seismic velocity. We used the later to produce a continent-wide 3D model of thermal conductivity of the Antarctic lithosphere that can be used to improve geothermal heat flux.

A second aspect of my thesis involved using constraints provided by subglacial lakes to place reasonable bounds on subglacial heat flux. The existence of subglacial lakes results from two types of processes: the balance of energy at the rock-ice interface and the ponding of fluids transported beneath the ice sheet, often related to seasonal processes. I developed unsupervised and supervised machine learning methods to predict the geographic distribution of lake types using a set of simple observables including crustal thickness, bedrock elevation, ice thickness, ice velocity, average surface temperature and bedrock slope. The Principal Component Analysis, while shown not to be a good predictive map, is excellent at identifying regions of Antarctica as either containing active lakes (with current water infill/outflow) or stable lakes (in which water levels remain constant). The Subspace KNN classifier meanwhile, is able to both identify lake melt sources and type of lakes generated from those sources.

I also tested the proxy-based heat flux estimates using a basal heat flux constraint assuming melting at the base of the ice sheet. In the presence of subglacial lakes, regions where proxy-based estimates should exceed this constraint. I find that while results show a subtle relation between lake and regions of elevated heat flux, a large number of lakes are in regions of insufficient heat flux to generate melting. These results indicates that current proxy models currently underestimate geothermal heat flux. Since there is a relation between heat flux and lake locations, the proxy-based estimates can be combined with other maps of Antarctic surface temperature, ice thickness, bedrock elevation, crustal thickness, bedrock slope and ice velocity to predict lake melt source regions.

This work improves our ability to accurately map the geothermal heat flux at the base of the Antarctic ice sheet by giving proxy modellers by showing the importance of bedrock thermal conductivity as well as mapping it over a large section of Antarctica. We also show future avenues of research that can improve upon or use these geothermal heat flux models including mapping the melt sources of subglacial lakes.

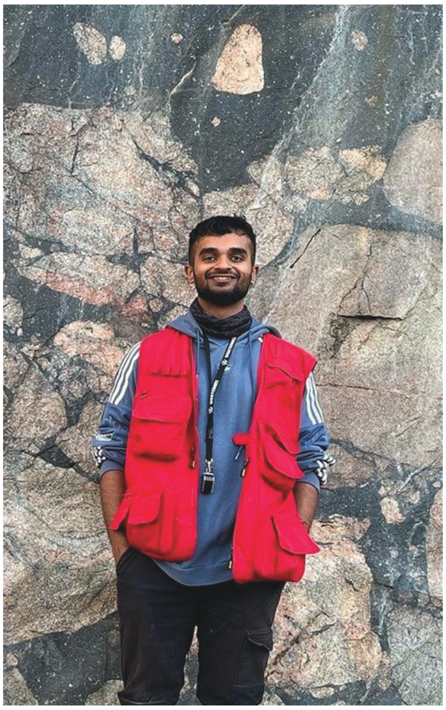
Ping Zhang, Australian National University: *Understanding arc-continent collision in the Banda Arc through 3-D seismic imaging.*

The active arc-continent collision in the Banda Arc is a result of convergence of the Indo-Australian plate with the Eurasian plate in SE Asia. From west to east along the Sunda-Banda arc, the subducting Indo-Australian plate changes from the Cretaceous to Jurassic age Indian Ocean lithosphere to continental lithosphere of Australian margin as it collides with the Banda arc. This young collision effectively captures spatial transition between subduction zone to arc-continent collision, which can be alternatively viewed as the temporal transition of these processes along-strike. Detailed knowledge of seismic structure is key to understanding this complex tectonic transition. A new Banda Arc Seismic Experiment composed of 30 broadband stations was carried out from March 2014 to August 2019 (~5 years) in the Timor-Leste and Nusa Tenggara Timor region of Eastern Indonesia.

In this thesis, I analysed this dataset with multiple techniques including receiver function, auto-correlation, ambient noise tomography, as well as teleseismic surface wave tomography, aiming to image the first comprehensive and high-resolution 3-D crust and upper mantle seismic structures at different scales. An up-to-date seismic catalogue that is foundational for structural studies was also built. I successfully imaged the subducted Australian continental margin at lithospheric depths, with pronounced along-strike structural variations at different scales. I suggested it may reflect the diachronous (progressive) collision as a result of oblique plate convergence or the inherent structural heterogeneities of the incoming and colliding Australian (lower) plate, or both. The present-day crustal structure may also be complicated by exotic terranes or microplates formed during the Jurassic breakup of eastern Gondwana. Tectonic fabrics related to orogenic, strike-slip, and volcanic structures from a variety of crustal depths are imaged across the entire collisional zone. The distribution of their strikes is interpreted to be associated with orogenesis, variable magmatic systems, strike-slip motion, and strain partitioning in response to the arc-continent collision and plate convergence. The new catalogue describes a complex pattern of crustal events and abundant deep slap seismicity. Lastly, I analysed the observed crustal fabrics, mantle anisotropy, isotropic structures in the crust and upper mantle as well as the seismicity together with the topography and existing geochemistry and geology observations. Altogether, these new seismic observations make a strong case that links the surface geology with subsurface crust and mantle structures, unravelling an enigmatic structural and compositional boundary along the Banda volcanic arc.

Masters theses

Abhijit Kurup, University of Western Australia: *Understanding magnetic responses in high-grade gneiss terrains in the Southwest Yilgarn Craton, Western Australia.*



This study involves the interpretation of high-resolution aeromagnetic data from the highly prospective southwest Yilgarn Craton. By integrating magnetic susceptibility (MS) data, with petrography and biotite geochemistry, the research investigates the relationship between geophysics and geology in a poorly outcropping amphibolite-granulite facies granite-gneiss domain within the Youanmi Terrane.

Field work, MS data and the study of the Fe-Ti oxide minerals has allowed the classification of the granitoids based on oxygen fugacity as oxidized magnetite-series granites and reduced ilmenite-series granites. The chemistry of biotites through electron probe microanalysis has also aided the classification of granitoids based on the I-type metaluminous and S-type peraluminous sources. Both the classifications show good correlation and the four broad outcropping lithologies are: a monzogranite migmatite gneiss (I-type and magnetite-series) characterised by high MS, a syenogranite (I-type and magnetite-series) with high MS, a monzogranite (S-type and ilmenite series) with low MS and a porphyritic monzogranite with two subgroups: one with high MS (I-type and magnetite series) and the other with bimodal MS (boundary of I-type and S-type and magnetite-series).

MS data demonstrates a high amount of variation within rock types at the outcrop scale necessitating a substantial number of measurements per outcrop for reliable MS averages, hence populations of MS are studied. Significant findings include the observation that MS bimodality in certain rock types is related to the degree of martitization of magnetite, change in mafic-mineral content and the presence of unevenly distributed secondary coarse-grained magnetite.

Aeromagnetic data was processed to generate a series of products, aiding in the identification of key geological features, such as faults, regional scale shears, mafic dikes, and lithological contacts between four observed granitoid units and one inferred mafic gneiss unit. The existing regional bedrock geology map is refined, underlining the influence of oxygen fugacity conditions and lithotypes on magnetic responses in the area.

Jessica Latimer, The University of Melbourne: *Insights into the tectonic evolution of the Middleton Basin, northwestern Zealandia (Te Riu-a-Māui).*

Previous tectonic reconstructions for the breakup of eastern Gondwana are of low resolution, which only consider the evolution of large, aerial landmasses, such as Australia and New Zealand. Despite Zealandia (Te Riu-a-Maui) being recently defined as New Zealand's own continent, 95% of the new continent lies underwater, meaning the information about the submerged regions has been inaccessible by first-order geological mapping techniques. Zealandia contains at least 20 sedimentary basins, all of which preserve an immaculate record of tectonism.

Continental breakup is an enigmatic tectonic process that irreversibly changes the structure of land on the Earth. However, modern plate reconstructions barely recognise the Earth's eighth continent: Zealandia (Te Riu-a-Maui), meaning the geological history of a large portion of the Earth is left unaccounted for. Zealandia is unlike any other continent, being submerged and containing significantly thinner continental crust (~20-24 km to the usual ~40 km), therefore providing a unique context in which continental rifting and extensional processes can be analysed. A better understanding of Zealandia's place on Earth provides significant value to the understanding of plate tectonics and will better constrain future tectonic models.

Both Australia and Zealandia were once a part of the megacontinent, Gondwana, which resided on Earth during the early Phanerozoic. The breakup of Gondwana began at ca. 105 Ma as the megacontinent separated and the bounds of many modern southern hemisphere continents were established. A considerable knowledge gap is presented by the lack of geological data present throughout much of offshore Zealandia, especially in the northwestern section where few drillholes are found. Despite the evolution of Australia and New Zealand being well understood, this presents a difficult situation in which the adjoining continental region is not accounted for, which contains a wealth of information about the evolution of eastern Gondwana.

Zealandia contains key information, much of which is preserved within sedimentary basins and it is here that insight into the rifting history of the continent can be found. Here, modern geophysical and seismic reflectance data is synthesised to investigate basin formation in northwestern Zealandia, as the continent rifted away from eastern Gondwana. The Middleton Basin provides a relatively unexplored location in which Gondwana's rifting history can be unravelled.

A new tectonic model for the evolution of the Middleton Basin is presented, highlighting the two-stage rifting history of the basin. The Middleton Basin is suggested to have formed during Mesozoic backarc extension, followed by rifting and subsidence as part of Zealandia in the Cenozoic, as the continent broke away from Gondwana.

This study deduces that the Greater Middleton does not appear to be a fault-controlled region and the basins do not contain oceanic crust. The presented genesis model addresses the formation of multiple, proximal basins by insinuating that extension took place over two distinct phases. The model allows basin extension to take place over time periods sufficient for slow strain rates. This model highlights why extensional strain propagated from one region to another adjacent area and suggests that strain hardening of northwestern Zealandia was responsible for the westward ridge jump that ultimately formed the Tasman Sea. Consequently, the Dampier Ridge and the Lord Howe Rise are considered undeformed basin margins. The model also acknowledges orogenesis in the development of eastern Gondwana and proposes that pre-existing lithospheric-scale heterogeneities, inherited from earlier orogenesis, may have governed the nucleation of extensional strain during Mesozoic rifting. This may have contributed to the location of basin formation throughout northwestern Zealandia.

Further study into the Zealandian region, especially the nature of basins in the northwest would be beneficial to the understanding of Gondwana evolution and breakup.

Rebecca Latto, University of Tasmania: *Active glacier processes from machine learning applied to seismic records.*

The buttressing, outlet glaciers of Antarctica are largely experiencing mass loss, affecting sea level rise, which creates changes to climates and communities. Glacier seismology, or cryoseismology, is a unique method for monitoring changes in motion through the glacier body in continuous data streams. Cryoseismology offers a geophysical lens

that can supplement satellite imagery with key information about how these remote glaciers change. However, there are a few challenges at present: namely, the ability to detect events above ambient noise and the ability to detect all types of events.

In this thesis, the challenges to cryoseismology are addressed in two parts. First, a novel event detection algorithm is presented that improves upon the popular STA/LTA algorithm to establish a more catch-all approach that better suits the glacier environment. Event detection is then applied to real seismic data from the Whillans Ice Stream in West Antarctica, retrieved during a 2010-2011 field study. The resulting catalogue is then investigated in preliminary correlation-type analyses. In the second part of the thesis, semi-supervised machine learning is applied as a tool to extract patterns in the diversity of event types in the Whillans Ice Stream catalogue. The event groups are studied in relation to tidal, temporal, spatial, and climatic cycles. Through a standardised workflow, events are then related to potential source mechanisms, such as melt-related processes impacting the nearby Ross Ice Shelf, teleseisms, and documented stick-slip events. Other events are related to diverse noise-type processes.

The final chapter of the thesis synthesises these two parts to present a data-driven way forward for glaciologists to study changes to glaciers. The work in this thesis provides improved context for the Whillans Ice Stream and an advancement to the ability to monitor and compare glacier environments.

Tom McNamara, University of Melbourne**:** *Characterisation of metavolcanic megaclast structures within the Moyston Fault hanging wall mélange (Moornambool Metamorphic Complex), western Victoria: Insights from potential field modelling and machine learning.*

The Stawell Corridor is a 15 to 20 km wide structural wedge that sits on the hanging wall of the Moyston Fault, and hosts a set of major gold deposits amidst western Victoria's goldfields in southeast Australia. Stawell Gold Mine extracts ore from the Magdala Dome, a metabasalt megaclast that sits within the Moornambool Metamorphic Complex high-strain tectonic mélange. Murray Basin sedimentary cover obscures the rest of the Moornambool Metamorphic Complex structural trend, so further exploration has historically been limited. Relative contrasts in density and magnetic susceptibility between the metabasalt and the country rock of the metamorphic complex make geophysical methods an ideal vector for targeting Magdala-style dome anomalies and reveals a trend of analogous structures northwest of Magdala.

The project aimed to fill gaps in the exploration model for Magdala-style dome structures by acquiring a ground gravity survey at high resolution to forward model the cross-sectional geometries of the Magdala, Wildwood and Lubeck dome structures, and establish the character of their expression in potential field signals (gravity and magnetic fields). Domes were modelled with geometries that resolve potential structural 'waterloo' targets known to be associated with mineralisation. Outcomes from the forward modelling were used to reclassify dome target extents, which were applied in a neural network-driven dome structure prospectivity model over the broader Moornambool Metamorphic Complex. The model successfully predicted the known Kewell Dome target and mapped instances of metabasalt outcrop, as well as potential targets further beneath cover near Lake Hindmarsh and Mortlake. The exploration technique is theoretically generalisable to any genetically analogous tectonic mélange setting.

The research was completed with the generous support of an ASEG Research Foundation grant, was approved and supported in the field by North Stawell Minerals, and the machine learning component was mentored by Mark Grujic from Datarock.

Honours theses

Kristy Ellis, University of Sydney: *Late Mesozoic-Early Cenozoic rifting evolution of the Coral Sea.*

The Coral Sea, located on the northeastern margin of Australia in the southwest Pacific, is currently used as a type example of a marginal sea that has undergone successive rifting events. The most recent extensional history consists of three overlapping extensional megacycles occurring each in the Triassic (R1), Jurassic-Early Cretaceous (R2), and the Late Cretaceous (R3), followed by seafloor spreading from 61.2-52 Ma. Despite its use as a type example, its polyphased extensional history prior to seafloor spreading has not been well modelled due to limited availability of geological samples and geophysical data.

