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# PREVIEW

## NEWS AND COMMENTARY

ASEG RF Projects – progress reports

Fibre-optic cable based systems for data collection

Google for nonprofits – including the ASEG

## FEATURE

Discovery and geophysics of the Khamsin iron oxide - copper - gold deposit, Gawler Craton, South Australia

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## ASEG CORPORATE MEMBERS



## FRONT COVER


Evgenii Sidenko, a recently graduated PhD student at Curtin University, carrying out field experiments with distributed fibre-optic sensors (DAS). See the last issue of *Preview* (227) for more information. DAS is also the topic of Mike Hatch's column (*Environmental geophysics*) in this issue of *Preview*.

*Preview* is freely available online at https://www.aseg.org.au/publications/PVCurrent and also https://www.tandfonline.com/toc/texp20/current



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# Editor's desk

This is the first issue of *Preview* produced by our new Graphic Designer, Elise Knotek of Stripe Design, and printed and distributed (for those of you who are reading the print copy) by CanPrint in Canberra. As previously advised, the digital version of the magazine will continue to be published on the ASEG website and, at this stage, Taylor & Francis 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, but also so that we maximise international exposure to *Preview* content. The ASEG has also resumed control of advertising and hopes eventually to cover all publication costs from advertising, so if you know of anyone in your part of the world whom you think would benefit from advertising in *Preview,* please urge them to get in touch with me!

This first issue (of the New Era) of *Preview* features an article by Jim Hanneson and his colleagues. This article, entitled "Discovery and geophysics of the Khamsin iron oxide - copper - gold deposit, Gawler Craton, South Australia", carefully and methodically dissects the exploration process from a geophysical perspective, and is sure to become a firm favourite with exploration geophysicists around the world!

In other news and commentary, Peter Gunn rouses himself from his retirement slumber (he is still very active, despite his protests to the contrary!) to pen a *Letter to the Editor* about the geophysical expression of the Deniliquin Impact Crater. David Denham (*Canberra observed*) reviews the performance of Australian resource companies in 2023. Mike Hatch (*Environmental geophysics*) gets excited about fibre-optic cable based systems for data collection. Terry Harvey (*Mineral geophysics*) muses on form and substance. Mick Micenko (*Seismic window*) revisits the demise of ASEG polarity. Tim Keeping (*Data trends*) experiments with ways to manipulate Big Data files, and Ian James (*Webwaves*) brings us up to speed with the ASEG's move into Google Workspace.

Enjoy!

***Lisa Worrall***
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# Letter to the Editor

***Re: Comments on the Deniliquin Impact Crater***

Dear Lisa

In 2000, when I was Head of the Geophysical Mapping group of Geoscience Australia (GA) I mentioned to Tony Yeates, a colleague at GA, that a large circular magnetic anomaly in western New South Wales could be evidence of an asteroid impact crater. Tony got very excited and as a result we jointly published a paper (Yeates *et al*. 2000). I was not entirely convinced with Tony's estimated diameter of 1240 km for this feature plus all his explanations for its other influences on Australian geology. The subject was dormant until Tony teamed up with Andrew Glickson, who was at GA at the same time as Tony and me and is now an Associate Professor at the University of NSW. One of Andy's impressive achievements has been co-authoring a book on Australian impact craters (Glickson and Pirajno 2018). In recent times Andy has been collaborating with Tony Yeates and they recently published a paper in *Tectonophysics* (Glickson and Yeates 2022) presenting a very good case for the existence of a large impact structure centred on Deniliquin. Their paper has received considerable attention in various media outlets (just Google check "Deniliquin impact crater"). They had access to better and more geophysical datasets than Tony and I had back in 2000.

The Glickson and Pirajno, (2018) book mentioned Deniliquin as the site of a major asteroid impact. The main evidence for an impact feature is a large multi-ringed magnetic anomaly with possible radial fractures, a ringed gravity feature coinciding with the magnetic feature and a local uplift of the crust underneath the gravity and magnetic anomalies. As explained by Glickson and Yeates (2022), these features are expected from a major impact feature. Drilling in the area has not been deep enough to identify shock metamorphic features expected from a major asteroid impact. I note that the interpreted impact feature now has an interpreted diameter of about 520 km. The probable date for the impact appears to be during the Ordovician.

The following comments on datasets, not accessed and processing routines not used, by Glickson and Yeates (2023) are not intended as a criticism of their work but rather some ideas to strengthen their hypothesis.

The most significant of these is the unfortunate fact that Glickson and Yeates (2022) were unaware of the *Tectonophysics* publication of Kirkby *et al*. (2020), which presents various inversions of GA magnetotelluric data in New South Wales. This paper displays various datasets showing that something strange is going on in the vicinity of the possible impact. Fig. 5c of their paper, a resistivity model from an inversion routine, shows a clear doughnut type circular feature (depth 25 km) circling the centre of the Deniliquin magnetic high. This could be imaging the edge of an impact crater. It seems that this paper was in press at much the same time as the Glickson and Yeates' paper.

The second criticism is that some of their geophysical images may not have displayed data in an optimal way to support their case. Most of their images of magnetic data do not show reduced to the pole (RTP) results. Reduced to the pole data, that correct for distortions of the inclination of the earth's magnetic field, normally show clearer outlines of magnetic features and trends. A RTP image of NSW presented in slide 2 of Gunn (2021), an ASEG You Tube presentation, shows a clearer circular feature at Deniliquin than the original total magnetic intensity image of Glickson and Yeates. Application of vertical derivative operators to the gravity data and even the seismic depth results may have imaged structures that further supported the theory.

Elevation images of Australia show a large regional topographic low over Deniliquin. This could be the result of the area being flanked to the east and south by the Great Dividing Range but may be a residual sag over the impact crater.

It was once suggested to me, by the well-known geophysicist, Hugh Rutter (now deceased), that the trends of gold mineralisation in Ordovician rocks at Ballarat and Bendigo in Victoria could have been related to radial fractures of the impact structure.

There were apparently five mass extinctions of life during the Earth's history (not including the Noah's ark episode). The best documented of these is the extinction of the Jurassic dinosaurs related to an asteroid impact in the Yucatan Peninsula in Mexico. There was a mass extinction in the Ordovician. Was this due to the Deniliquin impact? Was this the reason graptolites never took over the world?

***Peter Gunn***
***Gentleman geophysicist***

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## References

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# President's piece

Happy New Year to all our readers! I wish for everyone in 2024 a year filled with successes, good health and happiness.

The end of last year and start of this year have, on a personal level, been defined by new beginnings. Toward the end of the year, the company I had been working for, Newcrest, was acquired by Newmont. This transaction closed in a global environment of rising M&A activity, which many forecast to continue into 2024 with companies positioning themselves to meet the challenges of the energy transition and increasing headwinds for developing new projects. While there is undeniably a real sense of uncertainty that goes hand-in-hand with these corporate transactions, experience has taught me that they can also lead to great opportunity.

I find myself enriched as a professional by being immersed within a much larger peer group. There's the prospect of exchanging knowledge and ideas with colleagues who are drawing on experiences and skills which are different from those that I have previously been exposed to. For me, and those around me, it may provide the next step in career growth and great opportunities for professional development. I am excited and curious about the unknowns and look forward to seeing what prospects this new year brings. Of course, wearing my ASEG hat, I will be seizing the opportunity to make the case for ASEG membership especially to our overseas colleagues.

On this very morning I have just returned from witnessing another significant beginning this year. My daughter, and eldest child, has just started her first day of high school. We rode our bikes up to school together, in the blistering near 40-degree Brisbane summer heat, and after a brief stop to take the embarrassing daddy-daughter selfie in front of the school gates she walked off into a hall with just a few familiar faces and hundreds of new ones. I could hear and see new introductions happening all over, and teachers there to catch anyone that needed some extra help. At the same time, my wife was settling our two younger boys into their new primary school classes.

I couldn't help but make the comparison between starting at a new school or grade, to my present experience of walking into a new company. I am heartened after observing the way the children quickly adapt to change - almost effortlessly. Curiosity was without a doubt the dominant emotion, over reluctance or even fear, and I will take this observation with me into my day-to-day professional being. I believe this generation is better at coping with change than my generation. They seem naturally equipped to walking into a new environment with an open mind and seeking opportunities. Surely this bodes well as we seek to attract students and professionals to our industries in the face of change brought about through the energy transition and growing focus on sustainable development. Our challenge as a Society will be to ensure we 'move with the times' and continue to offer Member value that taps into this curiosity and visibly responds to the changing industry.

As you are aware, our Society is run by volunteers. We need your help to continue to thrive and deliver Member value, and have a range of committees (Committees | Australian Society of Exploration Geophysicists (aseg.org.au)). If any resonate with your interest(s) please reach out to the respective chair directly. Any level of assistance will be welcomed. We would also love to have more volunteers for the Hobart conference, so please contact me directly if this might interest you.

I look forward to seeing many of you throughout 2024 and, as always, please reach out to me with any ideas about how we can improve the ASEG, general comments or feedback.

***Eric Battig***
***ASEG President***

**E** president@aseg.org.au


## Richard Lane Scholarship 2024

**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".

# 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 December FedEx meeting reported to 31 December 2023. The December 2023 operating income was $7945, which was mainly derived from AEM 2023. The December 2023 operating expenses were $29 434, which included meeting expenses of $13 528 and the monthly TAS Management Fee of $8865. For the month of December 2023, the ASEG was running at a loss of $21 489, and the YTD profit was $77 878.

| | December 2023 | YTD |
|---|---|---|
| **Total Income** | $7945 | $528 033 |
| **Total Expense** | -$29 434 | -$450 155 |
| **Net Profit** | -$21,489 | $77 878 |
| **Net Assets** | | $1 035 852 |

## Membership

The annual membership renewal process is in progress. If you have not already done so, please renew your membership at your earliest convenience. 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 our 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 2024.

## Events

FedEx is delighted to announce that the ASEG's DISCOVER conference will be held at the Wrest Point Hotel, Hobart, Tasmania, commencing on Tuesday the 15th of October and wrapping up on the afternoon of Friday the 18th of October 2024. Please save these dates! We have an Organising Committee in place, and they are working on developing the technical programme. An invitation to submit a paper and other details will be sent out early this year. We hope to see you in Hobart!

## Communications

There are many avenues for you to stay connected with ASEG including *Preview* magazine, the ASEG Newsletter, the ASEG website, and via various social media sites such as LinkedIn, Twitter and Facebook. The top posts on all three social media sites have been related to the December 2023 issue of *Preview*. There has been a steady increase in followers on LinkedIn and Twitter, but a decrease in followers on Facebook. Please consider using social media to promote all ASEG events and publications.

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

***Asmita Mahanta***
***ASEG Secretary***
**E** fedsec@aseg.org.au



## Welcome to new Members

The ASEG extends a warm welcome to nine new Members approved by the Federal Executive at its December 2023 and January 2024 meetings (see table).

| First name | Last name | Organisation | State | Country | Membership type |
|---|---|---|---|---|---|
| Januka | Attanayake | GHD | Vic | Australia | Active |
| Robert | Black | Black Geophysics | WA | Australia | Active |
| Kerry | Key | Columbia University | Wyoming | United States of America | Active |
| Mike | Oehlers | Tectosat Ltd | Surrey | United Kingdom | Active |
| Fabio | Nohara | | WA | Australia | Associate |
| Claire | Robertson | Rio Tinto | WA | Australia | Associate |
| Satyam | Sahu | Indian Institute of Technology Dhanbad | Uttar Pradesh | India | Student |
| Mark | Whelan | Anglo Gold Ashanti | Qld | Australia | Associate |
| Jean d'Amour | Uwiduhaye | RMB | Musanze | Rwanda | Associate |

# Notice of the ASEG Annual General Meeting

The 2024 Annual General Meeting of the Australian Society of Exploration Geophysicists will take place on **Tuesday 30 April 2024,** at a venue to be confirmed in **Brisbane** and via Zoom.

***Be there to make a difference!***

For more information, contact ASEG Secretariat at secretary@aseg.org.au, or by telephone on **+61 2 9431 8622**.

## Call for nominations for members of the Federal Executive

In accordance with Article 8.2 of the ASEG Constitution, "the elected members of the Federal Executive are designated as Directors of the Society for the purposes of the Act". These are the President, President-Elect, Immediate Past President, Secretary and Treasurer. They shall be elected annually by the Members of the Society at the Annual General Meeting. These office bearers shall succeed the previous ones upon the conclusion of the Annual General Meeting. At the end of their term each officer will retire but may nominate and be eligible for re-election except for the President's position, which will be automatically filled by the outgoing President-Elect, and the Immediate Past President's position.

The Federal Executive shall comprise up to 12 members, and shall at least include the five elected members:

(i) a President (elected as a two-year term, one year as President, immediately followed by one year as Immediate Past President)

(ii) a President-Elect

(iii) the Immediate Past President

(iv) a Secretary

(v) a Treasurer

**These officers will be elected by a ballot of Members.**

In addition, the following offices are recognised:

- the Chair of the Publications Committee
- the Chair of the Membership Committee
- the Chair of the State Branch Committees (unless otherwise a member of the Federal Executive)
- Up to four others to be determined by the Federal Executive.

**These officers will be appointed by the Federal Executive Committee but nominations will be welcomed.**

**TUESDAY 30 APRIL 2024, BRISBANE**

Please forward the name of the nominated candidate and the position for which they are being nominated, together with the names of the nominators, who must be two Members eligible to vote, to the Secretary:

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**Nominations should be received via post, or email no later than COB Friday 29 March 2024.**

Positions for which there are multiple nominations will then be determined by an online ballot of Members, and the results declared at the Annual General Meeting.