In this study, a new time-evolving deforming plate tectonic reconstruction was developed using *GPlates* to describe the main rifting events involved in the evolution of the Coral Sea, and to describe the pre-rift positions of the various basins and continental plateaus in the region. This was achieved via a palinspastic restoration approach, wherein the continent-ocean boundaries (COBs) and unstretched continental crust locations (UCCLs) were revised from a synthesis of published seismic, gravity, magnetic and crustal thickness data, and from recovered samples from RV *Investigator* voyage IN2019_V04.

Deforming models overcome the limitations of rigid plate models by providing a more comprehensive history of deformation by tracking changes in the deforming region, defined by the COB and UCCL through time. For example, changes in crustal thickness, strain rate and tectonic subsidence in the deforming region can be tracked based on rotations allocated to each margin.

A focused deformation model, which centres the deformation around the rift axis, was implemented for the Cretaceous rift. This uses a joint optimisation approach to assesses the best combination of parameters related to the deforming region which best matches the present-day crustal thickness and topography. Palaeobathymetry reconstructions from the Cretaceous to the present-day were developed based on the derived tectonic subsidence from the deforming model. Key findings include defining the pre-Jurassic position of the Queensland and Townsville Troughs and pre-Cretaceous position of the Papuan Plateau, Louisiade Plateau and Mellish Rise. Further, palaeobathymetry since the Cretaceous has been modelled at this region for the first time.

By redefining the COB for the northern and southern margin of the Coral Sea, it was found that chron 27 (o) is not present on the seafloor between the Papuan Plateau and the Queensland Plateau, although it is present further west at the Cato Trough. This indicates that seafloor spreading began first between the Mellish Rise and the Queensland Plateau at 61.4 Ma, and then propagated westward, rather than beginning simultaneously across the entire region. Seafloor spreading between the Papuan Plateau and the Queensland Plateau began as late as 59 Ma, up to 3.6 Ma later than originally thought. The region was believed to have experienced anomalously fast seafloor spreading at the beginning which eventually slowed. This has been resolved by bringing the COBs outboard; the newfound absence of chron 27 (o) insinuates a slower initial rate of spreading that increased with time.

A rotation for the opening of the Queensland and Townsville Troughs during the Jurassic rift was constructed, with a common pole of rotation to the southwest of the junction of the troughs. This pole of rotation coincided with the structural lineaments as described in the literature, and for the first time, a plate model has been developed to describe the formation of these structures during the Jurassic rift. The results provide some insight into the evolution of the eastern Gondwanan margin and an understanding of the deformation associated with multiphase rift systems.

Claire Mortimers, University of Western Australia: *Using geophysics to explore for graphite in southern Eyre Peninsula in South Australia.*

The southern Eyre Peninsula in South Australia is host to several occurrences of flake graphite of which only the Uley deposit has significant production. Minor deposits occur at Koppio and Kookaburra Gully. All known occurrences of graphite in the area are in the Paleoproterozoic Cook Gap Schist (biotite-flake graphite schist and quartzite) and structural control of mineralisation has been postulated. Outcrop in the region is sparse.

Regional scale interpretation of Geological Survey of South Australia aeromagnetic data successfully mapped the regional geology confirming the Uley deposit occurs in the nose of a regional scale fold.

Large-scale folding is less evident at Koppio or Kookaburra Gully.

A combined interpretation of magnetic and resistivity data from airborne electromagnetic data (TEMPEST) has revealed an electromagnetic anomaly at both Koppio and Kookaburra Gully. Interpretation of these data showed kilometre-scale tight-isoclinal folding structures within an interpreted subunit of the Cook Gap Schist. Mineralisation is on the flanks of the folds, not the hinge zone.

An interpretation of high-resolution Loupe ground TEM survey over the Koppio deposit identified a sequence of Middleback Jaspillite, Cook Gap Schist and Donington Suite gneisses. Interpretation of these data suggests that graphitic strata within the Cook Gap Schist is tightly-isoclinally folded at the scale of a few hundred metres. An extension of the graphitic stratigraphy was interpreted to the west of the survey area. Parasitic folds identified in the Koppio adit, suggest that the Koppio lode is a part of a larger fold sequence extending westward. Conversely, no folding structures were interpreted from the TEM survey over Kookaburra Gully.

Petrophysical investigations of magnetic susceptibility and galvanic resistivity measured low values within subunits of the Cook Gap Schist. High-grade graphitic samples exhibited greater conductivity compared to low-grade graphitic samples but there is little difference in the resistivities of host rock and mineralised lithologies due to significant clay, magnesite, and silicification of graphite.

Based on these findings, a systematic workflow for graphite exploration in this region has been established:

1. Aeromagnetic interpretation to locate areas where the Cook Gap Schist occurs as a shallow horizon and to map structure.
2. Airborne Electromagnetic (AEM) survey to identify potential graphitic lenses.
3. Ground TEM survey to refine graphite targets and establish deposit boundaries.

Addison Tu, University of Sydney: *Miocene to present landscape evolution models and implications for porphyry copper preservation.*

Development of highly calibrated Landscape Evolution Models (LEMs) has allowed for the first-order simulation of the New Guinea margin response to external forcings. Results include constraints for uplift rates, denudation rates and palaeo-elevations. Furthermore, the erosional history was extracted from the preferred LEM to: estimate the depth of emplacement for known porphyry deposits; and refine a prospectivity map explicitly estimate whether probable deposits would be at the near-surface.

Nathan Wake, The University of Sydney: *Machine-learning in lateritic Ni-Co prospectivity mapping by utilising public geological and geophysical datasets in the Lachlan Orogen of NSW*.

The state government is aiming to develop a Critical Minerals production and downstream processing industrial hub in the central-western region of NSW due to the potentially rich mineral endowment of the Lachlan Orogen. Nickel and cobalt have been identified as being particularly prospective in laterite deposits by relatively recent exploration initiatives in the eastern and central sub provinces of the Lachlan Orogen. There is a knowledge gap in identifying and representing the potential for lateritic Ni-Co and this project focusses on machine learning to generate prospectivity maps for new resources in the East-Central Lachlan Orogen. Machine learning utilises data-driven algorithms and techniques that automate clustering, classification and prediction of data (Rad, 2018). Supervised machine learning will be used in this project, which trains a model on known input and output data so that it can predict future outputs. It aims to provide prospectivity maps of lateritic Ni-Co by integrating various exploration data layers using machine learning algorithms and designing a workflow to process available public exploration datasets in NSW and turn them into features to determine the probability of finding target mineralisation types in potential regions. In addition to the prospectivity maps, the most important features in exploring the targeted mineralisation type and its relationship with the mineral system model will be investigated. This interdisciplinary project will use the power of data science for mineral exploration and tackle the challenges that the industry will face in the coming decades, particularly in the scope of critical minerals needed for the clean energy transition.

The main technical challenge is the relatively low number of known lateritic Ni-Co mineral occurrences ("positive training samples") and choosing negative samples in barren regions. This study presents a machine learning-based framework for generating prospectivity maps of lateritic Ni-Co in the East-Central Lachlan Orogen that will address this problem. There are some limitations associated with available exploration datasets of the Lachlan Orogen, such as the irregularity of crucial basement outcrops, variations in the preservation and thickness of lateritic weathering profiles, and the presence of widespread Cenozoic sedimentary cover and complex regolith. This can impede understanding the geological setting and landform evolution that leads to large-scale mineralisation events. However, employing geophysical data such as magnetic, radiometrics, and spectral remote sensing along with other data types can aid in imaging the basement source rocks beneath sedimentary cover and highly potentially prospective and well-preserved lateritic weathering profiles.

Marc Young, Flinders University: *Experimental evaluation of protocols for the separation of Younger Dryas magnetic microspherules.*

Since 2007, a growing body of evidence has provided support for the notion of a major cosmic impact event at the onset of the Younger Dryas (YD), an abrupt cooling event that occurred between ~12 800 and ~11 600 BP. Rather than a large single-impact event akin to the Cretaceous-Paleogene impact,

it is thought that Earth encountered a particularly violent meteor shower at the YD onset, resulting in many smaller-scale impacts and airbursts over much of the world within a short time. While controversial, recent reviews have determined that the YD impact hypothesis was prematurely rejected after early attempts to replicate key lines of evidence were unsuccessful.

Despite every subsequent attempt to replicate elevated concentrations of magnetic microspherules in YD sediments having been successful, this early failure is still cited by critics today as fatal to the hypothesis. This study sought to test the claims of proponents regarding the reasons for an early failure to replicate a particular line of evidence, magnetic microspherules, using experimental methods. Following the early failure to replicate, proponents published a detailed study successfully replicating the evidence at multiple locations and offering explanations for why the replication had failed, which informed the methodological basis of this study.

Thus, using experimental methods, I investigated the effects of insufficient aliquots of the sample and the exclusion of subspherical candidates, but also variations in the magnetic separation protocols used by the relevant studies. The utility of scanning electron microscopy and energy-dispersive X-ray spectroscopy (SEM-EDS) for characterising the morphological and geochemical attributes of microspherule candidates to determine how they were formed was also a major focus.

Magnetic separation protocols used during the failed replication produced significantly larger magnetic fractions, significantly reducing the ratio of microspherule candidates to non-candidate grains. The aliquot sizes examined during the failed replication were found to produce highly variable, and therefore unreliable results when calculating the number of spherules per kg in each sample. The inappropriate requirement for perfect sphericity imposed by the failed replication was found to significantly reduce the number of spherule candidates in each sample and would have caused spherules formed during the impact to have been excluded from their analysis. Finally, SEM-EDS was found to be an essential method for confirming whether a spherule candidate was indeed formed during an impact event. Overall, this study found that inappropriate modifications of the protocols of the original study were the likely cause of the failed replication. The results affirm the specific claims made by proponents, and the notion that the YD impact hypothesis has indeed been prematurely rejected.

Marc is currently undertaking a PhD in geoarchaeology at Flinders University.

Participants in CAGE 2023.

Environmental geophysics

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Welcome readers to this issue's column on geophysics applied to the environment. For this issue, I welcome Dave Allen from Groundwater Imaging (https://groundwaterimaging.com.au/) as the guest contributor. He is going to introduce many of us to a more modern world of geophysical instrumentation and, possibly more importantly, data transfer. There is a fair bit of jargon here (and more than a few abbreviations) – we have tried to explain most terms, but some you may just have to look up for yourself. Interestingly (at least to me), Dave contacted me after my article in the June 2023 issue *Preview* where I had skimmed this subject; he kindly offered to write some more about modern communications and GNSS. Thanks Dave!

Before we go any further, I need to correct an error that I made in the last column. In that column I incorrectly stated that Bradley Moggridge worked with the CSIRO. In fact, Bradley is an Associate Professor at the University of Canberra.

Communicating using microwaves - a primer for geophysicists

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Microwave communication technology is now ubiquitous throughout the modern world. However, many of us (younger than Mike) were trained in the days when microwave frequency communication was limited mainly to telco use and ground penetrating radar (GPR) and was certainly not part of our legacy geophysical instruments (maybe these should be consigned to the "boat anchors" category). There is a lot to learn to take full advantage of the opportunities these technologies provide to geophysics and the modern geophysicist.

Typical opportunities in geophysics include:

1. Distributed acquisition systems with multiple nodes / cable replacement,
2. Telemetered time-lapse geophysics,
3. Geophysical sensors transmitting autonomously from mining and agricultural equipment,
4. Precision positioning and timing using GNSS (Global Navigation Satellite Systems) correction services, and
5. Ergonomic design improvement of geophysical controllers without the need for long cables and connectors between sensors and controllers – *i.e.,* a better environmental footprint.

Interestingly, the same communication frequency range is used for both cellular communications and GNSS communication, so the learning curve for both cellular and GNSS technology is similar, and there is a lot in common, as well, between emerging low earth orbit communication systems and GNSS.

Microwave communication facilitates transfer of large data volumes quickly with compact, low-power, low-cost circuitry, and small antennae. In some applications the signal transmission distance can be thousands of kilometres (*e.g.,* satellite to earth station), but at the high frequencies used in some systems signal attenuation can limit transmission distances. Examples of short distance communication are BlueTooth and WiFi, with distances typically still in the 10 to 100 m range when used in newer geophysical controllers. 5G cellular technology uses frequencies high enough that towers must be closely spaced (on the order of 200 m apart). For this reason, we don't see much advantage using 5G cellular services in the bush. Rather, 4G will continue to be important, with frequencies in the 700 MHz band, rather than the 2.4 GHz and 5 GHz bands commonly used in 5G.

Distributed geophysical devices may use either a Low-Power Wide Area Network (LPWAN), long range WiFi, cellular or satellite communication. The most promising LPWAN technology for geophysics is likely to be Long Range Wide Area Networks (LoRaWAN) which require at least one Gateway device, typically connecting to the internet (but not a requirement). The Gateway is typically a computer or router that sits between different networks or applications converting information, data or other communications from one protocol or format to another, then connects to node devices that are connected to our geophysical sensors. There is a cost playoff between LoRaWAN and direct connection to public cellular networks or satellites as the gateway infrastructure is more expensive than a combination of several direct cellular network connections. LoRaWAN nodes are extra-low-power devices and communicate only small packets of information via LoRa technology (packets of information sent over chirp pulses) distances typically over 10 km in the bush, or "just" 3km in noisy urban centres. The small data packet size combined with the relatively small distance limit are both factors that reduce the usefulness of LoRa technology for many geophysical applications and geophysical instruments that need to send *e.g.,* unprocessed, full waveform data.

Data sent using LoRaWAN technology uses basic (but modified) internet protocol as the basis for communication. But, as these systems are limited both by low-power transmission and low frequency, messages typically have to be optimised for efficiency. A common protocol packaged in a LoRaWAN system is SDI12, which is a simple text protocol in which one master device can manage and systematically poll communication with several sensors. This is a relatively simple protocol to learn and is becoming dominant in sensor communications.

Another approach is to go direct from sensors in the bush to the internet via cellular networks or good old-fashioned WiFi. This is typically handled by extra low-power Remote Terminal Units (RTU), which are effectively a modem board, a processor and physical sensor connections. When instrument design is optimised, the RTU is integrated directly into geophysical sensors. This is common already in telemetered seismic nodes. For remote operation, cellular type low earth orbit (LEO) satellite communication (Figure 1 shows a typical LEO satellite) is in its infancy, and we expect to see dramatic new opportunities and drastic cost reductions in this space soon.

In order to keep remote monitoring costs and power consumption down, cellular communication from remote sensors is (again) best limited to small messages, sent relatively infrequently, in small packets. Conventional cellular communication hardware and protocol do not work well for this; two new systems have been developed – NB IoT (short for Narrow Band Internet of Things) and LTE Cat M1. This one is a cellular LTE (Long Term Evolution – *i.e.,* basically cell phone technology after 3G) technology specifically designed for the Internet of Things (IoT) and machine-to-machine (M2M) communications. Access to these communication methods require specialised SIM cards, modems and

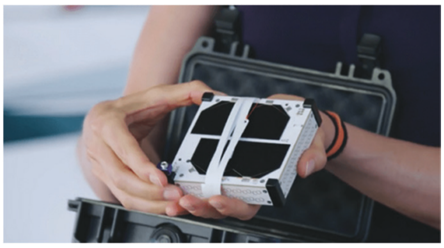


Figure 1. *A low Earth orbiting satellite typical of new microwave and VHF communications technology that change object dimensions and data transmission rates by orders of magnitude compared to old technology (image source - SWARM technologies).*

telco infrastructure/software. The good news is that both NB IoT and LTE Cat M1 are well supported in Australia. And both are suited to sending the requisite small packets of information. Unlike conventional cellular connections, these technologies are not restricted to a 30 km range (by *e.g.*, timing electronics in mobile phone towers), so coverage is more extensive.

In order to fit information into small packets that can be efficiently transmitted by low power devices, overheads of data sending/receiving protocol have to be modest and well thought out. Common HTTP/HTTPS, FTP and other protocols that we are mostly more familiar with are overhead-heavy, so the MQTT protocol was developed, and most new low-power telemetry now uses this protocol. MQTT, a legacy acronym of no real meaning, adds a clever, broker-managed, means of handling periods when communication links are broken so that sending devices can operate with very low power drain. More data intensive applications are now more likely to send data using an alternative Application Programming Interface (API) type called REST (Representational State Transfer) which typically operates over HTTP/HTTPS.

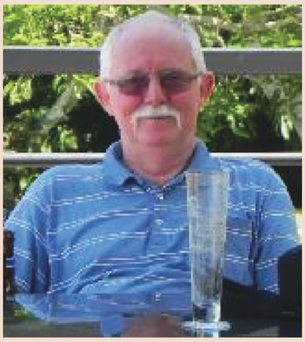
Not only do protocols need to be efficient for low-power microwave communication, but the data sent needs to be compactly and sensibly managed. Until recently this was done using compact, highly specific binary data formats. Unfortunately, these require both specialised knowledge as well as management skills. Software that reads and manages data today expects standardised formats that have intermediate to high organisational overheads. Files using standard ASCII text and comma-separated variables have been used to transfer information but are not suitable for complex generic data management systems. XML and JSON formats are improvements on text files, as they add nesting and hierarchy to information so that machine and human readers can efficiently search and allocate data as it is read. Of the two, JSON is more compact and therefore is becoming the format of choice for data sent via low-power microwave communication. Python Dictionary is increasingly being used as a data structuring tool competing with JSON and XML.

Global Navigation Satellite Systems (GNSS)

Another area in geophysics where microwave communication is important is in GNSS, *i.e.* satellite-based timing and locational services. Receivers connected to geophysical systems are commonly used to absolutely locate and time-synchronise geophysical equipment. If precision positioning (<10 cm) is needed, then differential corrections are required along with dual-frequency receivers. It wasn't that long ago that these systems cost around $200 000 per pair. In contrast, recent advances in electronics have allowed the development of, for example, the uBlox F9 dual frequency chipset and Point Perfect corrections that use the open-source, compact SPARTN correction format transmitted using the MQTT protocol. This information is either sourced via satellite using the UBlox NeoD9S chipset, or by cellular network. Cost of these systems is now below $1000 and becoming cheaper. The uBlox chipsets are now readily available on chipset evaluation boards popular with electronics enthusiasts and are starting to filter into mainstream GNSS devices. For the geophysicist they will be a really good opportunity to improve positioning, although, at first, they will require a high degree of understanding to properly configure the system to get the differential corrections right, and then will need to be integrated with existing applications. Simpler options, available now, include the free CORSnet corrections. Unfortunately, to use these corrections, operators will need to be using fully RTK-equipped GNSS systems. Both Geoscience Australia (https://gnss.ga.gov.au/stream) and the New South Wales government (https://corsnet.nsw.gov.au/), among others, offer this service. Positional corrections are applied either in real time via cellular signal, where coverage exists continuously, or in post processing using open-source tools such as RTKLib (https://www.rtklib.com/) or in commercial surveying packages. These advances in GNSS positioning are likely to usher in uptake of microwave-frequency communication that will dramatically improve the quality of geophysics data collected.

Geophysicist's understanding of fundamental geophysical technology is of great value, yet its value can be greatly extended when uptake of modern microwave communication technology is integrated.

Minerals geophysics



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Geophysical follow-up

In mineral exploration the prime aim is to locate economic mineralisation, that is, orebodies. Geophysical components of green fields mineral exploration programmes typically comprise an initial literature research for and appraisal of pre-existing data, followed by commission and execution of appropriate broad-scale geophysical surveying, and analysis and interpretation of these results. Then, if things have gone to plan, there will be geophysical follow-up surveys designed to better discriminate geophysical anomalies of interest prior to drill-testing. It is aspects of this final follow-up stage that I'd like to address here. To maximise our chances of success we need to site drill-holes in the best possible position to test anomaly sources.

So, what sort of targets might we be investigating in the final follow-up stage? Ideally these would manifest as discrete geophysical anomalies reflecting direct detection of the targeted mineralisation. In some situations, *e.g.*, electrical geophysical surveys targeting zinc sulphides, we might be relying on indirect detection via responses from other directly associated conductive metallic sulphides. In other scenarios, it could be environments favourable to mineralisation that are being sought, such as fold closures, structural intersections, facies changes within favourable horizons, *etc*. And in most cases the broad scale geophysical survey should also contribute to the understanding of the geology of the area under investigation.

Before going further, we might consider whether we even need to undertake geophysical follow-up. If the geophysical survey results confirm other indications, such as the presence of gossans or anomalous rock or soil geochemistry, we might have sufficient reason and information to drill-test without further geophysical work. In the blind mineralisation scenario relying solely on geophysics, if our initial survey technique was uniquely appropriate to the target style sought, and sufficiently detailed to accurately discriminate the resulting anomalies, we might reasonably dispense with geophysical follow-up surveys. However, while the accuracy and capabilities of modern geophysical survey techniques and processing regimes have dramatically improved, this ideal scenario is unlikely in most circumstances.

Typically then we face the prospect of designing and implementing follow-up geophysical surveys to further investigate our geophysical responses. But, to what end? Two inter-related aims are relevant: to deduce the nature of the source material and to sufficiently delineate its disposition. These two aims should be considered in tandem, but I will treat them sequentially below for ease of expression.

Anomaly source material

Before we embark on detailed anomaly delineation, we might consider whether the source material for the anomaly is what we're after. Conventional geophysical follow-up surveys typically employ a ground-based version of the broad-scale survey technique – if we used airborne electromagnetics initially, then ground electromagnetics is the *de facto* choice for follow-up, detailed ground gravity would follow airborne or semi-regional ground gravity, *etc*. But this doesn't necessarily advance the understanding of the nature of the anomaly source material – the follow-up is still targeting the same petrophysical property. Improved knowledge of source disposition from a detailed ground survey may provide clues on the nature of the anomaly source material, but where this could reasonably be one of several options, we are going to need more information to minimise drill-testing of unwanted target material.

One approach would be to undertake blanket follow-up ground geophysics using a range of different geophysical techniques over all anomalies of interest, but this could be an expensive and time-consuming process. A staged approach, starting with an appropriate technique (or techniques) specifically designed to highlight anomalies of interest and/or eliminate spurious anomalies before fine-tuning targets makes more sense. So, some thought on what petrophysical properties could be used to discriminate between our target style and that of other spurious anomalies is required. Using the electromagnetics example, if we are after conductive sulphides, magnetics might help identify those sulphides carrying pyrrhotite, gravity might help to discriminate graphite from more massive sulphides, IP might separate sulphides from non-sulphidic source material such as porous crush zones, *etc*. Using the gravity example, if we are after massive sulphides, passive seismics might help to identify those gravity anomalies due to basement highs, electromagnetics might highlight those anomalies more likely to be massive sulphides, magnetics might help to identify those anomalies due to denser basic rocks, *etc*.

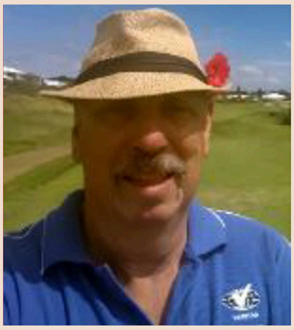
Anomaly source disposition

Having hopefully eliminated the spurious anomalies, we need to give some consideration to the design and extent of detailed geophysical ground follow-up. The specific aim here is to delineate the disposition of the anomaly source material for optimal siting of drill-holes. In modern geophysical exploration, this delineation is typically achieved with 3D inversion, so the parameters and extent of the follow-up survey should be appropriate. For potential field methods, station density to provide sufficient detail and survey extent to establish 'background' would be considerations. For electrical and electromagnetic methods, survey parameters would be an additional consideration. 3D inversion of IP-resistivity surveys, for example, will greatly benefit from a tailored survey design – inverting the results from a series of parallel dipole-dipole lines can be fraught where the geology is more complex than simple 2D at right angles to the lines.

Finally, having possibly used more than one ground geophysical technique over our target, co-inversion of the different results may improve the final model.

Good hunting!

Seismic window



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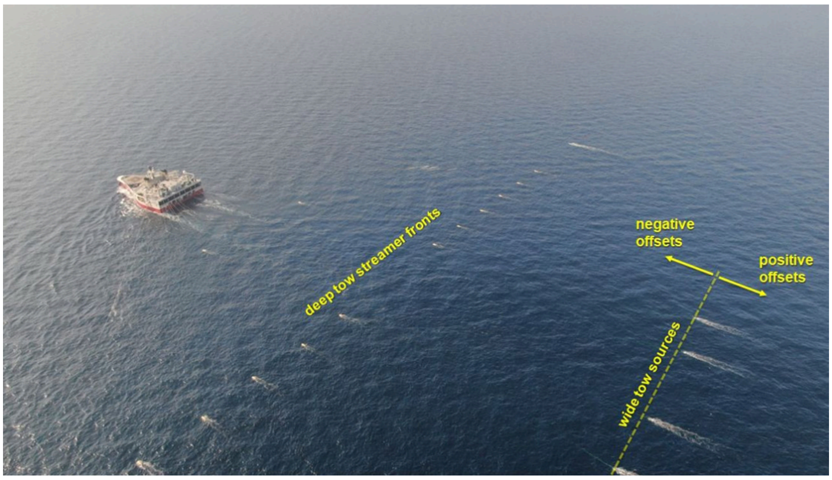

Figure 1. *View of split spread acquisition with source arrays (bottom right) positioned some distance behind the front of the streamers (centre). Photo by Aker BP ASA and OMV.*

Split spread acquisition

This article is shorter than usual because a day before the publishing deadline I had nothing to write about. But, with a day to spare, I stumbled across an item posted on LinkedIn by Andrew Long (PGS) with a comment by John Cant (a Perth based geophysical consultant).

Andrew commented on a photograph of an offshore seismic survey with an unusual acquisition geometry - a split spread with the source arrays positioned in the "middle" of the receiver array so that there are receiver locations in front (negative offset) and behind (positive offsets) the sources. This is a common geometry for onshore surveys, but it has been difficult to implement offshore. As Andrew says, this geometry with wide sources provides "the best platform for high resolution imaging of the shallow sediments and overburden". The photo published by Aker BP ASA https://www.linkedin.com/company/akerbp/ and OMV https://www.linkedin.com/company/omv/ with annotations by Andrew Long (Figure 1) shows the Ramform Atlas towing 'negative source offsets' as part of their Poseidon CCS survey, but this is only the most recent example as a similar set up was used to acquire the Keraudren Seismic survey (Santos 2019).

This idea is not new. Twenty years ago, BHP recognised a split spread geometry would be better for SRME – Surface Related Multiple Extermination/Elimination/Estimation. They recorded a small 44 km^2 experimental survey in an area where water bottom multiples were rife and primary reflections were very difficult to identify. At the time it was difficult to implement a negative offset because a separate source boat would be required. It was also feared that having the streamers in close proximity to the source could damage the towed equipment. So, the survey acquired data in two passes by sailing in opposite directions. The two parts of the split spread were then merged (Figure 2). As John points out, this experiment was unsuccessful. It seems obvious now, but tidal differences in water depth of each pass led to errors in matching the two halves, and this mismatch was more pronounced at depth.

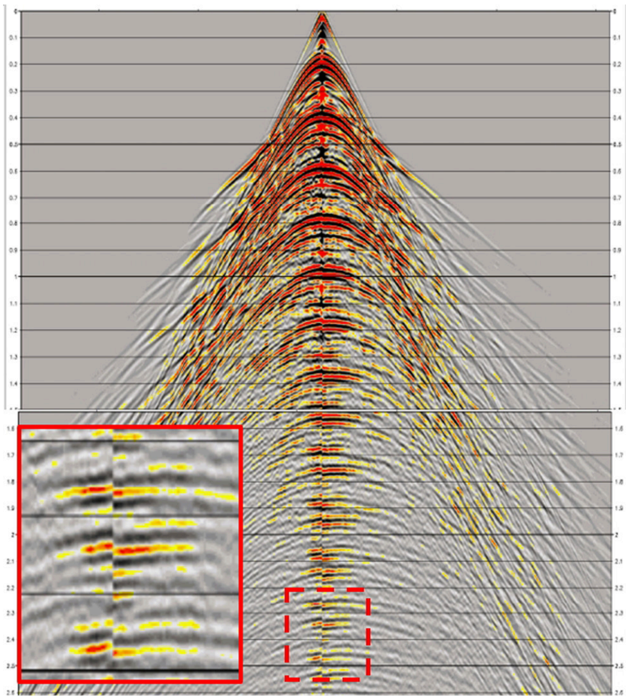

Figure 2. *Split spread gather created by merging two separate passes in opposite directions. The inset shows the mismatch at zero offset between the left and right sides of the gather.*

The use of a single boat with extremely long source umbilicals and independently steerable source sub-arrays means this solution is now common for surveys with a particular near-surface focus such as CCS. Of course, this geometry could end up in a tangled mess if it weren't for the expertise of the onboard crew on the back deck.