***Asmita Mahanta***
***ASEG Secretary***
**E** fedsec@aseg.org.au


*Participants in CAGE 2023*

# ASEG Research Foundation: Progress reports on projects

The ASEG Research Foundation continues to back students in their degree studies. Through a competitive process, the Foundation makes annual grants to support the laboratory and fieldwork necessary to carry out the research projects that are essential for the completion of Honours, Masters or PhD degrees. The Foundation has existed for 35 years and has spent over $1.6 m with the support of the ASEG, and tax-deductible donations made by Members, supporting companies and others.

Applications for 2024 grants are now open, closing March 1st, 2024. https://www.aseg.org.au/foundation/how-to-apply

Updates on selected current projects follow:

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**RF21P01 Monash University, PhD student Chibuzo Chukwu (supervisor Prof Peter Betts).**

*Role of basement structures in controlling triple junction formation and associated basins in southern Australia.*

The Precambrian-Palaeozoic boundary basement rocks of the south-eastern margin of Australia are segmented into several tectonostratigraphic provinces, bounded by broadly ~N-S trending deep-seated faults that extend into the Mesozoic and younger basins of south-eastern Australia. The location, architecture, and influence of these basement structures on the Mesozoic rift-failed rift-transform triple junction obscured by thick sequences of younger volcanic and sedimentary rocks of the Otway, Bass, and Sorell Basins developed during Australia's breakup from Antarctica remain a challenge. Consequently, the overarching goal of this project is to assess the influence of pre-breakup structures on the evolution and distribution of depocenters and structures related to southeast Australia's triple junction formation using multi-scale and integrated geoscience approaches. As the project nears its final year, our previous activities have culminated in two publication drafts slated for submission to peer-reviewed journals while we focus on the divergent arm of the triple junction.

Activities over the past years have led to two major paper drafts. The first draft, submitted to *Exploration Geophysics*, introduces an innovative technique that combines Euler deconvolution with an unsupervised machine learning algorithm named Density-Based Spatial Clustering Application with Noise (DBSCAN) on potential field data. This method determines the location and dip of geologic structures at multiple scales. Additionally, we demonstrate its efficacy in imaging structures at depths of approximately 30 km, masked by the magnetic signals of the Pleistocene basaltic rocks of the Newer Volcanic Province in Victoria. It showcases how this method delineates structures in low-resolution global and high-resolution airborne magnetic data within central Victoria. We highlight both the limitations and the potential our innovative method holds in imaging structures in 3D space. Notably, our results from this method align with pre-interpretations from deep 2D reflection seismic data, as shown in **Figure 1**.

The second publication draft, destined for the *Journal of Geophysical Research*, illustrates how our novel method on magnetic data, augmented by enhanced and drill hole-constrained seismic reflection data, has identified a fresh network of Cambrian-Silurian basement faults within southeast Australia. This research redefines the boundary between the Proterozoic and Palaeozoic basement rocks stretching from southwest Victoria to western Tasmania. Our analysis further reveals that these deep-crustal faults, which appear as near-vertical dipping faults inland, undergo reactivation and transition into steep-dipping listric faults, bounding and partitioning Cretaceous faults and depocenters. They control the overall evolution of the arms of the Mesozoic southeast Australia's triple junction. Our work also provides analysis that provides a strong control in correlating the structural domains between southeast Australia and northeast Antarctica's margins.

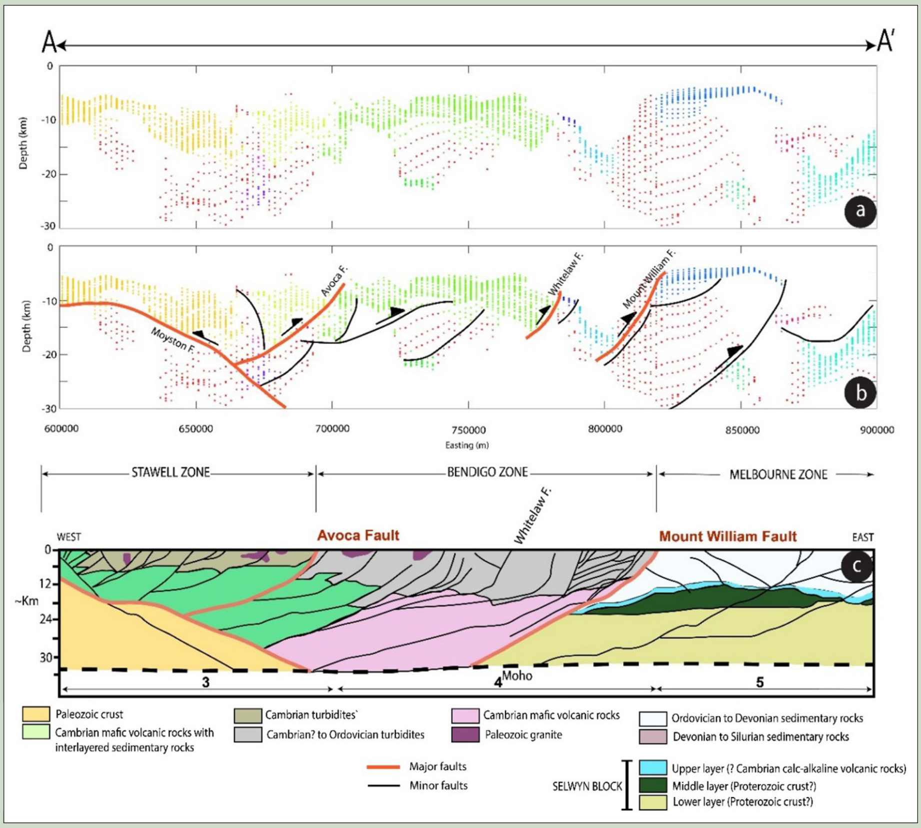


**Figure 1.** *Comparison of optimised clustered Euler depth solutions along A-A′ traverse with geology. (a) Uninterpreted clustered Euler depth cross-section. (b) Interpreted Euler depth traverse (c) Near-parallel interpreted seismic cross-section to A-A′ profile. Cluster boundaries strongly correlate with the locations of the major zone-bounding faults at depth. The first-order cluster boundaries are in red and, along with other cluster boundaries, in black. Notice the high frequency of cluster boundaries in (b) and faults in (c) within the Bendigo Zone compared to other structural zones.*

This year, our focus shifts to the in-depth analysis of the divergent arm of the triple junction that spans the Mesozoic depocenters of the Otway Basin. We're employing a novel approach, amalgamating petrophysical samples from 180 wells with high-resolution gravity and magnetic data, to generate 2D and 3D models of the Otway Basin. We plan to analyse these 3D models, produced through combined 2D seismic constrained forward and inverse models, to delineate the rift domains and examine the major tectonic factors steering the evolution of the divergent and transform arms of the triple junction. Seismic interpretation combined with 2D forward models of intersecting traverses covering Otway Basin has been completed. Our final endeavour is to produce constrained 3D models of the Otway Basin.

We wish to express our profound gratitude to the Members of the Australian Society of Exploration Geophysics (ASEG). Their ASEG Research Foundation grant has been instrumental in facilitating a significant portion of this PhD project.

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**RF21P02. University of Melbourne, MSc student Youssef Hamad (supervisor Dr Graeme Beardsmore).**

*Utilisation and comparison of conventional wireline precision temperature sensing, DTS, and aDTS to detect and quantify subsurface geothermal anomalies in the on-shore Gippsland Basin.*

This project integrates three temperature measurement technologies, all tailored for borehole geophysical logging, and investigates how they can complement each other. The sensors include thermistor-based instruments, self-contained button-style loggers, and fibre optic distributed temperature sensors (DTS), each with its distinct advantages and disadvantages. Conventional thermistor instruments, while known for precision, contend with drawbacks such as slow logging speeds, heavy and costly wireline cables, and extended equilibration times in air-filled bore sections, diminishing their accuracy. In contrast, self-contained button-style loggers offer a more economical alternative, but not without compromising the resolution of temperature and depth measurements. DTS uniquely captures time-series spatial-temporal data, logs entire borehole profiles instantaneously, and has a potential for conducting *in-situ* thermal conductivity assessments during active operations. Nonetheless, it demands a more intricate calibration process, necessitating additional labour, processing, extended setup, and logistical considerations.

The project targets accessible boreholes in the Gippsland and Murray Basins for sensor deployment. It aims to examine these sensor technologies collectively to optimise operational efficiency, accuracy, precision, and *in-situ* calibration techniques for DTS. Gaining this understanding is pivotal for applications within borehole geophysics that rely on temperature measurements. These applications span fundamental lithospheric research (heat flow measurements), geothermal exploration, monitoring of groundwater temperatures, and the reconstruction of past land surface temperatures.

The project has advanced, thanks to partnerships between the University of Melbourne, AuScope, Geoscience Australia, CSIRO, and the geological surveys of Victoria and South Australia, which have provided crucial access to DTS equipment, boreholes, and related core samples and cuttings. We secured high-precision, lab-calibrated thermistor-based logs from eight boreholes in the Gippsland Basin, and two more from the Murray Basin in South Australia. We implemented DTS in five of those eight boreholes using passive sensing, and one of the Murray Basin boreholes with active sensing. In three of those boreholes, we also deployed button-style loggers as *in-situ* calibration sensors alongside DTS to enhance the accuracy of the DTS logs, particularly when encountering data noise. Collectively, these loggers demonstrated robust performance, capturing subsurface temperatures down to depths of 1 km and up to temperatures of approximately 65°C. An active DTS trial was carried out in a borehole in the Murray Basin to acquire *in-situ* thermal conductivity data, facilitated by CSIRO. Furthermore, we secured legacy rock cores from the Geological Survey of Victoria core library in Werribee and conducted thermal conductivity and diffusivity measurements.

The next stage of our project involves applying numerical modelling to derive *in-situ* thermal conductivity from the active DTS data from South Australia. This model is set for refinement through the integration of thermal properties derived from drill cuttings provided by the Geological Survey of South Australia. Simultaneously, we are set on inferring the land surface temperature history using temperature data from a single borehole with a substantial air-filled section in the Gippsland Basin. To address the air-filled section our methodology merges both DTS and thermistor-based logs in this borehole, which mutually complement each other, and incorporates the thermal conductivity and diffusivity data previously acquired from cores courtesy of the Geological Survey of Victoria. We sincerely thank the ASEG Research Foundation for the financial support bestowed by the grant, which has been critical for meeting the costs associated with our fieldwork and necessary equipment.

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**RF22P01. University of Adelaide, PhD student Kosuke Tsutsui (supervisor Prof Simon Holford).**

*Geophysical-geomechanical characterisation of igneous rocks in the Browse Basin: implications for exploration, development, and gas storage in volcanic-rich basins.*

## Introduction

Exploration in sedimentary basins impacted by magmatic activity faces a significant challenge in accurately predicting the presence of igneous rocks within sedimentary sequences (*e.g.* Planke *et al.* 2000; Schofield *et al.* 2017; Watson *et al.* 2020). These igneous rocks can profoundly impact various aspects of petroleum systems, such as influencing reservoir deposition by controlling sediment fairways, working as fluid migration pathways or barriers, and forming trapping systems (*e.g.* Holford *et al.* 2012; Senger *et al.* 2017). Additionally, igneous rocks can add complications to drilling operations such as low rates of penetration, rapid drill bit wear, drilling mud losses, and wellbore collapse, leading to unforeseen costs and complexities (*e.g.* Millett *et al.* 2016; Watson *et al.* 2020; Curtis *et al.* 2022).

The Browse Basin, covering an area of ~140 000 km$^2$ on Australia's North West Shelf, typifies many of these challenges, with the presence of igneous rocks having been recognised since its early exploration in the 1970s. Despite being one of several major hydrocarbon provinces on the continental shelf of Australia with numerous discoveries and significant production such as the giant Ichthys gas-condensate field, the extensive occurrences of igneous rocks within Mesozoic strata present ongoing challenges for exploration and development (*e.g.* Zahedi and MacDonald 2018). Their impact on petroleum exploration is demonstrated by the number of wells which encountered unpredicted or thicker than expected igneous rock units both within and adjacent to target sections. This study therefore aims to document the reasons why igneous rocks are unexpectedly encountered so frequently, and to develop capability for more accurately predicting the occurrence of igneous rock units prior to drilling in the Browse Basin. Studies on uncommercial exploration wells were conducted by integrating petrophysical and seismic reflection data, focussing in particular along the outboard part of the basin where igneous rocks are most prevalent. Our study highlights the importance of understanding both petrophysical properties, and the spatial and chemical heterogeneities of igneous rocks in basins to explain their emplacement and distribution, and thereby predict their occurrence prior to exploration and development activities.

## Data and methodology

This study uses publicly available well data from the National Offshore Petroleum Information Management System (NOPIMS) which includes wireline, borehole image, core and cuttings, along with completion reports and analytical studies such as X-ray diffraction analysis and quantitative evaluation of minerals by scanning electron microscopy. Publicly available 2D and 3D seismic reflection data are also compiled and examined to understand the basin framework and to investigate seismically resolvable igneous rock units. Cutting descriptions of mudlogs from 137 wells were reviewed to screen out the wells which encountered igneous rocks. We selected five exploration wells that penetrated thick igneous sequences (>500 m) as key wells which are located along the outboard basin; Buffon-1/ST1, Maginnis-1A/ST2, Warrabkook-1, Kontiki-1 and Grace-1. Wireline logs were used to classify igneous rock facies based on combinations of log values and motifs. For instance, acoustic velocity and density logs prove effective in identifying unaltered igneous sections, while gamma ray (GR) logs, commonly used for estimating clay content, also serve as indicators to distinguish felsic rocks rich in potassium feldspars from mafic rocks poor in alkaline components. The final lithofacies logs are interpreted based on integration of wireline responses, cuttings lithology, and available thin sections.