Acknowledgments

This article is based on a LinkedIn discussion posted in mid-October 2023 by Andrew Long with comments by John Cant.

Data trends

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Big data and machine learning updates

Some colleagues recently attended the PESA Python for Geoscience workshop https://pesa.com.au/events/pesa-qld-online-course-introduction-to-python-for-geoscience-2023/2023-08-15/. Sydney University's Nathaniel Butterworth showed the (relative) ease with which users can now analyse enormous amounts of data. While traditional exploration and GIS programs can display many layers simultaneously, trying to spot intersecting areas of interest may be difficult. Machine learning, and it's dreaded "data driven" models, can cut some of that time involved.

As we all juggle spreadsheets, a database or two, something for cross sections, a math programming language or specialist geochemistry plots, something to make a picture of drill holes in 3D and more and more, we all see the need to combine more aspects of geoscience.

The number of datasets publicly available is extraordinary and growing. Universities, state surveys, GA and CSIRO pump out mountains of company, research and government collected data each year. NCI/AuScope/ARDC 2030 Geophysics Data Collection Project at ANU spearheads the file types required for large scale analysis https://ardc.edu.au/project/2030-geophysics-collections/. Python opens the door to accessing this data all at once.

An appeal of the (free) Python high level programming language is that it inherently deals with file handling and text parsing and downloads extras (packages) allowing almost any data manipulation. The Panda package seamlessly transforms text and number columns for the NumPy package to crunch matrix operations. Web services allows Python to call data in from web sites on the fly so explorers can compare their geological setting with similar targets around the world.

Machine Learning then assesses the relationship strength between all layers with known occurrences (Figure 1) and pinpoints where more occurrences might be (Figure 2).

This is the oft maligned data driven version of machine learning (everything in) as opposed to knowledge driven (use chosen influences). But to paraphrase Sam Altman (CEO of OpenAI), engineers believe humans cannot see as much as electronic sensors, so let the algorithms paint their picture and critique their thinking https://www.youtube.com/watch?v=L_Guz73e6fw. Oz Minerals found this approach useful to question exploration bias due to classical deposit models https://www.youtube.com/watch?v=uLqKODrPsUU.

Why does elevation have the highest correlation with occurrences in South Australia? Probably because there have been nearly two centuries of exploration and fossicking in the close to home, well-populated Adelaide Geosyncline, instead of the hard-to-explore desert regions. But then, orogenies accumulate minerals and increase elevation. OK, can areas of past and present orogeny be visualised to illustrate expected similarities? This is why Oz Minerals called the process a game of geological Battleships™ testing ideas.

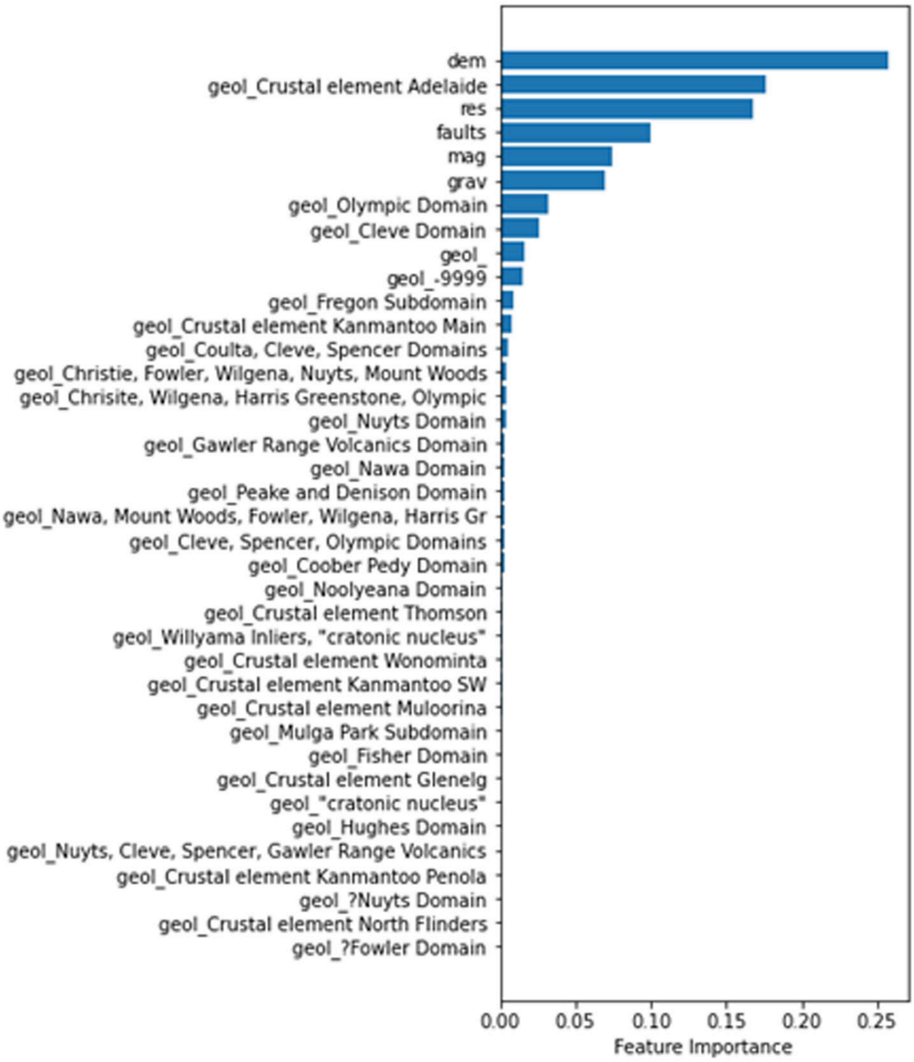

Figure 1. *Bar chart plot of most the significant input features associated with a mineral occurrence taken from Sydney Informatics Hub Python for the Geoscience 2023 Python workshop.*

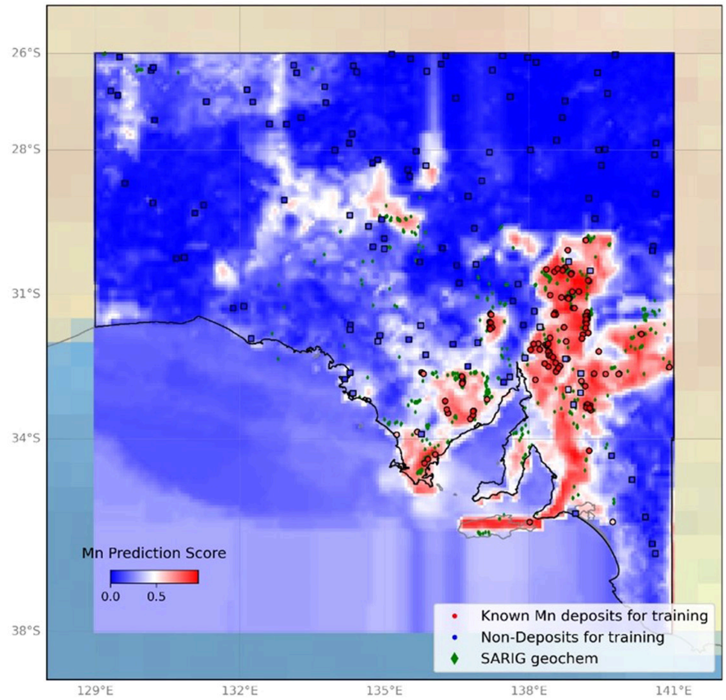

Figure 2. *Heat map of graduated statistical affinity with known manganese occurrences, map courtesy of Gary Reed of Geological Survey of South Australia.*

Coding is not everyone's cup of tea, so workflows offered by the likes of ANU allow simpler loading and filtering https://opus.nci.org.au/display/DAE/Geophysics. No doubt Mr Altman's ChatGPT could soon be commanded with "here is my exploration tenement, analyse for mineral exploration".

ASEG Research Foundation

Attention: All geophysics students at honours level and above

- **You are invited to apply for ASEG RF grants for 2024.**
- Closing date: **1 March 2024.**
- Awards are made for:
  - BSc (Hons) Max. $5000 (1 Year)
  - MSc Max. $5000 per annum (2 Years)
  - PhD Max. $10 000 per annum (3 Years)
- Application form and information at: https://www.aseg.org.au/foundation/how-to-apply
- Awards are made to project specific applications and reporting and reconciliation is the responsibility of the supervisor.
- Any field related to exploration geophysics considered, e.g. petroleum, mining, environmental, and engineering.
- The completed application forms should be emailed to Doug Roberts, Secretary of the ASEG Research Foundation: research-foundation@aseg.org.au

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

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

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

Webwaves

Ian James
ASEG Webmaster
webmaster@aseg.org.au

Outage

On Wednesday 8 November 2023, millions of Optus customers were affected by a mobile and internet outage. Starting at 04:05 AEDT and lasting approximately nine hours, the outage was caused by an unknown technical problem, possibly a software or system update gone wrong. Unlike in 2022 when Optus suffered a cyber attack, as discussed in *Webwaves PV* 221, the outage is not believed to have been the result of malicious activity.

While 000 calls were not possible from landlines, mobile phones were able to place emergency calls by roaming using other carriers, where coverage existed. Problems arising from the outage were widespread, with Melbourne's train services briefly stopping, Optus dependent EFTPOS services failing and various government services down.

So far, Optus has responded by providing customers with additional or unlimited data until the end of 2023, or faster speeds (unless you are on one of the >35 ineligible plans listed on their website). I suppose customers will be hoping that the network is outage-free for the next few months so that they can actually make use of these token gestures from Optus.

How to find out if there is a network issue

Other than jumping on social media, various internet tools exist to check if websites and networks are down. Downdetector https://downdetector.com/ crowd sources information on outages based on user reports as well as social media scraping. Cloudflare, as providers of content delivery network and cyber security services, hosts the Cloudflare

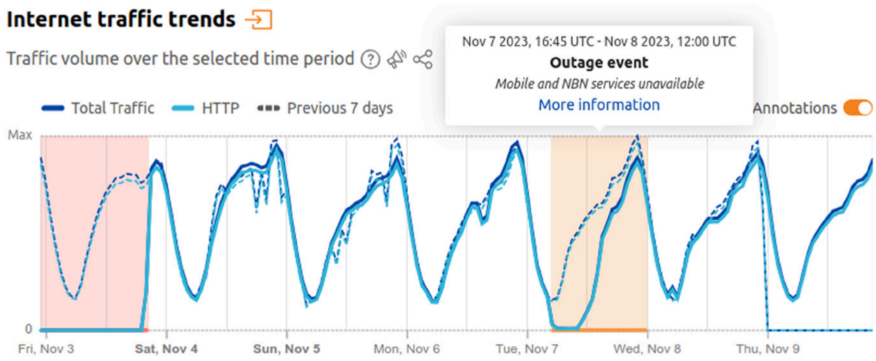

Figure 1. *Optus network traffic trends (from Cloudflare Radar).*

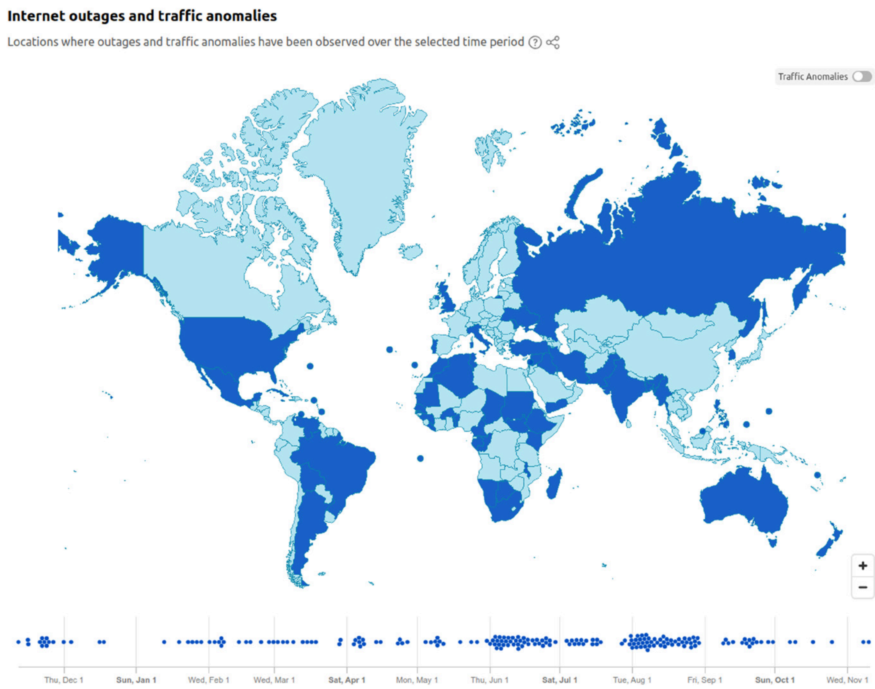

Figure 2. *Cloudflare Radar global map of outages in the last 12 months.*

Radar website https://radar.cloudflare.com/AU which aggregates anonymous information from their global network. Data from the Optus network in Australia is shown in Figure 1, with the orange shaded portion of the graph highlighting the outage and impact to services.

Cloudflare Radar also provides information on outages at a global level, with a map view as shown in Figure 2. Globally, outages in the last year have had various causes, from weather and natural disasters to cut cables, power cuts to cyber-attacks, government directed outages to military actions. Outages have been widespread, with a large number of countries affected.

With so much of life relying on the internet, it is sometimes difficult to remember that something as simple as a cut cable can potentially result in being unable to dial 000, as shown by the issues with Optus this week, or even being unable to pay for a coffee.

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https://downdetector.com/ (accessed 9 November 2023)

https://radar.cloudflare.com/AU (accessed 9 November 2023)

What lies beneath revisited – supergene enrichment and conductivity

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Overview

At the AEGC 2019 conference in Perth, the paper 'What Lies Beneath?' (Witherly 2019) examined several porphyry copper systems that had significant conductivity associated with the deposits. The source of this conductivity was not always well understood. The current study is an extension of this earlier work and will examine the interplay of supergene enrichment and conductivity. Unknown to much of the exploration community, high-grade supergene zones in porphyry copper systems, typically comprised primarily of chalcocite, can show a strong electrical conductivity that can be detected with techniques such as DC resistivity (part of an Induced Polarisation (IP) survey) and electromagnetics (EM). In this article, I'll look at how the industry responded, or did not respond, to evidence of the geophysical character of the supergene in porphyry copper systems over a forty-year period.

Sillitoe's seminal paper on the supergene (Sillitoe 2005) provides the following introduction that sets the stage.

Supergene leaching, oxidation, and chalcocite enrichment in porphyry and related Cu deposits take place in the weathering environment to depths of several hundred meters. The fundamental chemical principles of supergene processes were elucidated during the early decades of the twentieth century, mainly from studies in the western United States. The products of oxidation and enrichment continue to have a major economic impact on Cu mining in the central Andes and southwestern North America, currently accounting for >50 percent of world-mined Cu and have sustained these two premier Cu provinces for the past 100 years. Enriched grades may attain 1.5 to >2 percent Cu, commonly two or three times the hypogene tenor. Deep oxidation also transforms low-grade refractory Au mineralisation into bulk-mineable ore.

While many of the shallow porphyry copper deposits that host supergene systems have been found, still-to-be-found deposits, which are presumed to be located mostly under cover, could still be considered to be viable economic targets given the enhanced copper grades and lower energy budgets required to process the supergene ores. However, the still-to-be-found deposits will be more challenging to locate and require better search technology.

Introduction

The conductivity of chalcocite has been documented from at least 1928 (Harvey 1928), although Shuey (1975) is considered the most complete modern reference. The most recent reference that relates to a potential geoscience application of chalcocite's conductivity is Emerson (2021). So, while the petrophysical character of chalcocite has been known and studied for almost a century, the actual exploitation of its fairly unique conductivity behaviour has only occurred quite recently, starting in the 1990s. This recent activity appears to be due to either serendipity or basic field experiments that did not draw upon any specific knowledge of earlier laboratory studies as mentioned here.

This in effect means that during the heyday of modern porphyry copper exploration (defined as roughly 1950-1980), much of the industry seemed unaware and hence unable to exploit a significant petrophysical attribute of supergene chalcocite. The major strategic advantage that conductive chalcocite offers is that this response can be detected remotely from an airborne platform, thereby allowing for rapid coverage of large areas.

The possible exception to this could be the very early work Newmont carried out in the late 1940s-early 1950s in their development of the induced polarisation or IP (then called overvoltage). As part of this programme they carried out studies on several porphyry systems in Peru, namely Quellaveco and Cuajone (Baldwin 1959). While the porphyry systems which they studied showed supergene/chalcocite development (see Figure 1), scant attention seemed to be paid to the resistivity of the porphyry system, the major focus being on the IP (also termed chargeability) response.

In a major review of the state of mining geophysical interpretation in 1966 (Hansen *et al.* 1966), the anomalous conductivity of chalcocite is noted. It is also noted that it is a mineral with a high content of copper, but nowhere is it mentioned that it's petrophysical character offered an exploration opportunity.

The author had a serendipitous encounter with chalcocite in 1982 when assessing a line of IP data (acquired with the Zonge Complex Resistivity system) that covered the newly found La

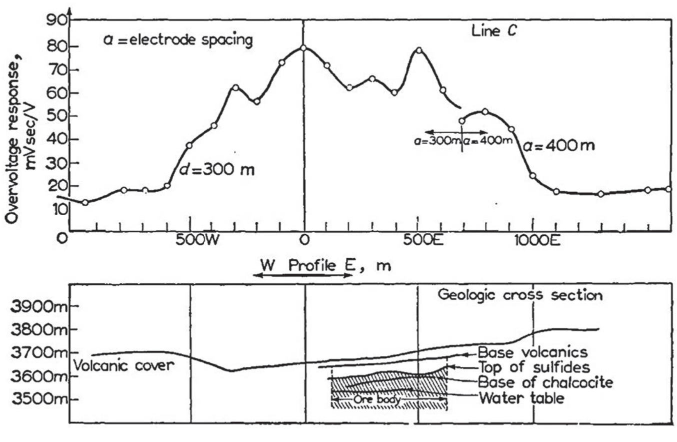

Figure 1. *Overvoltage profile over north end of Quellaveco ore body, Peru (Baldwin 1959).*

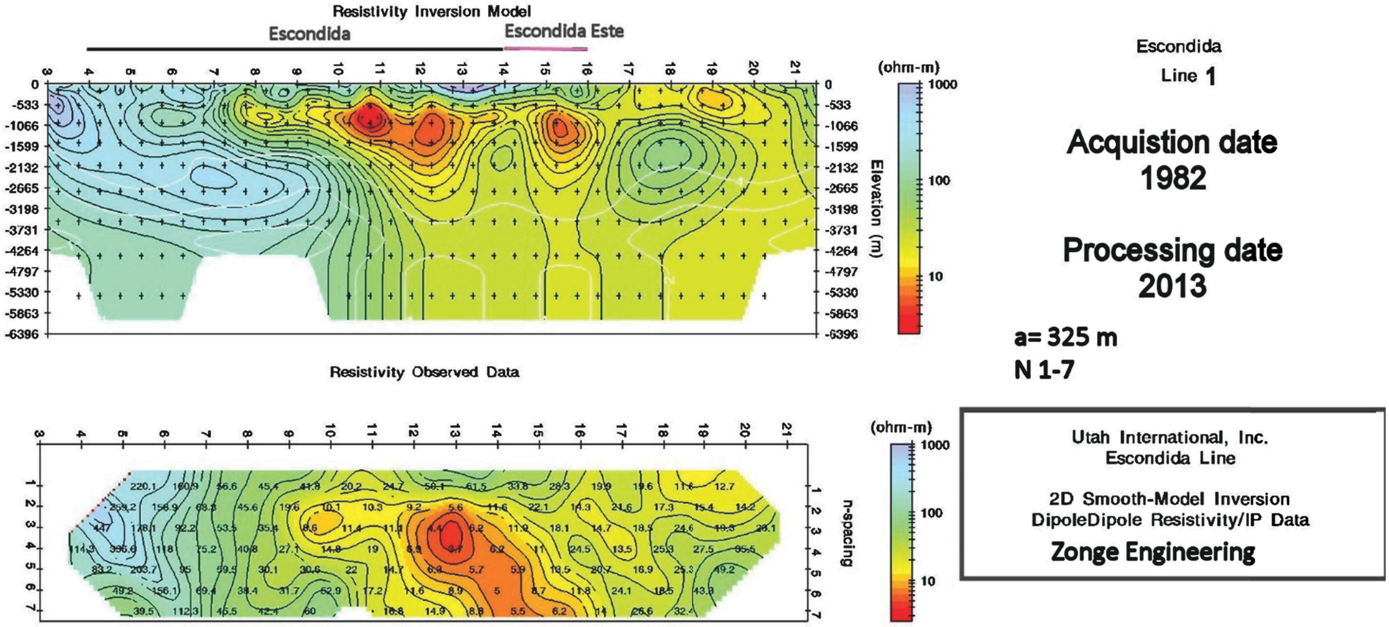

Figure 2. *Escondida DC resistivity data; top-observed, bottom-2D smooth layer inversion (Witherly 2014).*

Escondida porphyry system. This line of data (Witherly 2014, Figure 2) showed an anomalous conductivity feature that at the time was unexplained, but ultimately attributed to conductive ground water. While several strategies were proposed to attempt to map this feature using either ground and airborne EM, the perceived geopolitical risk at the time was such that the project was largely shuttered, and the exploration team dispersed.

Ten years later, there was a surge of activity that highlighted the conductive response of chalcocite. The first field work known to the author that showed chalcocite could be conductive in a field setting was a series of downhole geophysical logs acquired in 1989-90 by the USGS at the Santa Cruz deposit in Arizona (Figure 3, Nelson 1991). This was done as part of a study

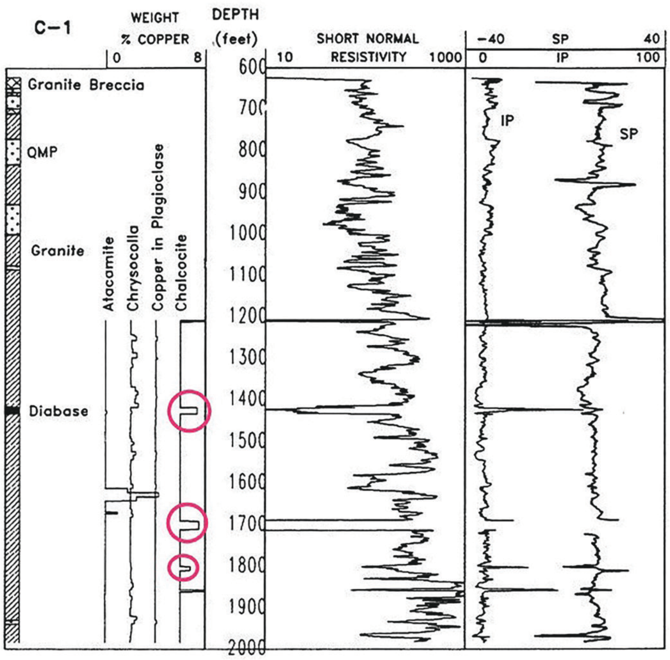

Figure 3. *Electrical logs; resistivity, Self Potential (SP) and IP plus copper analysis (Nelson 1991).*

to extract copper from a copper oxide deposit using *in situ* leaching. A number of chalcocite zones were encountered that showed strong conductivity.

However, the chalcocite zones were relatively thin and quite deep; situated at a depth of 1450 and 1700 feet (442 m - 523 m), suggesting that they were likely formed by hydrothermal processes and were not supergene in origin.

Soon after the Arizona study, significant programmes in Chile and Iran took place that highlighted the importance of conductive chalcocite.

In the early 1990s, efforts by Rio Tinto Exploration (RTE) in South America are discussed by Barrett (pers. comm. 2023); "I think it was probably Quantec who started running EM surveys in Chile, first with an old SIROTEM Mk2 (?); if my memory serves me correctly RTE had Hugh Rutter (Australian geophysical consultant-KEW) come out to help getting us going. Quantec then brought in a EM-37. In late 1992, RTE bought a Zonge GDP-16 and GGT 10 system where yours truly cut his teeth using to run TEM surveys in Ecuador before bringing it to Chile. Here we ran a few TEM surveys for a short time but then, switched to a variant of the Kennecott-style 'recce' IP, although often acquiring TEM data as well."

In Chile the La Escondida deposit owned by BHP and several partners was being developed. Other companies were sending teams to Chile to explore for additional deposits. Geophysical contractors, especially from North America, were also arriving to support these programmes.

The Collahuasi district of Chile is host to three separate major deposits, namely Ujina, Rosario and Quebrada Blanca. Quantec Geoscience, a Canadian geophysical company, successfully carried out an IP survey over the Ujina prospect and follow-up showed that a major deposit had been located (Dick *et al.* 1993). The supervising geophysicist noted that the supergene zone associated with the deposit was quite conductive (Figure 4) and as an experiment, he organised to bring EM equipment to Chile and set up trials over several known supergene deposits.

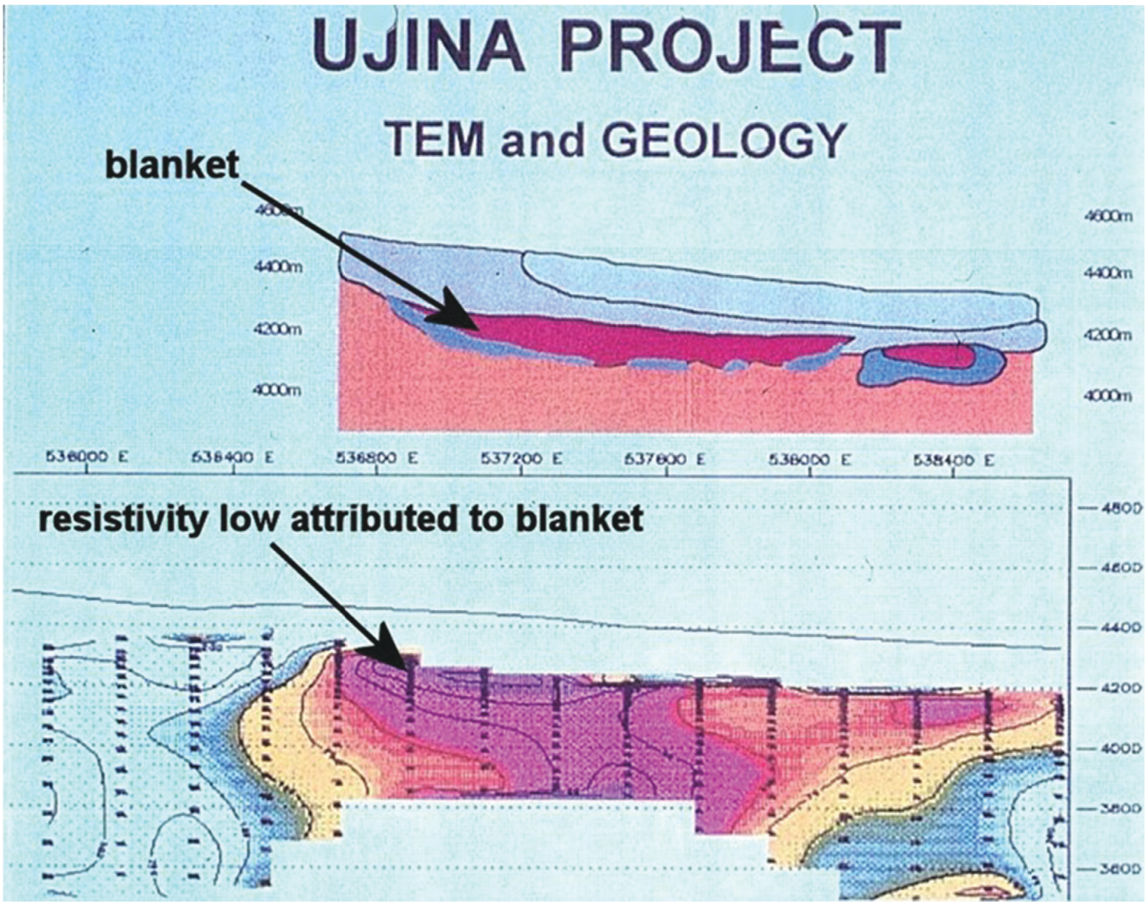

Figure 4. *Ujina deposit geology-upper image; TEM section-lower image (Nickson 1993).*

This work was carried out in 1993 and the results circulated by Quantec to interested parties (Nickson 1993). One such group was BHP who have been investing considerable effort at upgrading airborne EM technology along with Aberfoyle LLC and Geoterrex Ltd (Smith *et al*., 2003). Based on the Quantec work, and other trials carried out by BHP near the Escondida Mine, BHP then undertook a major programme of airborne EM looking for the supergene part of undiscovered porphyry systems. This work was summarised in Harrison (2002).