## Results

This study examined drilling results of 137 wells that were drilled in the Browse Basin and revealed that over 53% of them encountered igneous rocks in the Mesozoic interval, primarily within Jurassic-aged strata. Results from Buffon-1/ST1, Kontiki-1, and Grace-1 wells illustrate that the fault-bounded structure in the north-western part

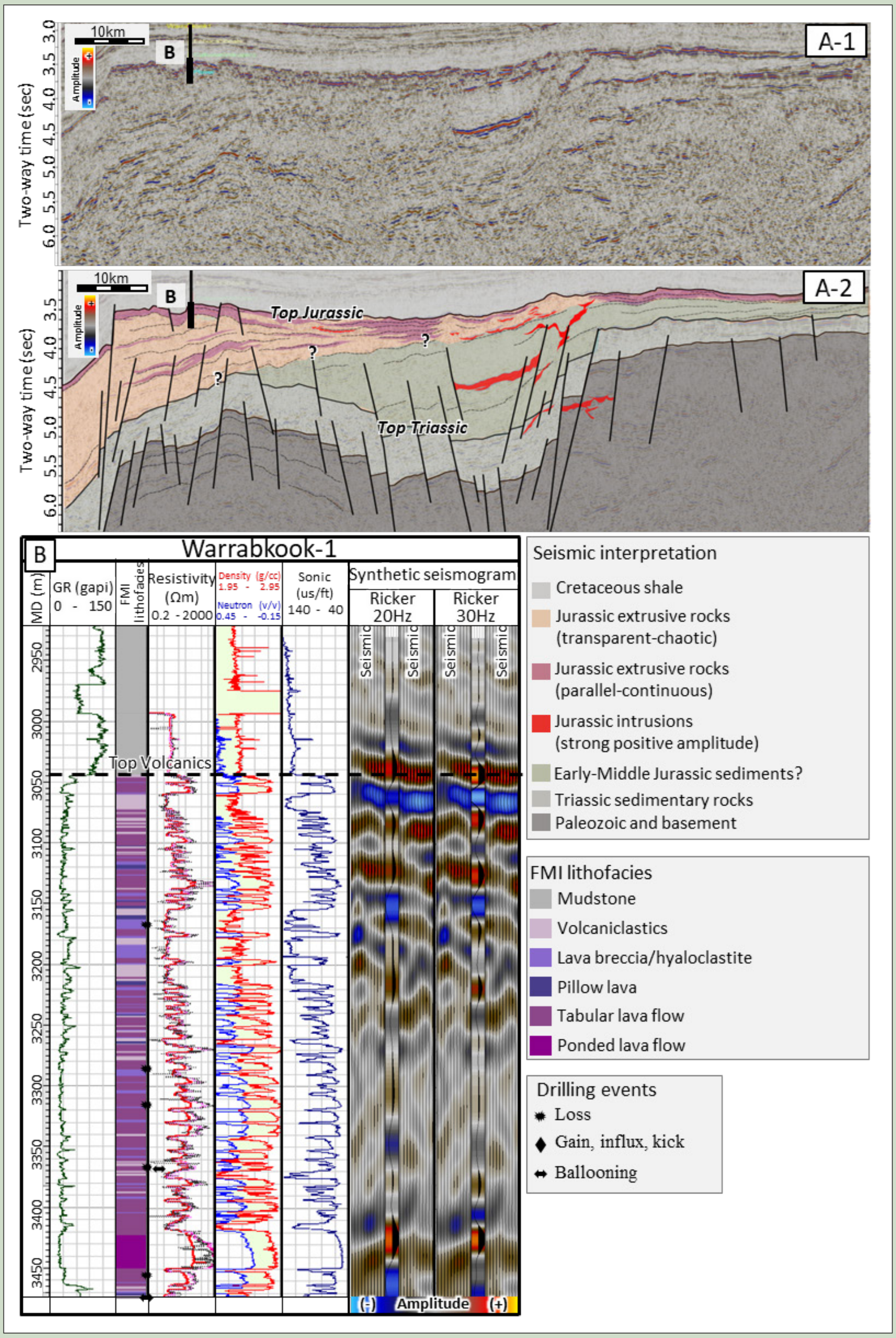


**Figure 1.** *Well summary of Warrabkook-1. A-1) Seismic section through Warrabkook-1 (Browse 1998 2D Spec line 26). A-2) Distribution of igneous rocks interpreted from seismic facies. B) Wireline logs and facies interpretation of the Jurassic igneous rock interval.*

of the basin contains a substantial Jurassic igneous sequence, with Grace-1 specifically confirming a thickness of at least 1100 m. The uppermost section consists of 100 to 450 m of basaltic tabular lava flows, which are characterised by low GR wireline log values and repeating high-low cyclic patterns of density and sonic wireline log values. The lower section is composed of felsic igneous rocks (with relatively higher GR values) are followed by altered igneous rock interbedded with Lower Jurassic sedimentary rocks, extending several hundred meters in thickness.

The findings from the Maginnis-1A/ST2 and Warrabkook-1 wells suggest that the western outboard area is characterised by a basaltic sequence exceeding 400 m in thickness, with limited development of sedimentary reservoirs. These substantial basaltic sections led to drilling challenges; Maginnis-1A/ST2 faced extremely low rates of penetration, required four tri-cone bits to penetrate a 483-meter interval. Meanwhile, Warrabkook-1 experienced significant mud losses and subsequent ballooning effects.

Failure to accurately predict the distribution and characteristics of igneous rock formations is a significant factor in the lack of successful exploration outcomes in the outboard basin. Variety in rock type and physical properties complicates the correlation between well interpretations and seismic data, hindering precise predictions of igneous intervals and potential sandstone reservoir locations. This study underscores the importance of comprehending igneous rock properties, connecting them to seismic data, and evaluating their distribution in a regional context. Addressing these aspects will enhance the understanding of igneous rock complexities, ultimately improving exploration efforts in magma-rich basins. The study offers valuable insights into the Browse Basin, providing lessons and implications for future petroleum exploration, field development, and the feasibility of carbon capture and storage in this region.

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**RF22M02 University of Melbourne, MSc student Tom McNamara (supervisor Dr Mark McLean).**

*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.*

Stawell Gold Mine extracts ore from mineralised zones along the flanks of the metamorphosed, structurally buttressed metabasaltic Magdala Dome, an uptorn megaclast about 4 km long and 1 km across sitting in a tectonic melange. The competency contrast between the Magdala Volcanics metabasalt and the surrounding metaturbidite that makes up the Moornambool Metamorphic Complex controlled the local faulting and shear planes during Victoria's orogenic history, allowing for extensive and repeated mineralising fluid mobilisation along the flanks of the dome. There's also a significant density and magnetic susceptibility contrast between the metabasalt and the metaturbidites that make potential field methods an ideal vector for imaging buried portions of the structure.

A set of potential field anomalies analogous to Magdala occur along-strike within the structural trend of the Stawell Corridor, where the Murray Basin sedimentary cover obscures outcrop and geochemical pathfinders (**Figure 1**). A handful of the anomalies have been confirmed by drilling to be metabasalts with gold intervals at prospective grades. The Wildwood and Lubeck dome targets fall within the North Stawell Minerals tenement, where an AGG survey was acquired in 2021 to better target the structures. Lateral boundaries for Wildwood and Lubeck are well imaged by the AGG, but their cross-sectional geometries are largely unconstrained by direct drillhole intersections. On the other hand, the geometry and structural style of Magdala has been thoroughly constrained by mine mapping and drilling, but was only covered by sparse gravity measurements.

For this project, we collected ground gravity measurements in profiles across the Magdala, Wildwood and Lubeck domes to get a comparable dataset for forward modelling their geometries according to their potential field signals, at enough resolution and sensitivity to attempt to resolve the buttress structures on the dome surfaces that controlled fluid flow and mineralisation. The profiles were planned with variable station spacing, up to 25 m apart at the crests of the domes to target the fine-scale structures, and down to 100 m apart beyond the flanks of the domes to ascertain the regional trend. A total of 397 new gravity measurements were taken spanning 16 km.

The gravity profiles were forward modelled in 2D cross-sections, together with TMI data extracted from a Geological Survey of Victoria regional compilation. A section extracted from the existing mine model at Magdala was tested against the observed gravity, and while it matched the character of the main Magdala Dome anomaly, there were complexities in the signal that were unaccounted for. Incorporating surface drilling and mapping constraints, the profiles were forward modelled to account for the unanticipated anomalies. Results for each profile suggested that metabasaltic clasts may be distributed throughout the Moornambool Metamorphic Complex more widely, more frequently, and across a greater range of scales than expected. An example from the Magdala forward model is included in **Figure 2**.

The quality and coverage of the AGG data supplied by North Stawell Minerals allowed for an additional opportunity to test a machine learning model that would carry the learnings from forward modelling into a regional potential field-based predictive targeting model. The forward models were used to map the constrained dome extents, which were then used to label segments from gravity and magnetic lines as dome target signals for a training dataset. The gravity and magnetic signals were each fed to neural networks to train it on the signal, then the trained networks were applied to a set of potential field lines spatially separated from the training set.

The approach was first tested within the North Stawell Minerals tenement, taking advantage of the quality and coverage of the AGG survey data. After training the neural network on the northern or southern half of the data then testing it on the withheld half, the gravity and magnetic neural nets were each able to reliably identify, with spatial coherence, the anomalies that correlated to the dome structures. The model was then generalised to the broader Stawell Corridor using the 2019 National Compiled Gravity Grid 1VD instead of the AGG data. Neural nets for gravity and magnetics were trained on a labelled dataset in the North Stawell Minerals study area, which was extended to include Magdala and the Stawell Granite, then tasked to classify the new unlabelled data along the rest of the corridor. Outputs from the gravity and magnetic neural nets were composited to form a combined predictive potential field targeting model. The model successfully predicts the location of the Kewell Dome target, which lies 40 km northwest of Magdala, outside the extent of the training dataset. It also highlights some other areas of interest, including targets with a similar character to Kewell further beneath the Murray Basin to the east of Lake Hindmarsh, and highlights signals beneath the Newer Volcanics at Mortlake. The composited model results and some highlighted areas are included in **Figure 3**.

The model represents a method of quantifying the potential field interpretation process. The results are highly dependent on the quality of the training dataset, both in terms of the resolution of the input data and the accuracy with which the input data was interpreted. As such it's very important to have a thorough understanding of the training area, as was the goal with the characterisation of the dome targets in the forward modelling. However, with the machine learning-driven approach, a thorough exploration model of a small