The scope of the exploration programme allowed for a more careful examination of actual conditions within the ore body. Figure 5 shows a downhole resistivity log from Escondida Norte. Harrison (2002) also provided the following comments about what was observed:

Figure 5 is a physical property log from Escondida Norte showing the strong correlation between conductivity and total sulphide content (Pyrite, Chalcopyrite, Chalcocite and Covellite). Chalcopyrite tends to be more disseminated and not as well connected in hypogene ore and is generally not seen as a source of conductivity. Pyrite is the most abundant mineral, and although it does not have the lowest resistivity, it makes up for it in connectivity. In addition, chalcocite can form as surficial covering on incompletely oxidised pyrite crystals, increasing the connectivity and lowering the resistivity for non-economic occurrences of chalcocite. Metallic chalcocite is well connected and very conductive

Almost concurrent with this work, Aerodat Ltd., a Canadian airborne survey group, was commissioned by the Iran National Copper Company to carry out an extensive airborne EM,

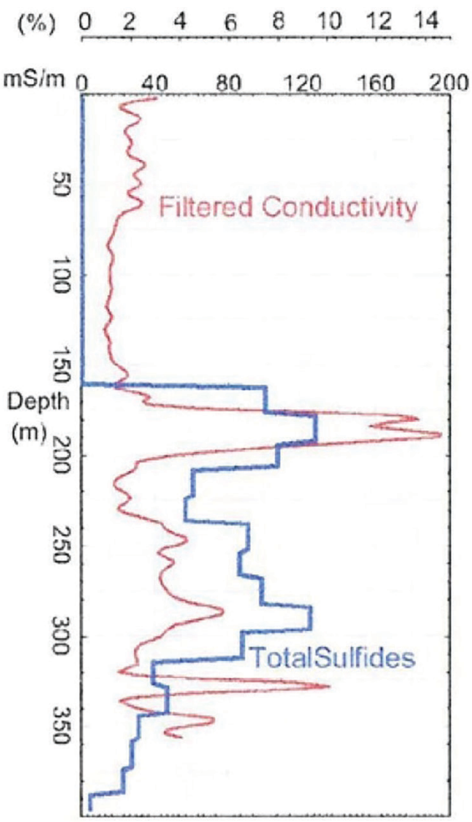

Figure 5. *Graph showing strong correlation between downhole conductivity and total sulphide content for ZERD62 at Escondida Norte.*

magnetic and radiometric survey (37 000 line-km) in the Kerman District of Iran.

The Kerman District was known to host a number of porphyry copper deposits, including the Tier 1 Sar Cheshmeh deposit. This work was documented in 1994 (Pitcher *et al.* 1994) and in their report, it was noted that a number of chalcocite-rich supergene zones were showing up as good conductors with the EM component of the Aerodat survey. This was not expected going into the survey, and unlike the Chilean experience where a theory was being tested, in the Iranian survey a serendipitous discovery led to mapping high grade copper zones with airborne EM. An example of these results is shown in Figure 6.

In the late 1990s, BHP was exploring for porphyry deposits in western Pakistan. As part of their exploration programme, ground TEM was carried out over a number of prospects (Schloderer 2003). One deposit, designated initially as H-4 (later called Tanjeel) had a well-developed supergene system that was clearly defined with the TEM survey (Figure 7). Also, in the mid-1990s, TEM was being carried out on a VMS deposit at Las Cruces located in southern Spain, which showed a well-developed supergene zone; Figure 8 (McIntosh *et al.,* 1999).

While chalcocite is believed to be primarily responsible for the incidents of conductive responses discussed above, the supergene process can also generate native copper, which is believed to have produced a strong conductivity response at the Ernest Henry deposit; Webb and Rowston (1995) and M. Webb pers. comm. (2023).

In some instances, a supergene development can exist concurrently with massive sulphide veins that can also be quite conductive. The Rosario deposit in the Collahuasi district in Chile, which sits adjacent to the Ujina deposit discussed earlier, shows supergene development. However, an extensive suite of massive sulphide veins dominates the conductivity response (Dick *et al.* 1994).

The change in sulphide habit from disseminated to massive and its effect on conductivity, was looked at by Nelson and Van Voorhis (1983). Their findings are summarised in Figure 9. At Rosario, this attribute has been exploited on several campaigns. The outcomes of a Crone DEEPEM ground TEM survey from the late 1980s (Wilt 1991), is shown in Figure 10. And in 2004-5 (A. Watts pers. comm. 2021), deep penetrating TEM was able to image the Rosario vein system to depths over 500 m (Xstrata 2006, Figure 11).

There are also a number of copper deposits (many porphyry coppers but not all) that have a supergene zone developed that hosts good grade copper but are not conductive. Two examples are shown in Figure 12 (Casino, Yukon, Witherly *et al.,* 2018) and Figure 13 (Silver Bell, Arizona, Thoman *et al.,* 1998).

The literature on supergene development suggests that the cycle must be repeated a number of times in order for the grade of the supergene (and assumed purity of the chalcocite) to be increased. In Alpers and Brimhall (1988), a suggested process is provided:

Supergene leaching, erosion of leached capping and lowering of base level in adjacent drainage channels during active weathering

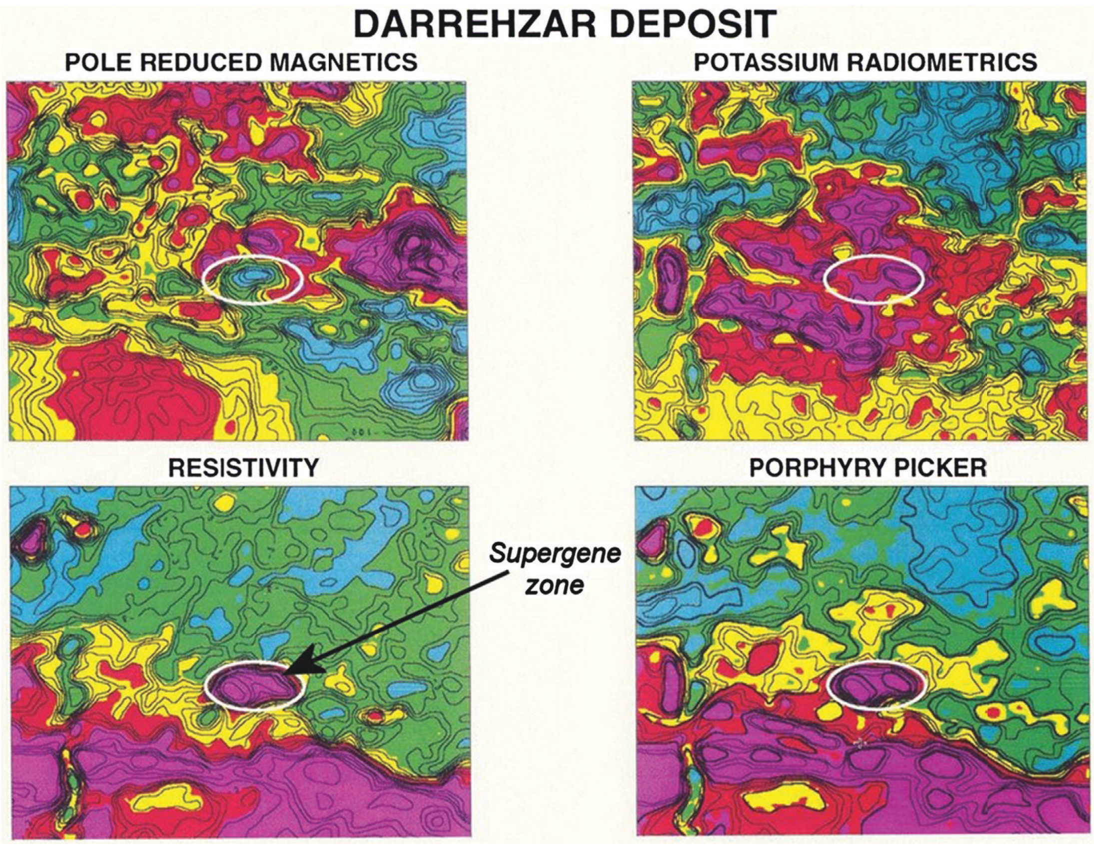

Figure 6. *Darrehzar deposit-Kerman District, Iran (Pitcher et al. 1994).*

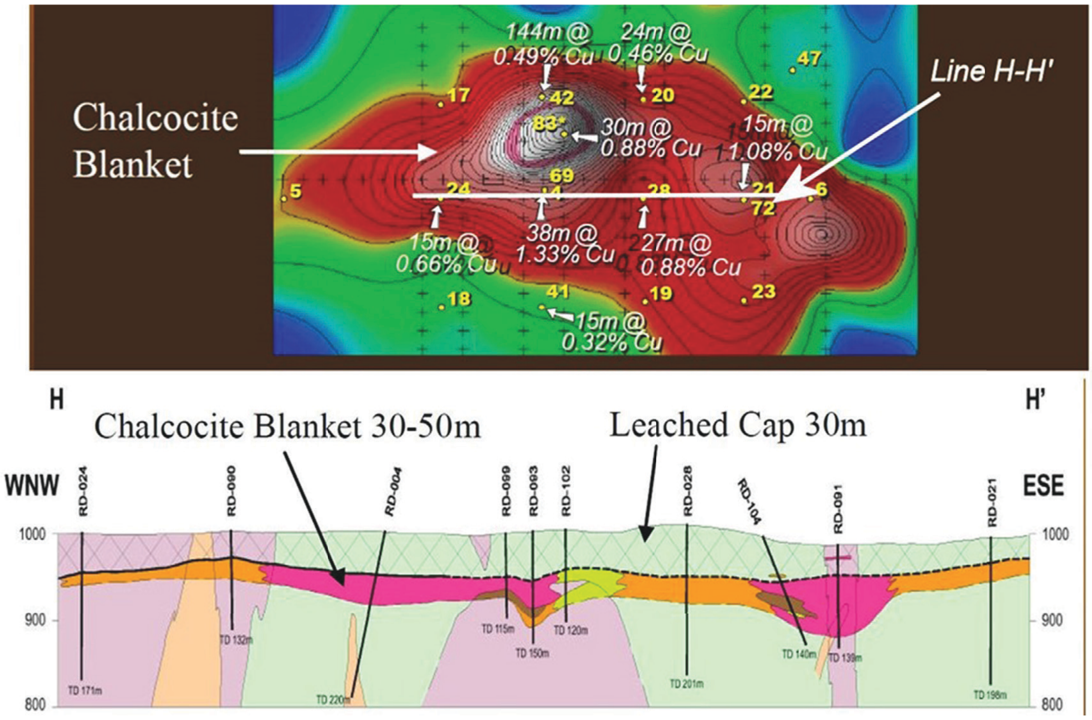

Figure 7. *H-4 (Tanjeel) deposit: TEM channel 15 + drilling-top image; geological section with supergene zone-bottom image (Schloderer 2003).*

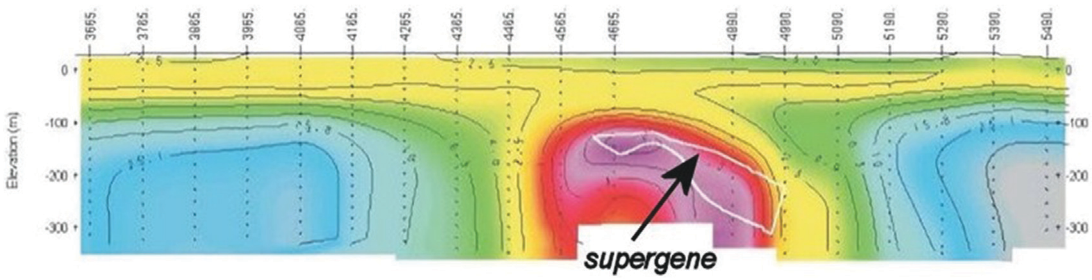

Figure 8. *TEM line over Las Cruzes (Spain) deposit-supergene zone (McIntosh et al. 1999). The figure show Zonge Engineering 1D STEMINV inversion results.*

of a porphyry-copper system tend to encourage descent of the water table, causing leaching of previously formed enrichment zones and reprecipitation of supergene copper sulphides at progressively lower levels and augmenting copper grades and enrichment blanket thickness.

It is considered likely that the Casino and Silver Bell examples formed as the consequence of one-event; a supergene zone is formed, but the enrichment process does not reach the copper grade, and hence the conductivity, that might be expected from multiple events. Multiple events seem to be associated with deposits that formed in very dry climates.

Summary

While there was a surge of examples in the 1990s showing exploration applications of EM to chalcocite mapping, the last 20 years have not generated many new examples, suggesting many explorers may never have heard of the relationship and may 'miss' making the connection, even if they are presented with data that shows the supergene 'effect' is in play.

Having field data on which to base judgments is always a good starting point, but for all the work in the 1990s there

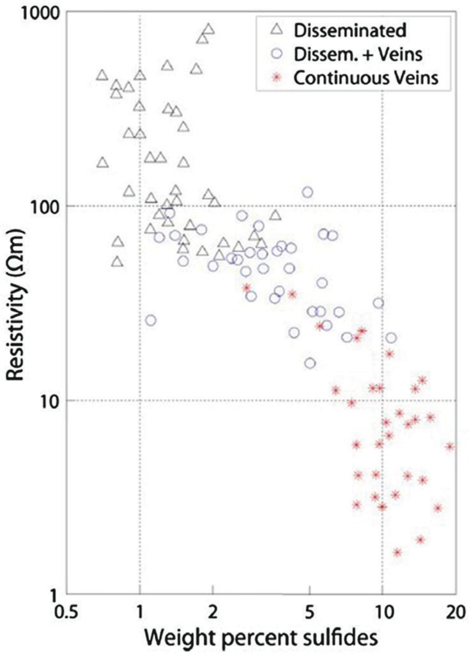

Figure 9. *Weight percent sulphides vs. resistivity (Nelson and Voorhis 1983).*

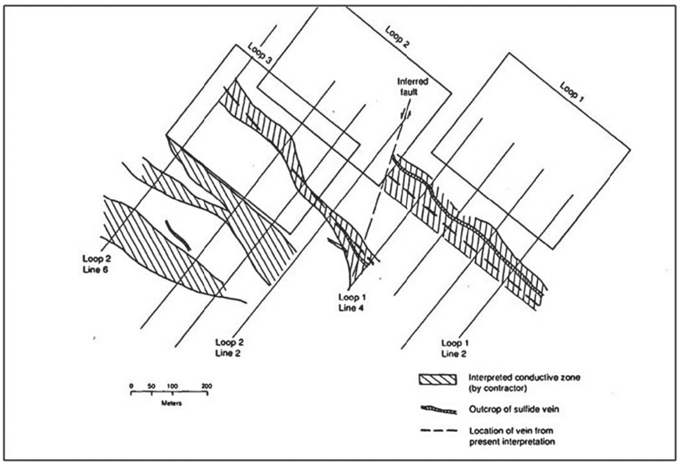

Figure 10. *Crone DEEPEM coverage over shallow portion of Rosario vein system (Wilt 1991).*

was a lack of petrophysical assessments that allowed the observed conductivity to be tied back to chalcocite *per se*, even though there was an extensive history of laboratory work and some field work (Nelson 1991) that showed that chalcocite is conductive. The major recent development in this field was the work of Don Emerson (Emerson 2021). Don was able to show that as density increased, so did the conductivity, a relationship expected to be observed. However, Emerson did not address the issues relating to the formation of chalcocite and supergene enrichment, as was done by Alpers and Brimhall (1988). Also, Alpers and Brimhall's ideas on how the supergene gets upgraded appear to be more 'suggestions' than well-documented theories. More work needs to be done to properly understand this mechanism.

The argument could be made that this sort of study is 'too late' to have any real impact on exploration 'best practice', the assumption being that most supergene deposits have already been found. However, whilst all shallow terrains may have been explored, covered areas unsuited to conventional geological mapping and geochemical exploration techniques are still potentially prospective.

The more important conclusion is that a significant petrophysical attribute, one that could help explorers map and define economic copper resources, has largely been ignored for 100 years. While a 'renaissance' in exploration for porphyry copper deposits appears to have occurred in the 1990s, little study of the phenomenon of conductive supergene copper deposits appears to have happened since then. My closing question is, if the chalcocite story 'slipped under the fence', what other potentially important petrophysical relationships has the exploration community missed?

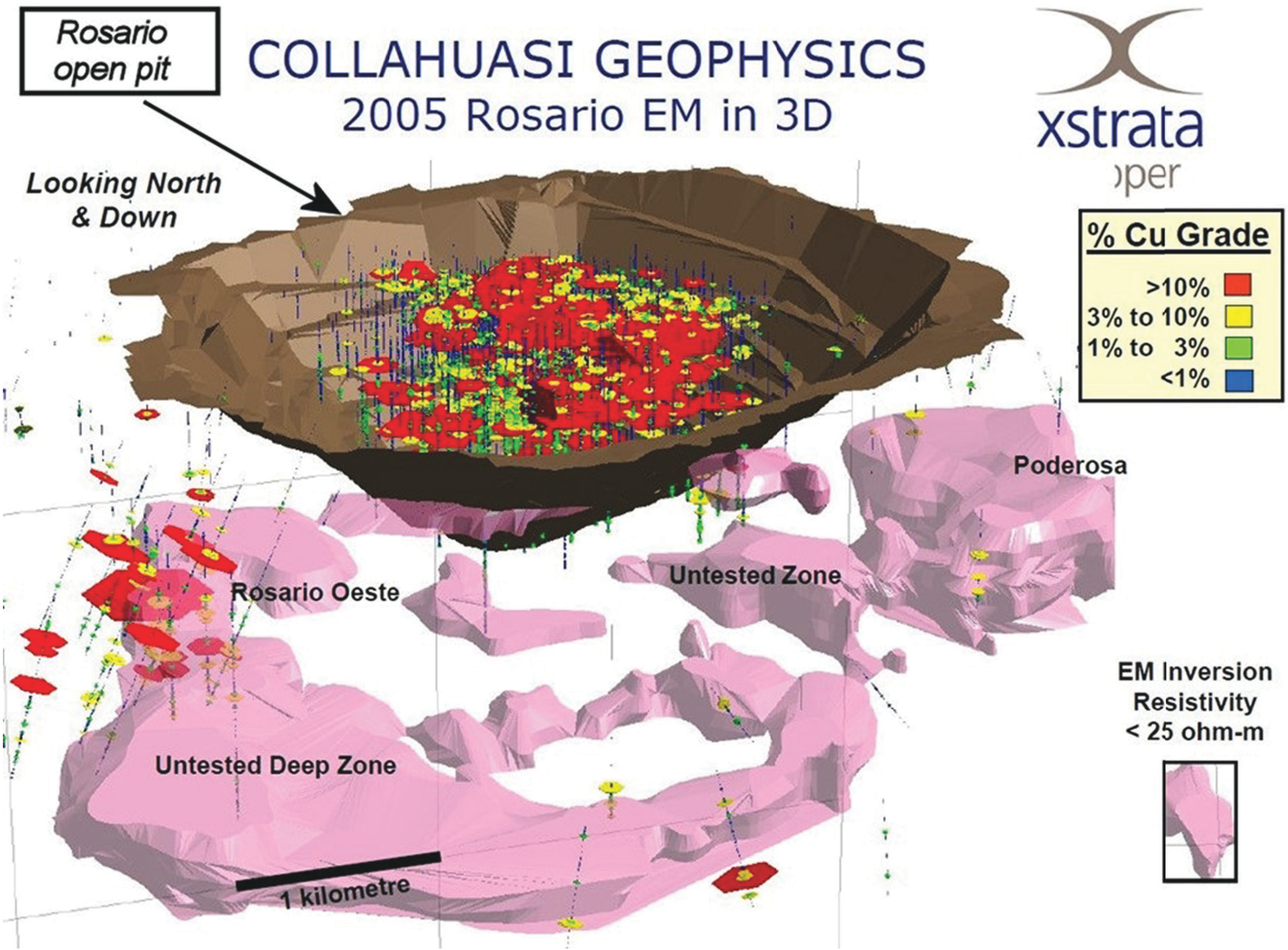

Figure 11. *3D view of Rosario vein system at depth; Xstrata Copper 2006.*

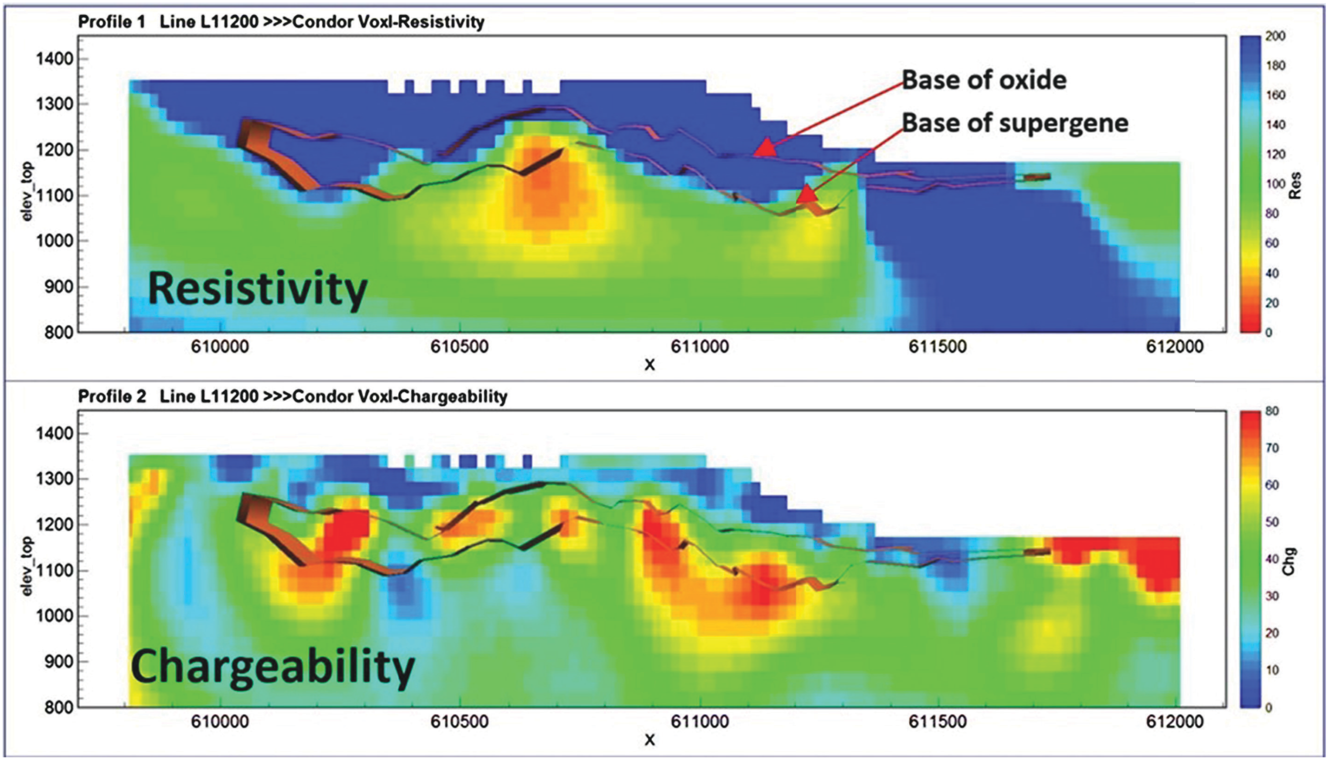

Figure 12. *Casino Deposit, Yukon. IP-DC resistivity section 11200 (Witherly et al. 2018).*

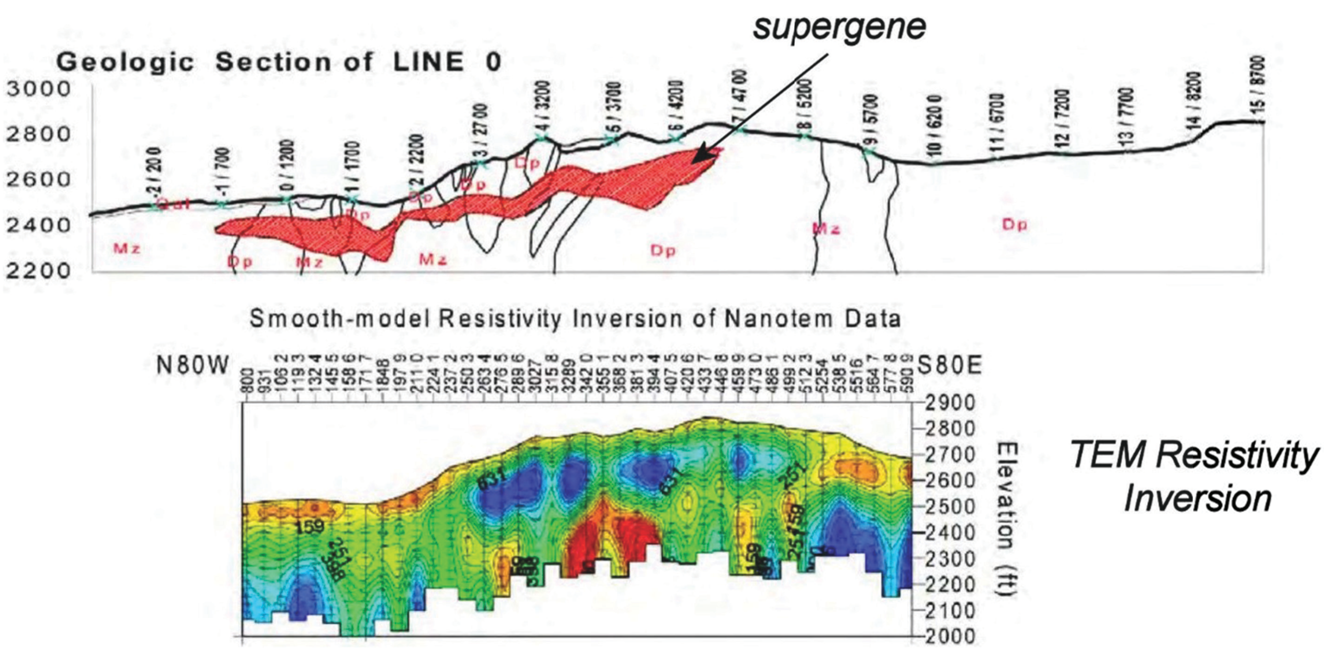

Figure 13. *Silver Bell Mine, Arizona. Geology section with supergene deposit shown on the top and the TEM resistivity section shown on the bottom (Thoman et al. 2000).*

Acknowledgments

This research would not have been possible without the help of several colleagues: Paul West-Sells, Leo Fox, Rob Gordon, Erik Tornquist, Dick Tosdal, Mark Rebagliati, Mo Colpron, Scott Casselman, Rob Carne, Jon Woodhead, José (Pepe) Perelló, Jeremy Richards (deceased), Fred Graybeal, Randall Nickson, Mike Harrison, Jeremy Barrett, Doug Pitcher, Lee Sampson, Andy Mountford, Paul Hayston, John P. Schloderer.