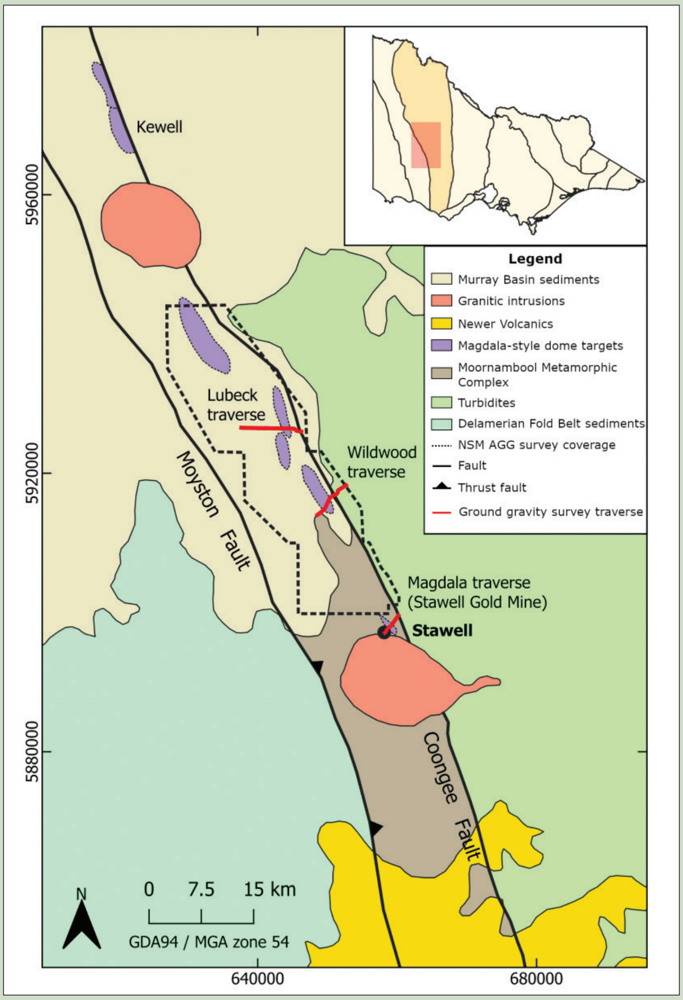


**Figure 1.** *Stawell Corridor study locality and geological map.*

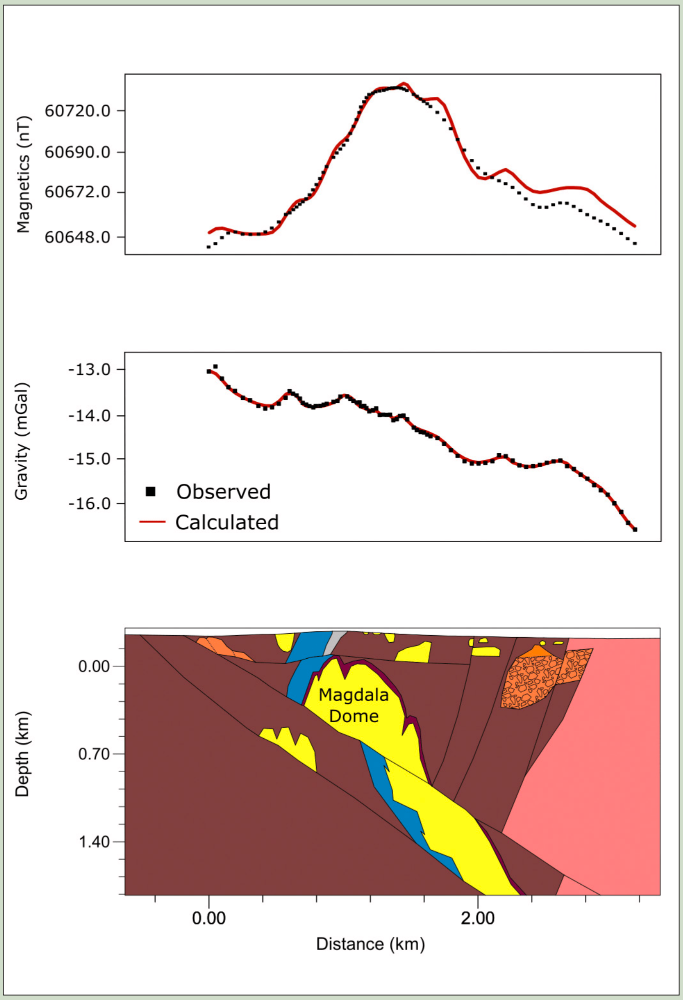


**Figure 2.** *Magdala ground gravity survey profile model.*

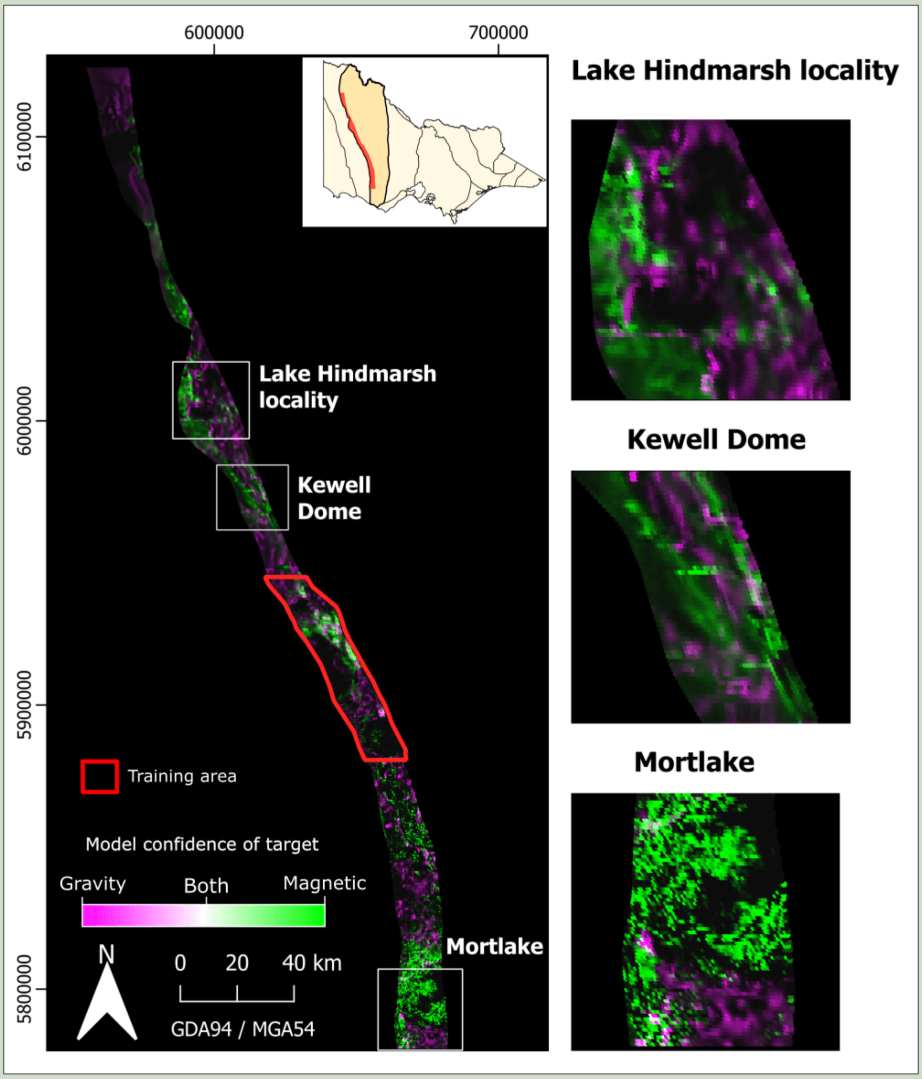


**Figure 3.** *Neural network predictive dome potential.*

area can be expanded to a regional scale rapidly, and at a low computational cost. The model can be used as a quantitative basis for potential field confidence as an element of a mineralisation potential model, for example, by compositing additional data about structural features and mineral occurrences.

This project was finalised as a masters thesis and submitted at the end 2023. The research has also been presented at AEGC 23 with the support of the ASEG research grant, and as a poster at the AIG OREAS Victorian Minerals Roundup. It's been a great project to see me through my post-graduate study, and I'm grateful to the ASEG for funding the project with a research grant, my project supervisor Mark McLean, North Stawell Minerals and Bill Reid for approving and supporting the fieldwork and modelling, and Mark Grujic from Datarock for mentoring the machine learning component.

**RF22E01 RMIT University, PhD Student Matthew Auld (Supervisor Dr Gail Iles)**

In-situ *physical property measurements with a novel multispectral, multistatic ground penetrating radar.*

## Summary

Matthew is investigating the required methodology to extract meaningful physical properties from Ground and Lunar Penetrating Radar surveys. The project utilises ultra-sensitive magnetic radar (MAPRad) sensors and transmitters developed at RMIT University, small enough to be installed on autonomous rover platforms. With the use of multispectral, multi-static data, the project aims to deliver software for survey geometrical design and the extraction of accurate layer radar wave velocity, attenuation and thickness.

## Progress in 2023

### *Technical*

Over the past year, 50% of workload has been dedicated to making instrumentational improvements to the MAPRad device. The antenna design has been modified, with the number of coil turns around the magnetic core being kept the same, while changing the core length has been experimented with to determine how large an effect this has on the radar's overall performance. This was briefly tested during a field test in the You Yangs, Victoria, but needs to be looked at further.

While the magnetic antenna itself has undergone minimal modifications, the electronics that the antenna feed into have undergone significant changes. The receiver antenna amplifier has been the focus of the project work, updating a previous amplifier schematic to use a four-stage amplification process before being fed through to the receiver for capture. The design consists of two channels, to provide differential signal amplification, with each channel containing four stages of approximately 15.8 dB of gain for a total of 63.2 dB gain across the entire amplifier board in each channel. Much consideration has been given to oscillations within the board and noise pickup from external sources, as such shielding and appropriate circuit design has been added to the circuit board to isolate and protect each channel from rogue signals. The PCB has gone through two major design changes thus far, as a result of initial lab testing before the current design. The software Altium is being used for designing the amplifier (**Figure 1a**) and the actual PCB has already been printed (**Figure 1b**).

The manufactured amplifier has been tested in a lab setting to verify operation across the designed range of frequencies, up to 30 MHz. Gain and phase linearity of the amplifier have been measured and has shown that the amplifier operates well within the lab and operating conditions. Real world testing is planned for the next few months to determine if the new amplifier is performing as expected when used in tandem with the other components of the system in the field.

### *Training*

In September 2022, Matthew attended The Camp for Applied Geophysics Excellence (CAGE) which provided insight into various geophysics processes. In 2023, ~30% of the year has been spent applying aspects of what was learnt from this trip in the processing of two field tests, one to the You Yangs national park and the other to a landfill site in Ballarat. These field surveys involved the collection of magnetic and electric field sets of ground penetrating radar data which have been processed in attempts to show subsurface features in each field dataset. Both field datasets have also been used in attempts to determine the viability of using a combination of fields can be used to find the conductivity of the subsurface materials, as opposed to estimating the dielectric constant from electric field data alone. So far this has been unsuccessful, but future surveys are planned to collect more appropriate and specific data to work towards this aspect.

### *Dissemination*

The remaining 20% of the year has been spent on disseminating scientific results from the PhD to the wider community. Matthew delivered two presentations at international conferences this year, the first on interference simulation of the antenna with a model rover body (Auld *et al*., 2023), and the second on collating lunar orbiter radar data to generate a map of potential lava tube sites in the south pole region of the moon (Tomas, 2023) that may be targeted by a rover mounted lunar penetrating rover.

### *Publications*

In 2022 Matthew undertook an extensive field trip in Queensland to use MAPRad to map the Undara lava tubes (Auld *et al*., 2022) (**Figure 2**). In 2024, we are preparing a manuscript describing the work undertaken during this field trip Auld *et al*., 2024.

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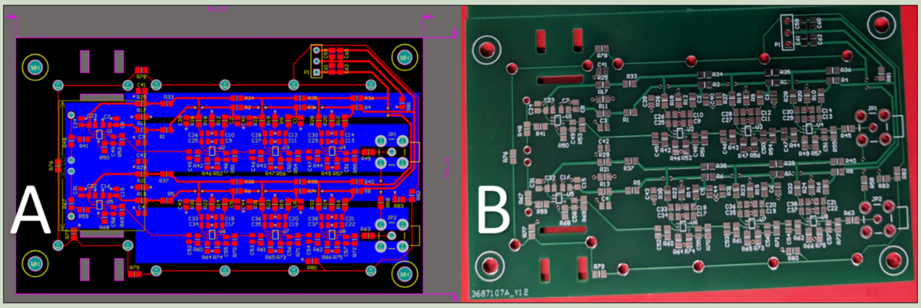


**Figure 1.** *MAPRad PCB design of receiver antenna amplifier. (a) Altium design (b) receiver amplifier.*

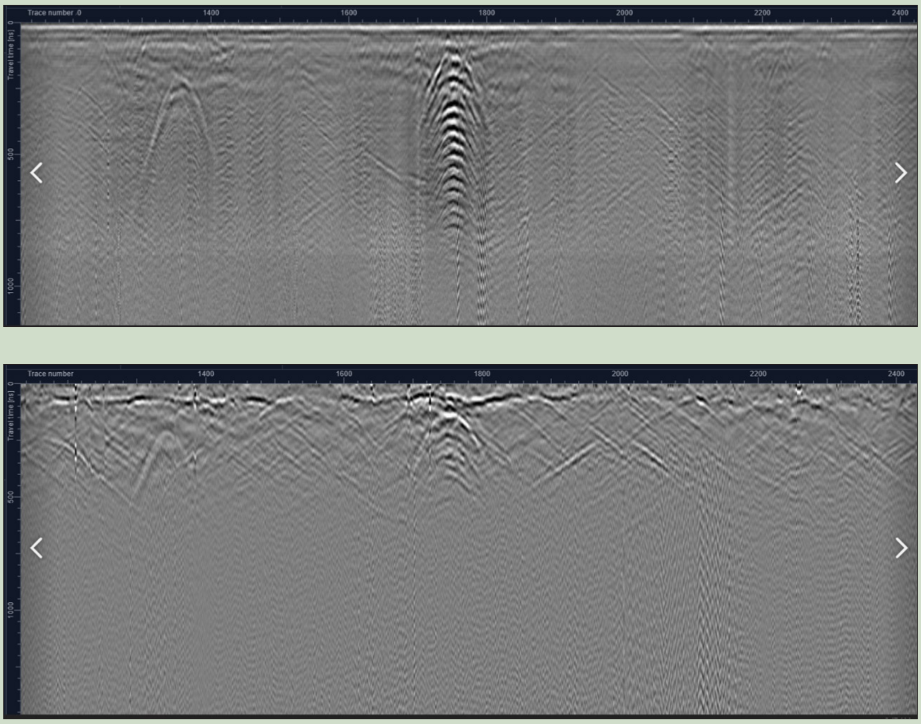

**Figure 2.** *GPR data collected at Undara National Park, Queensland with both electrical (top) and magnetic (bottom) data indicating the presence of an uncollapsed section of a lava tube.*

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### **RF23M01** University of WA, MSc Student Abhijit Kurup (Supervisor Prof Mike Dentith)

*Understanding magnetic responses in high-grade gneiss terrains in the Southwest Yilgarn Craton, Western Australia.*

This study involved the interpretation of high-resolution aeromagnetic data from the southwest Yilgarn Craton, a region recognised for its mineral prospectivity, by integration with magnetic susceptibility (MS), petrography and biotite geochemistry data. The study area is the amphibolite-granulite facies granite-gneiss dominant domain 2 of the Youanmi Terrane. Geology and MS data collection was made on the limited outcrops that are available. The aeromagnetic data was used to extrapolate the bedrock geology interpretation to parts of the area without outcrop.

Field work, MS data and the study of the Fe-Ti oxide minerals allowed the classification of the local granitoids based on oxygen fugacity as either oxidized magnetite-series granites or 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. The two classifications show good correlation and the four broad lithologies are recognised: 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 (sometimes up to a 100) per outcrop for reliable MS averages. In the monzogranite gneiss, MS is observed to increase in the mafic mineral rich melanosome layers when compared to the quartz-feldspathic leucosome, even though no significant difference in the distribution of magnetite was observed. In some regions the porphyritic monzogranite shows bimodality in MS, while in other regions it shows strongly ferromagnetic character, with thin sections showing an increased degree of martitisation of magnetite to hematite with decrease in magnetic susceptibility. The syenogranite shows a wide range in MS, which can be explained by the presence of unevenly distributed coarse grains of magnetite (possibly secondary).

The aeromagnetic data was processed to create a series of products: reduced to pole (RTP) total magnetic intensity (TMI), upward continuation (UC) and residual of UC and RTP at a series of depths, the 1st and 2nd vertical derivatives and the tilt derivative. The interpretation of the magnetic data involved combining the TMI products with satellite imagery, regional geology maps and all the data from the fieldwork. The orientation and geometries of several NE-SW trending faults, a N-S regional shear, E-W and NE-SW mafic dikes and lithological contacts have been delineated using the derivative products (**Figure 1 (b-c)**). Magnetic intensity and texture of anomalies in the RTP and residual of UC and RTP were used to map the four outcropping granitoid lithologies and an inferred mafic gneiss unit associated with intense magnetic highs predominantly present along major structures within the monzogranite and monzogranite gneiss (**Figure 1(c)**). The importance of field geological evidence to ground truth a geophysical interpretation was demonstrated with three major changes proposed to the published regional bedrock geology map of the area: (1) Change of a metamorphosed siliciclastic sedimentary unit to an ilmenite series reduced monzogranite, (2) Change of a tonalite-trondhjemite-granodiorite unit to a syenogranite and (3) Extension of the mafic gneiss along structures into the west of the area. All the regions of low magnetic intensity had previously been classified as a metasedimentary unit, which through ground-truthing has been disproved in this study. The low magnetic signature of these regions is due to an ilmenite series granite, as supported by the MS data (**Figure 1(a), Site 3**), absence of magnetite in thin sections and a presence of biotites characterised by high FeO, $Al_2O_3$ and low MgO composition. The magnetic responses in this area have been identified to primarily be controlled by different oxygen fugacity conditions giving rise to the two types of granites along with some local effects of weathering and alteration.

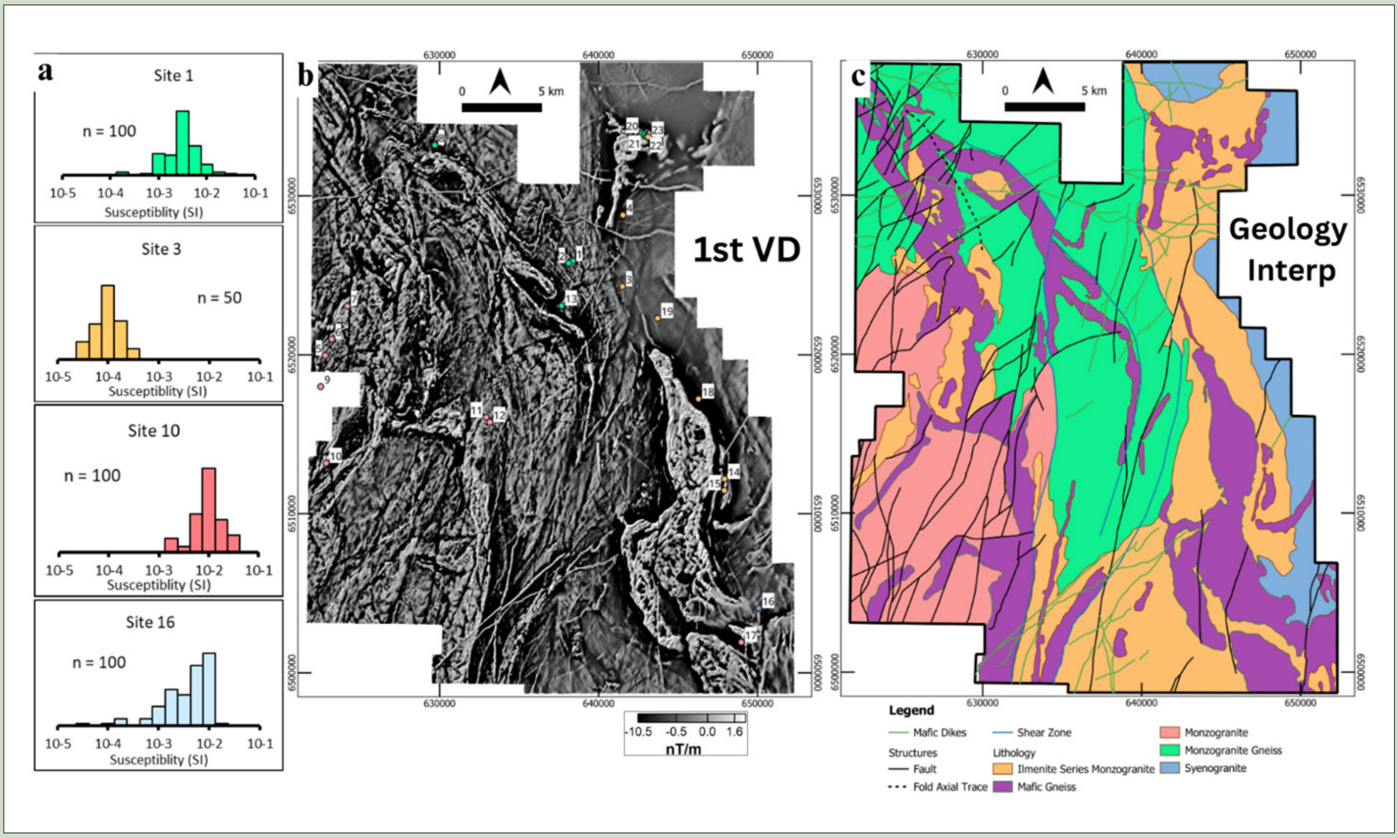



**Figure 1.** *(a) Magnetic susceptibility frequency histograms, (b) grey scale image of the 1st vertical derivative of the RTP-TMI and (c) the interpreted bedrock geology of the area.*

The MS, petrography and biotite chemistry data is a proxy for redox conditions of the granitic magmas which provides information pertaining to the source regions and economic mineral fertility of different granitoids.

**RF23P01 University of Adelaide, PhD Student Iain Campbell (Supervisor Prof Simon Holford)**

*Geophysical-geomechanical constraints on the operating limits for basin-scale $CO_2$ storage.*

Carbon capture and storage (CCS) is a critical component of pathways to limit global warming, but considerable upscaling is needed to meet Net Zero 2050 targets, including the identification of many new $CO_2$ storage reservoirs. Identifying favourable geomechanical conditions to avoid reservoir and seal deformation presents a key challenge in the selection and de-risking of safe and effective CCS sites, though the requisite geomechanical data and constraints on the presence and nature of faults and fractures are often scarce. This ASEG Research Foundation supported PhD research project will elucidate the technical and commercial viability of $CO_2$ storage in Australia's Cooper-Eromanga basins, which have the potential to be a world-leading CCS hub. There is a surprising lack of consensus as to the tectonic origin of this basin system, and limited data on the distribution and properties of faults, in part due to the spatially restricted focus of existing fault mapping and to difficulties in imaging basement-involved faults. The latter is particularly important for CCS, as fluid injection into supra-basement aquifers in the US has resulted in the largest induced earthquakes. The lack of an integrated structural framework for the Cooper-Eromanga basin means that the degree to both shallow and deep reservoirs that might be targets for $CO_2$ storage are in pressure communication with both over pressured sequences at depth, and potentially active faults in the basement beneath the basin, is a fundamental knowledge gap. This project will take advantage of the new Cooper Basin 2D$^{cubed}$ dataset, where the complete catalogue of seismic reflection data from the South Australian Cooper-Eromanga Basin has been reprocessed to generate pre-stack time and depth-migrated pseudo-3D volumes. The project will apply a consistent fault mapping approach to this dataset, and to available 2D and 3D data from Queensland, supported by regional potential field (gravity, magnetic) datasets, resulting in a whole-basin fault-framework from which reactivation potential can be elucidated through geomechanical modelling, whilst also maximising the broader resource (e.g. natural gas, geothermal, natural hydrogen) potential of the basin.

# ASEG Honours and Awards: Nominations close 3 September 2024

In 2024 the ASEG Awards ceremony will be held alongside the DISCOVER conference in Hobart 15-18 October 2024. The Awards Committee welcome all nominations and we rely on you to nominate people you consider deserving of these awards which include:

**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. Doug 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).

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**

The Honours and Awards Committee do not nominate people for awards, you do. I encourage you and your network to nominate someone you think is worthy of an award. The Honours and Awards Committee are here to help. If you have any questions don't hesitate to contact me.

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***
**E** **awards@aseg.org.au**

**NOMINATIONS CLOSE 3 SEPTEMBER 2024**

## 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.*

# ASEG branch news

## Western Australia

ASEG-WA Branch held its Annual General Meeting on 23 November 2023. Our President, **Michel Nzikou**, presented an overview of the Branch's activities in 2023. In summary, the Branch held eleven technical events, six social events, and four outreach events.

Michel stated that the Branch's goals moving forward would include:

- Continuing to raise awareness of geophysics
- Actively engaging with other branches
- Engaging with more women in industry, especially for future Tech nights.

Other Committee members also presented summaries. It was reported that membership of the WA Branch had steadily increased during the year to the current total of 273 Members. This is approximately the same membership total as at the end of 2022. The use of the Mailchimp service to manage the Branch's communications with Members was considered be a success, and this service will continue to be used to broadcast Branch activities in 2024.

Michel thanked departing Committee members: **Aruni Rajanayake**, **Michelle Thomas**, **Joseph Behan** and **Helen Anderson,** and called for nominations for all vacant positions. **Peter McMullen** volunteered to replace Joseph Behan as Treasurer, and **Teagan Blaikie** was named as the Chair of MAG 24.

The WA Branch's Christmas party was held on 6 December 2023 at the Leederville Sporting Club, a now well-established tradition. The party was well attended.

***Emad Hemyari***
***WA Branch Communications Officer***

**E** emad.hemyari@gmail.com

*The WA Branch Christmas party.*

*Barefoot bowling at the WA Branch Christmas party.*

## Australian Capital Territory

On 30 November 2023, two new colleagues from Geoscience Australia talked about their journey in geophysics. **Roger Miller** specialises in shallow geophysics utilising a combination of gravity gradiometry (FTG and FALCON), gravity, magnetic, marine CSEM/MT, seismic, airborne TDEM and well log data. He shared his experience in the interpretation and integration of multiple geophysical, geological and supplementary datasets. **Ravin Deo** comes from academia and has worked in Fiji and Australia. He has experience in numerical modelling and developing instrumentation and sensors for measurement and assessment and has strong expertise in geophysical systems for practical near-surface applications.

After the talks, ACT Members and friends participated in a Christmas dinner to celebrate the geophysical achievements of the year.

And, in 2024, don't forget the about Geoscience Australia's Wednesday seminars (https://www.ga.gov.au/news-events/events/public-talks). These seminars are a good source of geoscientific information that includes the use of geophysics.

***Wenping Jiang***

**E** actpresident@aseg.org.au

## New South Wales

Happy New Year to all Members of the NSW Branch!

After **Peigen Luo's** talk (entitled "Continental fragment collision in subduction and the dramatic uplift acceleration in the eastern Anatolian Region") in October 2023, we successfully hosted the Annual Dinner for the NSW Branch at The Harbour View Hotel, The Rocks. More than 20 people attended this event, which was held on 29 November. It was a wonderful opportunity to celebrate our achievements throughout the year and to raise a toast to an even more fruitful 2024.

Our first Technical talk in 2024 will be given by **Sarath Patabendigedara** (CSIRO Minerals) and will take place at Club York on 21 February.

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.

*Harikrishnan Nalinakumar*

**E** nswsecretary@aseg.org.au

## Queensland

The Queensland Branch welcomed **Dr Gerrit Olivier** from *Fleet Space* on 13 November to give the inaugural ASEG Discover lecture on "Ambient Noise Tomography – a new geophysical tool for mineral exploration". The ASEG Discover Lectures are a new lecture series where technical experts will travel Australia proselytising at local branches, so for those of you interstate, look out for Gerrit's excellent presentation, which is coming your way soon!

As detailed in last month's update the latest meeting was held at the recently refurbished (and renamed) Club Yeronga (formerly the Yeronga RSL). The land the RSL occupies was donated by Alfred Rigby who had five children who served in WW1/WW2 and his daughter was a major backer of the avenue of memorial trees in Yeronga Memorial Park. In recognition the Rigby family have a small riverside park in Yeronga named after them, close to the site of the former Rhyndarra military hospital. More recently, Yeronga has gained fame as the suburb where a burnt human body was found on a vacant block, an event that the police did not consider to be suspicious.

In December the unthinkable happened, and the Branch returned to Club Yeronga for the Christmas Party. An excellent event only marred by the failure of your correspondent to photographically record Queensland President (and ex-Pink Floyd roadie) Nick Josephs' presence as per his contract, and the absence of **Shaun Strong**.

Coming up… we have several excellent presenters lined up along with what will undoubtedly be some highly entertaining social events. The first of which is the latest Brisbane Brews at Fick Brewing North Gate on 2 February. For those who aren't lucky enough to live in Brisbane but do have the good fortune to be passing through, please let us know if you've got anything interesting to share, or are just looking for an evening out.

*Tim Dean*

**E** qldsecretary@aseg.org.au

*Gerrit Olivier's warm-up act, Queensland President (and third Winklevoss twin) Nick Josephs, speaks ahead of the former's presentation on Ambient Noise Tomography.*

*Eternally joyful Queensland President (and YouTube Red Diamond award holder) Nick Josephs rewards Gerrit Olivier for his excellent presentation with the customary bottle of wine (not forgotten in his car this time…).*

*Photos from the Queensland Branch Christmas party.*

## Branch news

### South Australia and Northern Territory

Happy New Year to all SA-NT Branch Members!

After the very successful Melbourne Cup Luncheon in November 2023, and the well-received ASEG wine offer, the SA-NT Branch is proud to be hosting **Dr Andrew Fitzpatrick** from IGO, giving a fantastic talk titled "Modern use of electromagnetics in Nickel exploration" for a technical talk in February 2024.

We also have the SEG Distinguished Instructor Short Course by **Phil Ringrose** in Adelade this February, focusing on "Storage of carbon dioxide in saline aquifers". This should be an excellent and informative course and I would encourage as many of our Members as possible to attend.

We have exciting plans in the pipeline for the year ahead, so keep your eyes out for notices of future events in the coming weeks.