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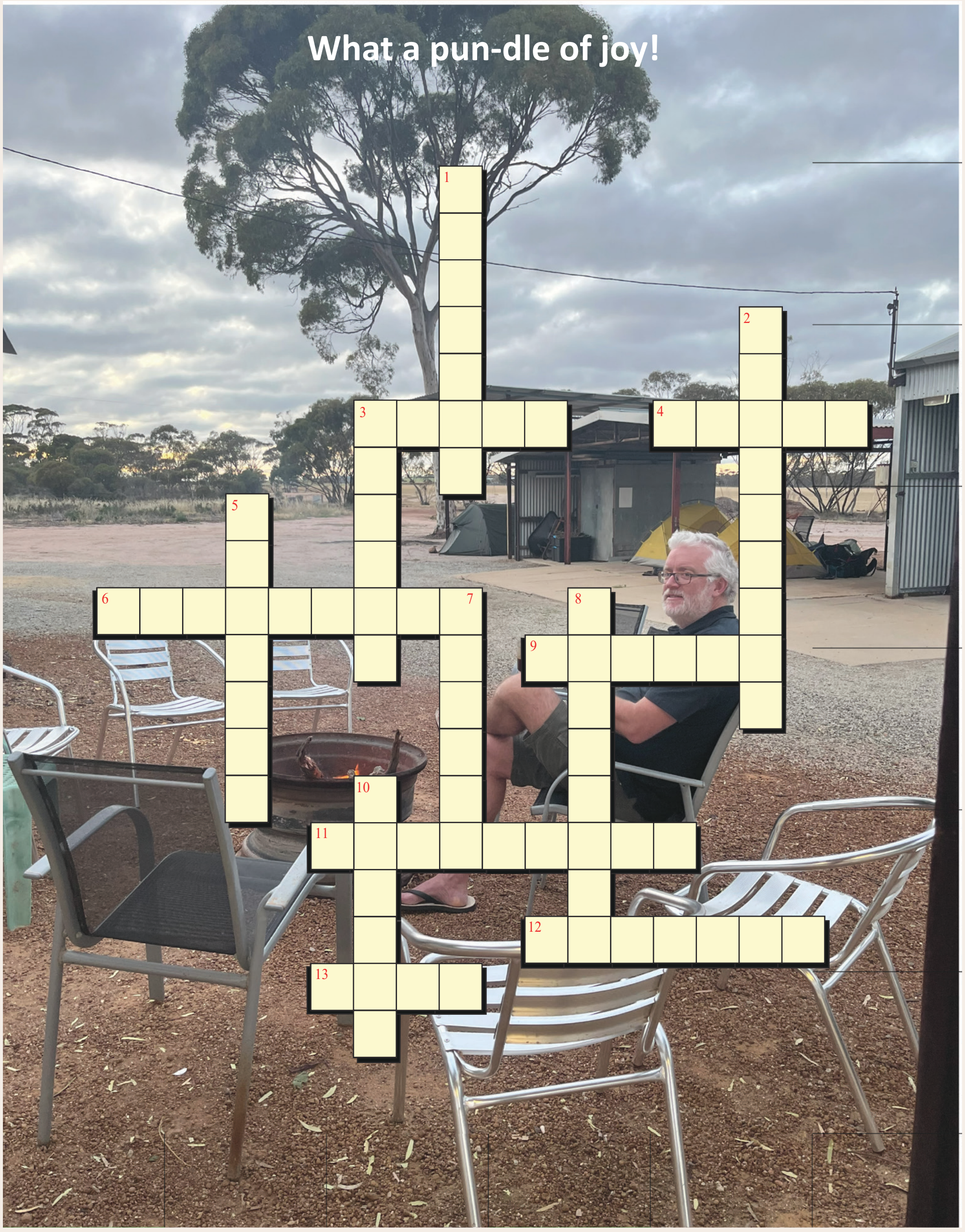
Papers marked with # have limited circulation and can be provided by the author on request: ken@condorconsult.com

Preview crossword #29



Across	Down
3. Getting paid to sleep would be my [——-] job	**1.** I met my wife on a dating site. We just [——-]
4. Jokes about German sausages are the [——-]	**2.** This girl thought she recognised me from vegetarian club, but I've never met [——-]
6. England doesn't have a kidney bank, but it does have a [——-]	**3.** Long fairy tales have a tendency to [——-]
9. Yesterday a clown held the door open for me. It was such a nice [——-]	**5.** A cartoonist was found dead. Details are [——-]
11. I once ate a watch. It was time [——-]	**7.** Having sex in an elevator is wrong on so many [——-]
12. A backwards poet writes [——-]	**8.** The other day I tried to make a chemistry joke, but got no [——-]
13. A boiled egg in the morning is hard to [——-]	**10.** I put all my cash into an origami business. It [———]

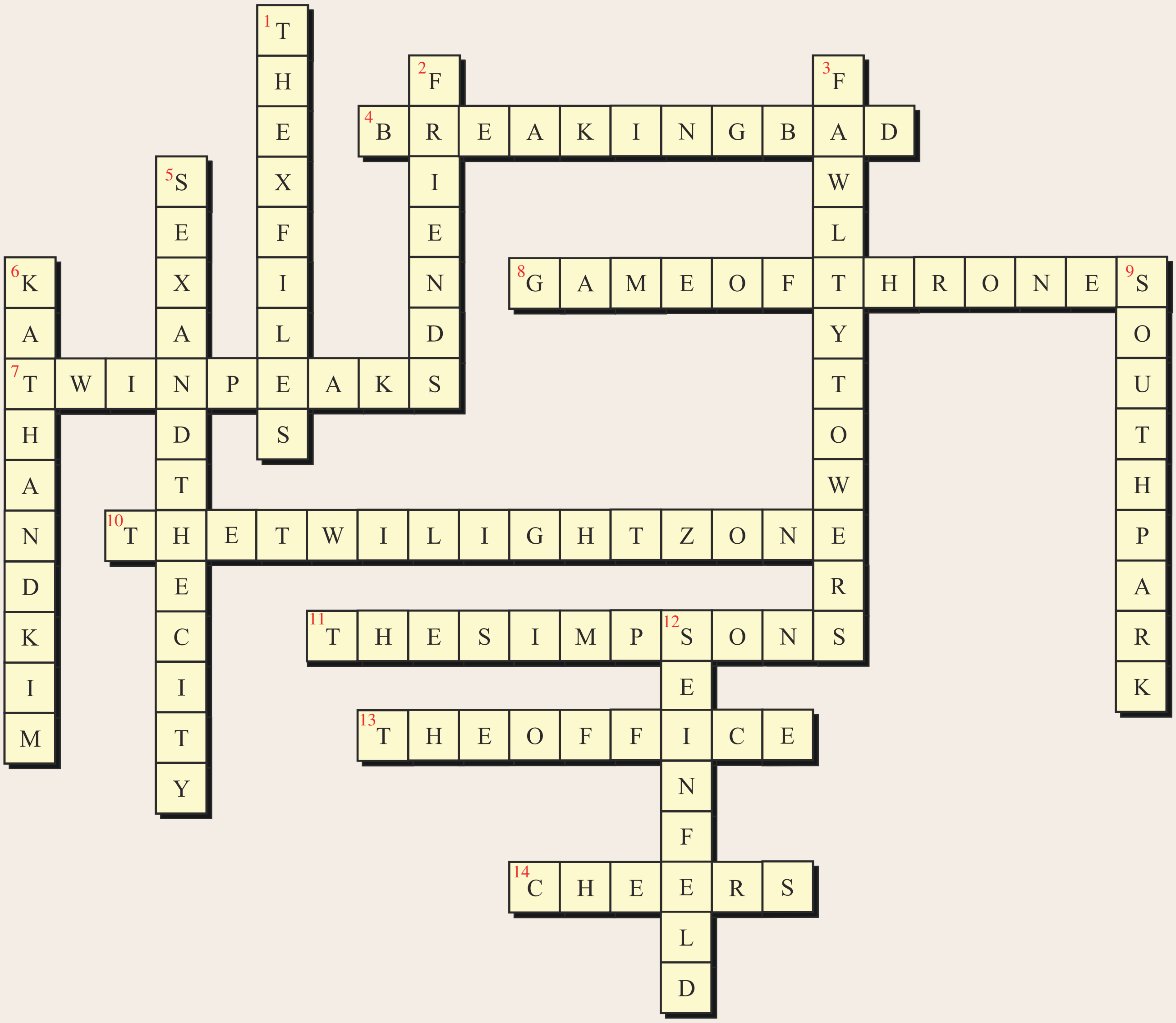
Play to win!!

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

Good luck!

Preview crossword #28 solution

Who has time for TV no more?



Business directory

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PO BOX 576, CROWS NEST NSW 1585 AUSTRALIA
Phone: +61 2 9431 8691 Fax: +61 2 9431 8677
Email: secretary@aseg.org.au Website: www.aseg.org.au

Application for Active & Associate Membership 2023

INSTRUCTIONS FOR APPLICANTS

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

Section 1. Personal Identification

Surname		Date of Birth
Given Names		Title
Address		
Country	State	Post Code
Organisation		
E-mail		
E-mail (alternate)		
Mobile	Phone (W)	Phone (H)

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

- ❑ Active — Please complete all sections
- ❑ Associate — Please complete all sections apart from Section 4 (Nominators)
- ❑ Graduate — Please complete Active or Associate application and also check this box
- Student — Please complete the separate Student Membership Application Form

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

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

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

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

Section 3. Academic and Professional Qualifications

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

Section 4. Nominators of Active Membership applicants must be ACTIVE Members of ASEG

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

Section 5. Membership of Other Societies

Australian:
❑ Aus IMM Grade ________ ❑ AIG Grade ________ ❑ GSA Grade ________ ❑ PESA Grade ________
International:
❑ AAPG Grade ________ ❑ EAGE Grade ________ ❑ SEG Grade ________ ❑ SPE Grade ________

❑ Others ____

Section 6. ASEG Member Record

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

❑ **Yes** ❑ **No**

Please complete this section for the ASEG membership database.

Employment area:
❑ Industry ❑ Contract/ Service Provider ❑ Government ❑ Student
❑ Education ❑ Consulting ❑ Other ___________________

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

Section 7. Membership Grades and Rates

❑ Active/Associate (Australia) - $193.00 (incl GST)	❑ Active/Associate 5 Year Membership (Australia) - $965.00 (incl GST)
❑ Active/Associate (Group IV Countries) - $175.50	❑ Active/Associate 5 Year Membership (Group IV Countries) - $877.50
❑ Active/Associate (Group III Countries) - $52.70	❑ Active/Associate 5 Year Membership (Group III Countries) - $263.50
❑ Active/Associate (Group I & II Countries) - $19.30	❑ Active/Associate 5 Year Membership (Group I & II Countries) - $96.50
❑ Associate-Graduate (Australia) - $97.00 (incl GST)	

Section 8. Preview & Exploration Geophysics

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

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

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

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

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

❑ **Yes** ❑ **No**

Preview is published bi-monthly and is available for open-access at www.aseg.org.au/publications/PVCurrent.

ASEG members can elect to have hardcopy Preview delivered to their nominated address (offer does not apply to Student members).

I would like to receive hardcopy Preview as part of my ASEG membership.

❑ **Yes** ❑ **No**

Section 9. Promotional Opportunities

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

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

Section 10. Declaration

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

*Signature:*__________________________________ *Date:*_________________

ASEG CODE OF ETHICS

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

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

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

Application for Student Membership 2023

INSTRUCTIONS FOR APPLICANTS

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

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

   Student Membership must be renewed annually.

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

2. Fill out the application form, ensuring that you provide contact details for your supervisor or coordinator

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

Section 1. Personal Details

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

Section 2. Student Declaration

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

Section 3 Membership Grades and Rates

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

Section 4 Preview & Exploration Geophysics

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

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

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

❑ **Yes** ❑ **No**

Section 5 Declaration

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

Signature: ____________________________________ Date: __________________

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

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

December	2023		
5–7	Latin America URTeC https://urtec.org/latinamerica/2023/	Buenos Aires	Argentina
February	**2024**		
14–16	State of Energy Research Conference (SoERC) 2024) https://www.erica.org.au/soerc2024	Perth	Australia
25–28	ASCE Geo-Congress 2024 https://www.geocongress.org/	Vancouver	Canada
27 Feb–01 Mar	Offshore Technology Conference Asia (OTC Asia) https://2024.otcasia.org/	Kuala Lumpur	Malaysia
March	**2024**		
3–6	PDAC https://www.pdac.ca/convention	Toronto	Canada
11–13	Carbon Capture, Utilization, and Storage (CCUS) https://ccusevent.org/2024	Houston	USA
April	**2024**		
14–19	EGU 2024 https://www.egu24.eu/	Vienna	Austria
May	**2024**		
7–8	International Mining Geology 2024 https://www.ausimm.com/conferences-and-events/mining-geology/	Perth	Australia
6–9	Offshore Technology Conference (OTC) https://2024.otcnet.org/	Houston	USA
13–15	6th Asia Pacific Meeting on Near Surface Geoscience and Engineering https://eage.eventsair.com/6th-asia-pacific-meeting-on-near-surface-geoscience-and-engineering/	Tsukuba	Japan
June	**2024**		
10–14	85th EAGE Annual Conference & Exhibition	Oslo	Norway
17–19	The Unconventional Resources Technology Conference (URTeC) https://urtec.org/2024	Houston	USA
August	**2024**		
18–23	Goldschmidt2024 https://conf.goldschmidt.info/goldschmidt/2024/meetingapp.cgi	Chicago	USA
25–31	International Meeting for Applied Geoscience & Energy (IMAGE) https://www.imageevent.org/	Houston	USA
September	**2024**		
8–12	EAGE Near Surface Geoscience Conference & Exhibition 2024		
October	**2024**		
TBA	ASEG 2024	Hobart	Australia
August	**2025**		
24–29	International Meeting for Applied Geoscience & Energy (IMAGE)	Houston	USA
September	**2025**		
8–11	Australian Exploration Geoscience Conference (AEGC) 2025	Perth	Australia

Preview is published for the Australian Society of Exploration Geophysicists. It contains news of advances in geophysical techniques, news and comments on the exploration industry, easy-to-read reviews and case histories, opinions of Members, book reviews, and matters of general interest.

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All proposed contributions should be submitted to the Editor by email at previeweditor@aseg.org.au

For style considerations, please refer to the For Authors section of the *Preview* website at: https://www.tandfonline.com/toc/texp20/current

Preview is published bimonthly in February, April, June, August, October and December. The deadline for submission of material to the Editor is usually the second Friday of the month prior to the month of issue. The deadline for the February issue is Friday 12 January 2024.

For the advertising copy deadline please contact the Publisher on advertising@taylorandfrancis.com.au