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

***Paul Soeffky***

**E** 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***

**E** taspresident@aseg.org.au

### Victoria

Greetings and welcome to whoever you are. I hope you've had a fantastic start to the year. I want to kick-off by giving a shout-out to our unwavering (paid-up) Members. Without your support, I would not have been able to give myself a rare case of Macallan's finest 25-year-old single-malt scotch whisky as a parting gift. For those that have not renewed their ASEG membership for 2024, I have only one thing to say to you (edited from the movie *Taken*):

> *"I don't know who you are. I don't know what you want. If you are looking for ransom, I can tell you I don't have money, but what I do have are a very particular set of skills. Skills I have acquired over a very long career. Skills that make me a nightmare for people like you. If you promise to renew your membership after reading this, that will be the end of it. I will not look for you, I will not pursue you, but if you don't, I will look for you, I will find you and I will kill you."*

Well, I won't actually kill you. Not without further cause, anyway ☺. In fact, I probably won't even bother to go looking for you. But know this, "the times they are a changin" (Bob Dylan, you are a legend).

You can run but you can't hide. You see, I've found my replacement on the Victorian Branch Committee. He's young, and he's ready to play hide and seek with you… with his paintball gun. A few skirmishing rounds never hurt anyone, right?

Leading the charge is my nominee for Branch President, **Dr Mark McLean**, an accomplished structural geophysicist, a senior lecturer in applied geophysics at The University of Melbourne and an expert 3D modeller with the Geological Society of Victoria. He may seem a little shy, but he's brash and he's uninhibited. He's also quite a nice fella…and he's tall, too. Mark has assembled an elite supporting cast to help him eradicate the controversies, the damages and the disgrace that has become a blight on our good reputation during my dubious tenure. Out with the old and in with the new I say! It's probably easier to just simply torch everything I've stained, eh Mark?

The Committee anticipates holding an AGM in the not-too-distant future to coincide with an upcoming technical meeting night where Mark and other nominees to the committee will put forward their names for consideration and for voting by Members. Please keep an eye out for this notice.

Now, pay up on your damn membership fees, or I'll be forced to unleash hell. Disclaimer: I am a tragic cinephile because there's no way I get paid enough for this standover man gig.

Signing off for the very last time (again). Sayonara.

***Thong Huynh***

**E** vicpresident@aseg.org.au

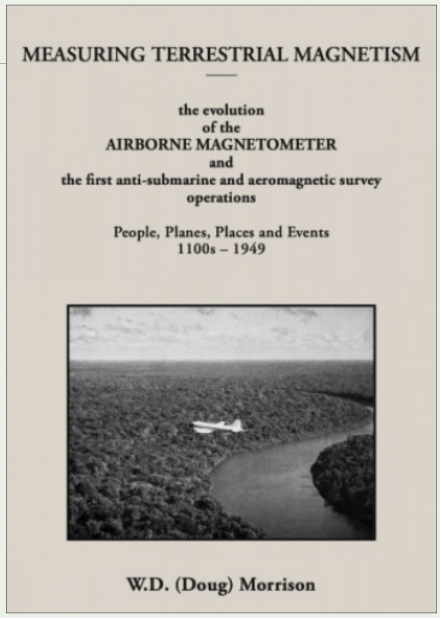
## ASEG national calendar

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/2ZNgIaZ**). Please monitor the Events page on the ASEG website for the latest information about events.

| Date | Branch | Event | Presenter | Time | Venue |
|---|---|---|---|---|---|
| 2 Feb | Qld | Brisbane Brews | TBA | 1700 | Fick Brewing, Northgate, Brisbane |
| 8 Feb | WA | Student/YP Networking night | TBA | 1730 | Mayfair Lane, 72 Outram Street West Perth |
| 8 Feb | SA-NT | SEG DISC | Phil Ringrose | 0800 | Ayre's House, 288 North Tce, Adelaide |
| 13 Feb | SA-NT | Technical talk | Dr Andrew Fitzpatrick | 1730 | Thomas Cooper Room, Coopers Alehouse, 316 Pulteney St, Adelaide |
| 21 Feb | NSW | Technical talk | Sarath Patabendigedara | 1800 | Level 2, Club York, 99 York St., Sydney |
| 30 Apr | National | AGM | TBA | TBA | TBA, Brisbane |

Australian Society of Exploration Geophysicists

1970-2020




## 50TH ANNIVERSARY SPECIAL PUBLICATION

# MEASURING TERRESTRIAL MAGNETISM

### the evolution of the AIRBORNE MAGNETOMETER and the first anti-submarine and aeromagnetic survey operations

### People, Planes, Places and Events 1100s – 1949

W.D. (Doug) Morrison

**This Special Publication is co-sponsored by Geoscience Australia and ASEG**

https://www.aseg.org.au/publications/book-shop

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

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

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

The story explores the inextricable cross-discipline connections of terrestrial magnetism and magnetometers as used for navigation, geodesy, anti-submarine and military purposes, and their role in the geophysical oil and mineral exploration industry. Organisations, people and specific instruments and aircraft are noted, including (at times coincidental) Australian connections.

The extraordinary depth and scope of research, over many decades, by the author W.D. (Doug) Morrison, as well as his collection of photos and illustrations, and his astonishing attention to detail, make this book an amazing and immersive historical reading experience and a future primary reference work. Through several decades Doug has developed an extensive 'reference' network of geophysical survey practitioners, and former experts in military, aviation and maritime matters. Through their little-known stories and personal reflections, and his access to personal and official archive material from this network, Doug's narrative brings unique insights into the evolution of the airborne magnetometer. Along that timeline he has produced details that are not available in public historical material.

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



ISBN978-0-6450691-0-5 (paperback)

https://www.aseg.org.au/publications/book-shop

# 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 also complete. Acquisition was along east–west lines spaced 200 m apart and north–south lines spaced 2 km apart.

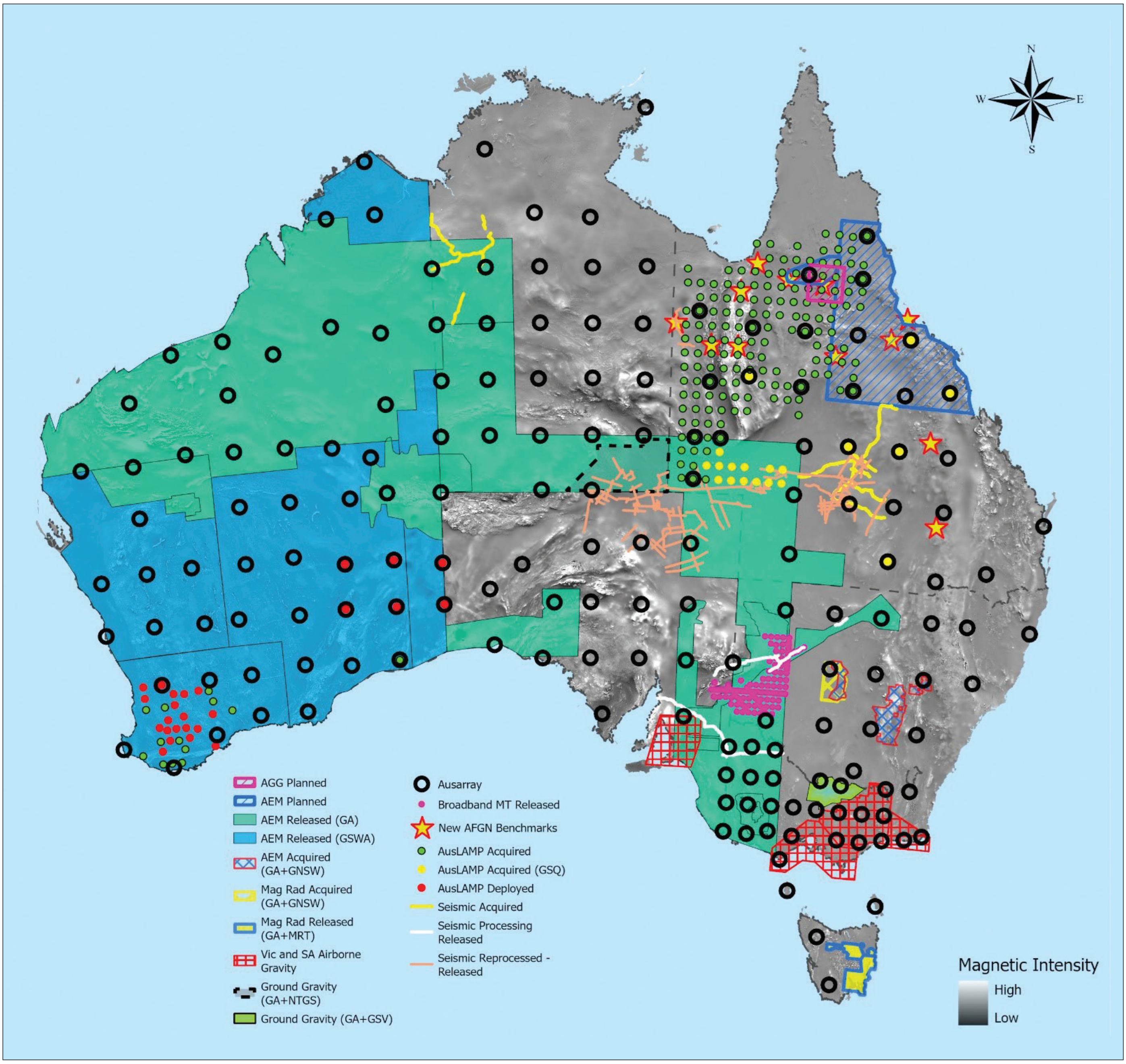



**Figure 1.** *2021-2024 geophysical surveys – in progress, released or for release by Geoscience Australia as part of EFTF, and in collaboration with State and Territory agencies. Projects that are partially or wholly funded by state government agencies are identified by the bracketed contributors. 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).*

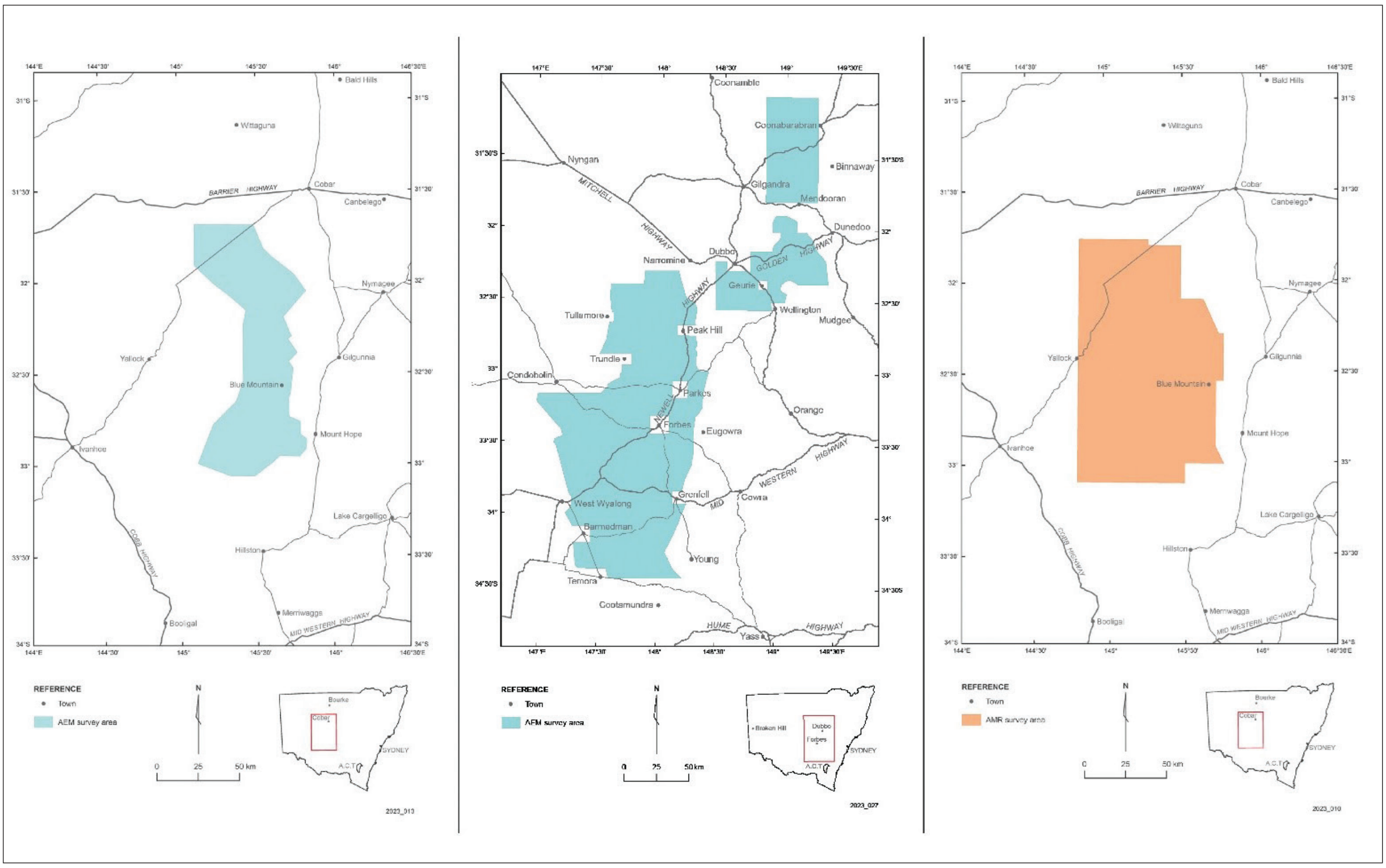



**Figure 2.** *Location of the Yathong (left) and Forbes-Dubbo (centre) AEM surveys, and the Yathong Airborne Magnetic and Radiometric Survey (right).*

These surveys are currently undergoing final quality assurance and quality control checks prior to a release of the data in the coming weeks. For more information about 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 final release, however, preliminary data is available via the Northern Territory's Resourcing the Territory website: https://resourcingtheterritory.nt.gov.au/news-and-events/news/2023/preliminary-gravity-data-available-from-ntgs-pedrika-basin-survey. For more information about 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, are nearing completion of acquisition of the Shepparton Numurkah ground gravity survey in central north Victoria. This survey is fully funded by the Government of Victoria and is infilling the existing ground gravity network at approximately 500m spacing along existing public roads and tracks. As part of this survey previous survey nodes and base stations have been included to assist merging the new gravity stations with existing gravity data. This survey is currently approaching 80% completion, with acquisition expected to continue into 2024.

For more information about this survey please contact Suzanne Haydon, Geophysicist – Geological Survey of Victoria at Suzanne.Haydon@ecodev.vic.gov.au.

## Central Australian basins 2D reprocessed seismic data package 2023

Geoscience Australia has released 2100 line-km of reprocessed 2D seismic data spanning parts of northeastern South Australia and southwestern Queensland. This extensive, newly reprocessed Central Australian Basins 2D seismic dataset was prepared under Australia's Future Energy Resources project.

The dataset, consisting of 33 mixed-source, multi-vintage legacy lines, underwent advanced seismic processing techniques to enhance seismic reflectors, delineate faults, attenuate noise, and optimise frequency content. The resulting dataset links several Palaeozoic and Mesozoic geological provinces, including the Pedirka and Warburton basins in the west, to the Cooper and Adavale basins in the east. These regional seismic transects provide new information on the stratigraphic relationships and structural architecture across a region known to host untapped potential for energy, minerals, and groundwater resources, as well as carbon dioxide and hydrogen storage opportunities.

For further information on the reprocessed Central Australian basins seismic data release and the Australia's Future Energy Resources project, please contact Tom Bernecker, Director of Energy Resources Advice & Promotion– Geoscience Australia, at Tom.Bernecker@ga.gov.au

## Adavale Basin 2D reprocessed seismic data package 2023

The Australian Government's Data Driven Discoveries project, being delivered by Geoscience Australia, has reprocessed 57 selected multi-era legacy seismic lines, totalling approximately 2356 line-km across the Adavale Basin, south-central Queensland. Reprocessing of legacy seismic data from the Adavale Basin aims to create a modern, consistent and integrated seismic dataset that provides new insights into the geological structure of the basin and deepens our understanding of the basin's minerals, energy, underground storage and groundwater potential.

The Adavale Basin 2D Reprocessed Seismic Data Package ties into 5 wells that were previously sampled for chemostratigraphic analysis through the Data Driven Discoveries project (Riley *et al*., 2023), including Allendale 1, Boree 1, Gilmore 1, Quilberry 1 and Stafford 1. The reprocessed seismic lines complement new deep crustal seismic data acquired and currently being processed in the Adavale Basin by the program and ties into the Central Australian Basins 2D seismic dataset recently published by Geoscience Australia.

The reprocessing workflow prioritised enhancing the image quality of the selected legacy seismic lines, reducing noise, and fine-tuning frequency content for specific target depths. Techniques employed included creating a 3D static model, applying noise attenuation methods, surface-consistent deconvolution, and constructing an accurate velocity model to optimise pre-stack time and depth migration.

For further information on the Data Driven Discoveries project, or the Adavale Basin Reprocessed 2D Seismic Data Package, please contact Mitchell Bouma, Director of Strategic Basins – Geoscience Australia, at Mitchell.Bouma@ga.gov.au.

***Adam Bailey***
***Geoscience Australia***
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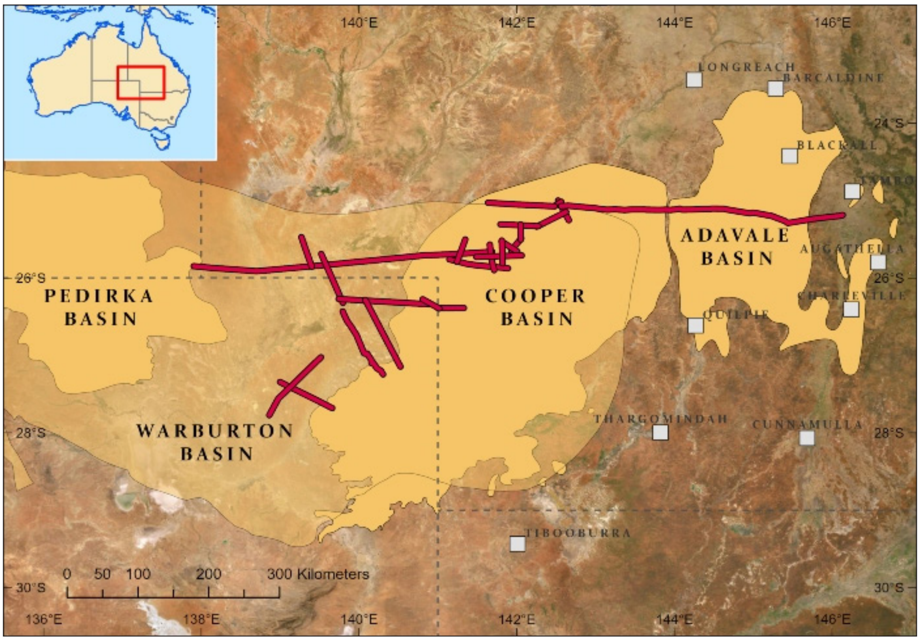


**Figure 3.** *Modern seismic processing techniques were applied to 33 selected multi-vintage legacy lines covering parts of northeastern South Australia and southwestern Queensland.*

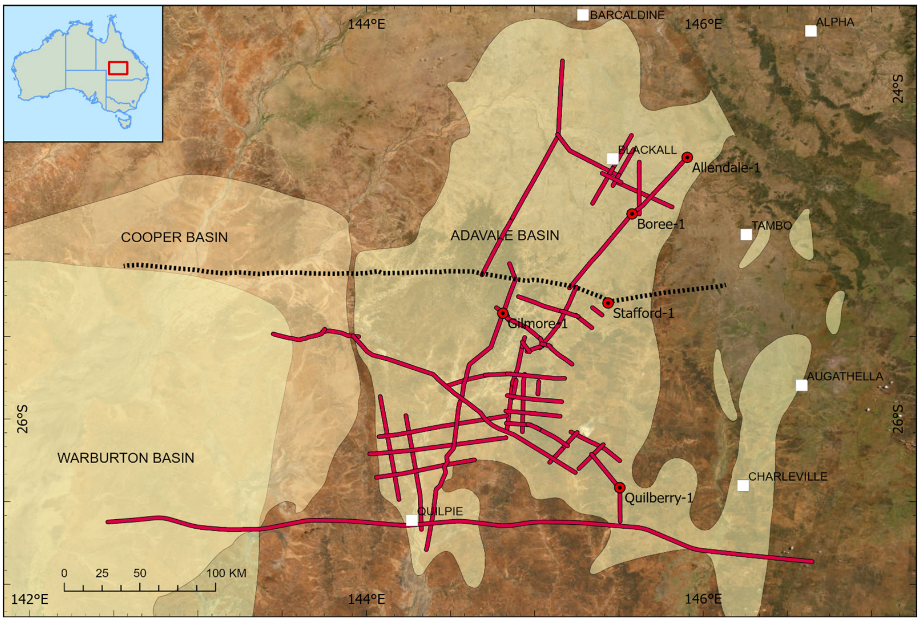


**Figure 4.** *Modern seismic processing techniques were applied to 57 selected multi-vintage legacy lines covering the Adavale Basin. Reprocessed lines are shown in red. The dashed line from the adjacent Central basins reprocessing project (Figure 3) is shown for reference.*

# 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 5 February 2024)

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<br>Terrain clearance<br>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<br>GSV<br>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<br>E Block: 18 Jul 2018 | 52 090 | 2500 m | 129 400 | W Block: 3 Jun 2018<br>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<br>GVD: 22 Jul 2018 | 62 500 | 2500 m | 153 300 | Warb: 31 Jul 2018<br>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 Northern Australia model: http://pid.geoscience.gov.au/dataset/ga/145233 Data acquired 2020-23. Queensland model update and data release: https://dx.doi.org/10.26186/148633 Queensland time series data release: https://dx.doi.org/10.26186/148978 |
| 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 6 sites remaining to be acquired or reacquired. Phase 1 data release: http://dx.doi.org/10.11636/Record.2020.011 Phase 1 time series data release: https://dx.doi.org/10.26186/148544 |
| 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 extends 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 | 19 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 raw and processed 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. The objective was to produce a modern industry standard 2D land seismic reflection dataset to assist in imaging the subsurface. Reprocessing of the legacy data is complete and the data package is available for download at https://pid.geoscience.gov.au/dataset/ga/148931. |

*(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.<br>See: http://www.ga.gov.au/eftf/minerals/nawa/ausarray<br>Various applications of AusArray data are described in the following Exploring for the Future extended abstracts:<br>• AusArray overview: http://pid.geoscience.gov.au/dataset/ga/135284<br>• Body wave tomography: http://pid.geoscience.gov.au/dataset/ga/134501<br>• 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<br>• 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 New South Wales: Largest geophysical survey data release in NSW

The Geological Survey of New South Wales (GSNSW), as part of Mining, Exploration and Geoscience Division of the Department of Regional NSW, completed six geophysical surveys between 2022 and 2023, totalling about $6 million, and covering a sixth of the state with new geophysical data (**Figure 1**). The data acquired supports numerous projects:

- Exploration in NSW for critical minerals and high-tech metals. GSNSW has acquired geophysical data around Cobar, Forbes to Dubbo and in the New England Orogen as these areas are highly prospective for critical minerals and high-tech metals and where improved geophysics will aid mineral discovery.
- NSW Government's Drought Proofing Project. GSNSW has been searching for deep groundwater for use in times of drought. Our programme focuses on Devonian sandstones in the Bancannia and Yathong troughs and small Devonian basins in the greater Dubbo to Forbes region.
- MinEx Collaborative Research Centre (CRC), which is working to improve exploration in mineralised terrain under cover. GSNSW will acquire geophysical data over the greater Forbes to Dubbo region and around Cobar to support mapping and drilling as part of MinEx CRC.
- Our ongoing mission is to provide precompetitive geophysical data, to encourage mineral exploration. You can access all our open-file geophysical data through MinView – the link has all geophysical data layers pre-loaded.

GSNSW collaborated with Geoscience Australia to acquire many of the surveys. Airborne electromagnetic (AEM) data was acquired at 2.5 km line spacing. The data is available for download and there will be 3D sections (curtains) available for viewing in MinView from February 2024.

The Yathong airborne magnetic and radiometric survey used a gradient magnetic system to better resolve the faint magnetic anomalies in Western NSW. These data will be merged into the latest statewide images. The magnetic image is due for release in May 2024 and the radiometric image in May 2025.

The NSW Department of Customer Service – Spatial Services has acquired airborne gravity over the entire state of NSW at 2.5 km spacing to improve the NSW geodetic model. GSNSW collaborated with DCS-SS to infill coverage over the New England Orogen to 1.25 km spacing. These data will be publicly available in June 2024 and merged into the statewide gravity image which will be release in the second half of 2024.

GSNSW also completed a hybrid shallow and deep-crustal reflection seismic survey over approximately 500 km of roads and tracks around Cobar. This data will be released in February 2024.

Please use MinView to download and view our publicly released data.

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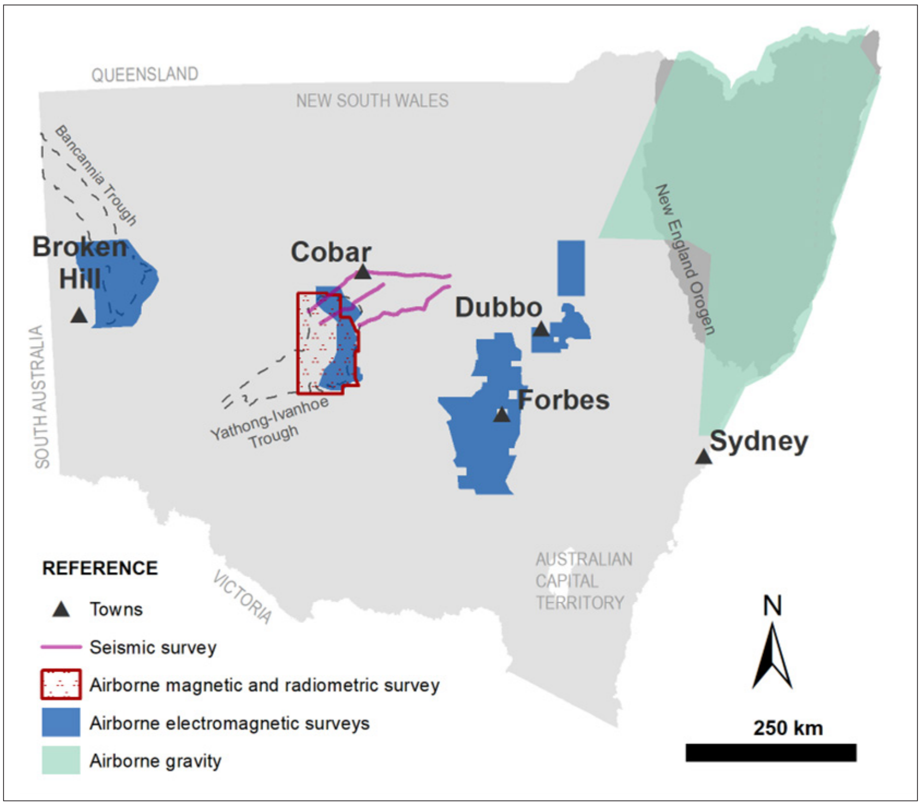


**Figure 1.** *Map of geophysical surveys completed in 2022 to 2023.*

# Geological Survey of South Australia: A DEM restructure and a brief mineral geophysics update

## DEM restructure

The Premier of South Australia recently delivered an economic statement, highlighting the Hydrogen and Renewable Energy Act, SA's world-leading renewable energy resources, and SA's mineral resources as key components of the green transition. The South Australian Department for Energy and Mining (DEM) recognised that to continue delivering on key strategic priorities for the state, the Department needs to operate differently. DEM needs to allocate internal resources to deliver high quality outcomes while concurrently responding to ongoing budget savings challenges facing the department and other agencies. DEM has therefore undergone a major restructure, reorganising its previous five divisions into three: Regulation & Compliance, Strategic Policy & Delivery, and Corporate & Commercial. The Geological Survey of South Australia (GSSA) is housed in the Strategic Policy & Delivery Division.

As part of the restructure, the previous GSSA and Energy Resources Division have joined forces. The new business unit retains the name Geological Survey of South Australia and combines teams of geoscience specialists and industry regulators. Especially relevant to the ASEG, there is a new dedicated geophysics team. The new team – named Petroleum & Geophysics Data – combines the professional officers in the minerals geophysics space (primarily dealing with statewide gravity, magnetic, radiometric, EM and MT data) with the professional officers and industry regulators responsible for seismic data analysis and storage, as well as petrophysics database experts and a drill-core specialist.

For the geophysics team, it's largely business as usual. All the familiar faces are still here, and we're still managing the same data and work programmes as prior to the restructure. We still QA/QC and load both mineral and petroleum geophysical data onto our databases, manage the databases, produce statewide imagery, assist with and provide advice to industry where we can, and ensure data are available through SARIG.

## Mineral geophysics update

At the time of writing, an audit of all gravity surveys in South Australia is complete. Surveys that were not loaded into the gravity module have now been loaded, and work is now commencing on a new statewide gravity grid. A grand total of 1 226 684 stations now exist on the database. Compared to the 909 328 stations at this time last year, it is a significant increase. By the time this article is published the gravity stations layer on SARIG should have updated, showing the position and details of 1 111 522 public domain gravity measurements. The new state grid will likely be another few months away. As in previous years, we will be employing the supervised variable density gridding methodology to create the seamless image.

Additionally, the entire collection of airborne geophysical data stored on DEM's network was revised and updated, with airborne survey data now available in a wider variety of data formats. The recent update includes new datum and projection fields added to datasets, notably GDA2020 and Lambert projections. Individual survey packages are available via SARIG and Geonet. Surveys can be found spatially in SARIG or can be found via keyword by the Geonet tool (the "SARIG catalogue" link at the top of the SARIG map page).

As always, questions and requests for assistance with data can be directed to DEM.CustomerServices@sa.gov.au, and there are some other contact options at https://www.energymining.sa.gov.au/home/contact.

Ngaityalya
(Kaurna, thank you)

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# Canberra observed

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## 2023 a solid year for Australian resource companies

2023 was a volatile year for the All Ords Index. It declined by 9% during August through October, but then rebounded by 11% to reach a record of 7829 at the end of the 2023.

Meanwhile, the resource companies in the top 150 companies maintained steady performances throughout the year. In January their total market capital was $594 bn, and at the end of 2023 it was $605 bn. The highest value was $624 bn at the end of January, and the value never went below $556 bn throughout 2023.

**Figure 1** shows the plots for the last two years and **Figure 2** shows how these parameters plot over the last 23 years. The trouble with these numbers is that they are dominated by the top four (BHP, Fortescue, Woodside and Rio Tinto). The total market capital of these four is 75% of the total of 25 companies in the top 150.

### *Investment in resource companies has been rewarding*

**Figure 2** shows how the All Ords, the total Market Capital of the resource companies in the top 150 companies listed on the ASX and our largest company BHP, has performed.

Notice the big increase in February 2022, when BHP transferred it shares from London to the ASX. From 2000 until now the resource companies have performed better the ASX, but that may have stopped in the last two years.

The CPI for Australia has increased from 70 in 2000 to 135 in 2023 – almost doubling. So, the All Ords, which have increased from 3258 to 7502 in the same period, have delivered an annual return of about 6 % per annum. This does not included dividends so it should have been a sound investment.

The resource companies have done better because their total value has increased from $81 bn to about $600 bn in the same period. However, in 2000 there were just 16 resource companies in the top 150, now there are 25. One must be careful using any comparisons.

## How did commodity prices fare during 2023?

**Figure 3** shows how four of the main commodities fared from 2021 through 2023.

### *Gold doing well*

Although it can't be drunk, eaten or used widely in manufacturing industries, the price of gold continues to rise. From October 2022, when the price dropped to US $1650/oz, it has risen steadily to December 2023 when it reached US $2023/oz

According to the World Gold Council (https://gold.org) Australia produced 328 t of gold in 2022 and is in third position behind China (368 t) and Russia (331 t). If you could cash in the gold, this amounts to about US$21.3 bn per year! No wonder explorers are still hunting for it.

### *Petroleum price declines*

Despite wars in Ukraine and Israel, the price of West Texas Crude has steadily declined from its peak of US$119/bl in June 2022 to about $US70/bl at the end of December 2023. No wonder the market capital of Woodside has declined from $65 bn to $60 bn during 2023.

### *Iron Ore price increases*

The iron ore price increased from $US 109/t at the start of 2023 to $US 135/t at the end of the year. Rio Tinto and Fortescue benefited from this increase because their market capital values during 2023 grew from $45-49 bn, and $68-87 bn, respectively.

The wars in Ukraine and Israel and the Chinese demand are crucial in

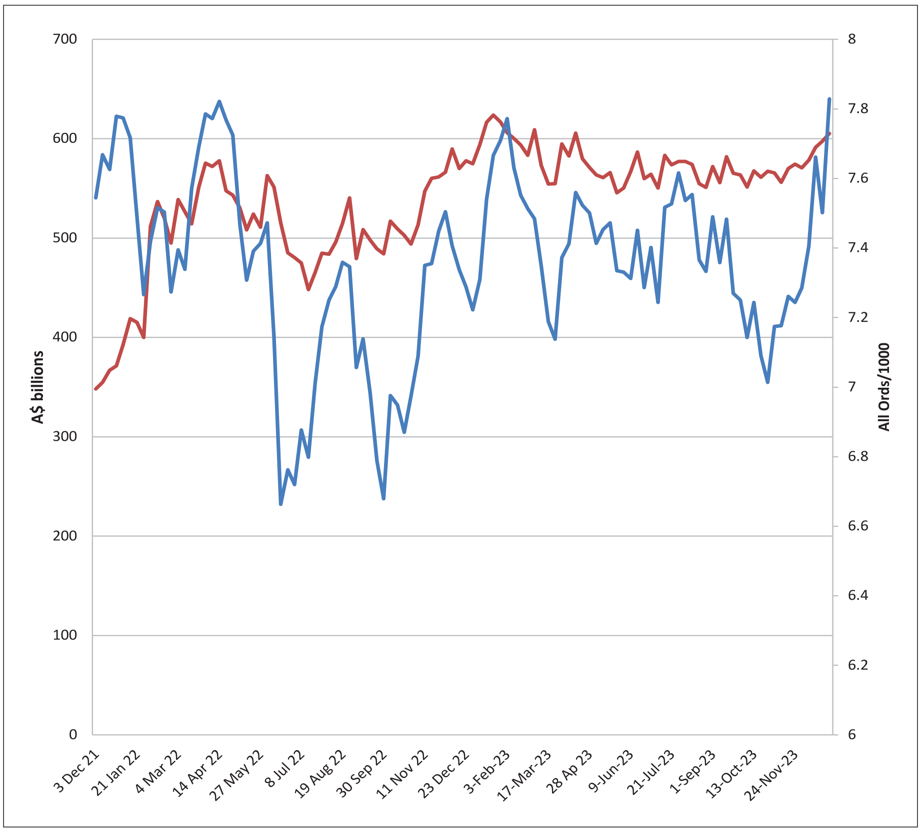


**Figure 1.** *The All Ords Index (blue) and the total Market Capital of the resource companies (orange) in the top 150 companies listed on the ASX in 2022.*

determining these prices, and you would not want to forecast how these might change in 2024.

### *Thermal coal demand continues to decline*

The price for thermal coal peaked in September 2022 at $US 468/t. At the end of 2023 it was only $US 135/t. The two only-coal companies in the top 150 are Yancoal and Whitehaven. Their market capital values declined from $8.1 bn to $6.5 bn and from $8.2 bn to $6.2 bn, respectively.

The price of metallurgical coal used to produce steel, remained at about $US 300/t throughout 2023. As it takes around 770 kg of coal to make one tonne of steel in basic oxygen blast furnaces, there is likely to be a constant demand for it in the foreseeable future (https://www.focus-economics.com/commodities/energy/coking-coal/).

### *Lithium loses its lustre*

As we know lithium is a key component to make batteries and the global production has increased from 28 000 t of lithium carbonate (or similar material) in 2010 to 130 000 t in 2022. **Figure 4** shows the history of the price of lithium since 2010. (https://www.statista.com/statistics/606684/world-production-of-lithium/). Australia topped the list of producing countries in 2022 by delivering about 50% of the global production. The second and third best producers were Chile and China (https://www.knowledge-sourcing.com/resources/thought-articles/the-top-10-lithium-producing-countries/).

In 2023 global production increased and the price plummeted to about one third of the peak in 2022. Australia will have to fight hard to maintain its number one position.

Fortunately, it is unlikely there will be situation like the Dutch tulip bulb market bubble of 1637 where the price of bulbs rose by a factor of 400, only to fall to half of the original price.

## Newmont buys Newcrest Mining, but Brookfield fails to swallow Origin

Newmont is the world's leading gold company and a producer of copper, zinc, lead, and silver. It has projects in Africa,

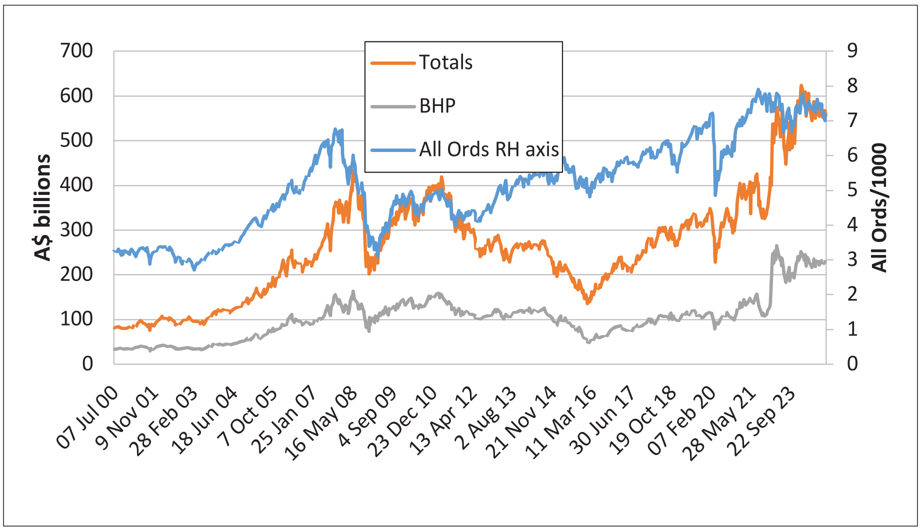


**Figure 2.** *The All Ords index (blue) and the total market capital of the resource companies in the top 150 companies and BHP (grey). There has not been any correction for inflation.*

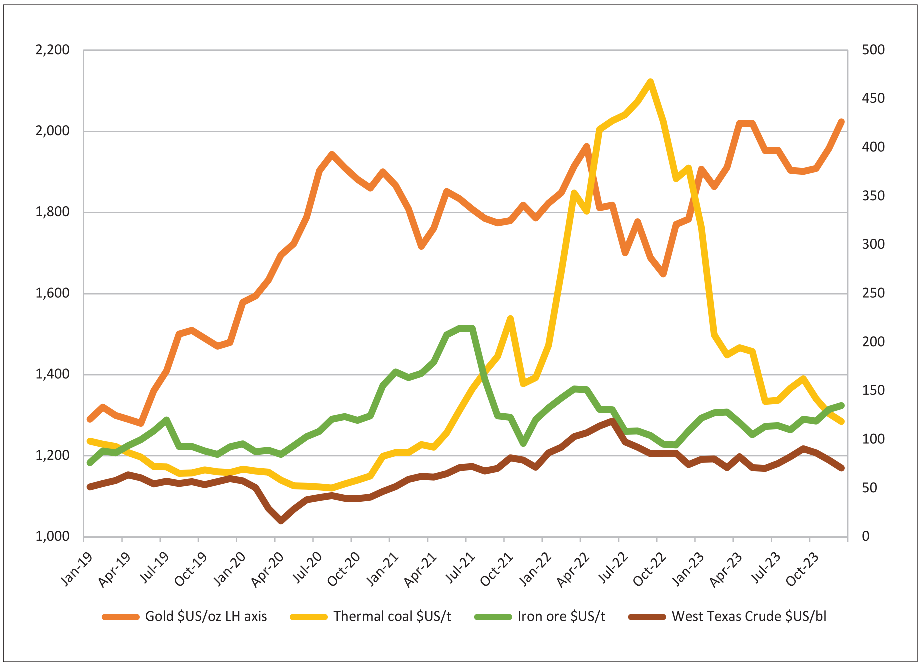


**Figure 3.** *Selected commodity prices from 2019-2023 for thermal coal, gold, iron ore and West Texas crude.*

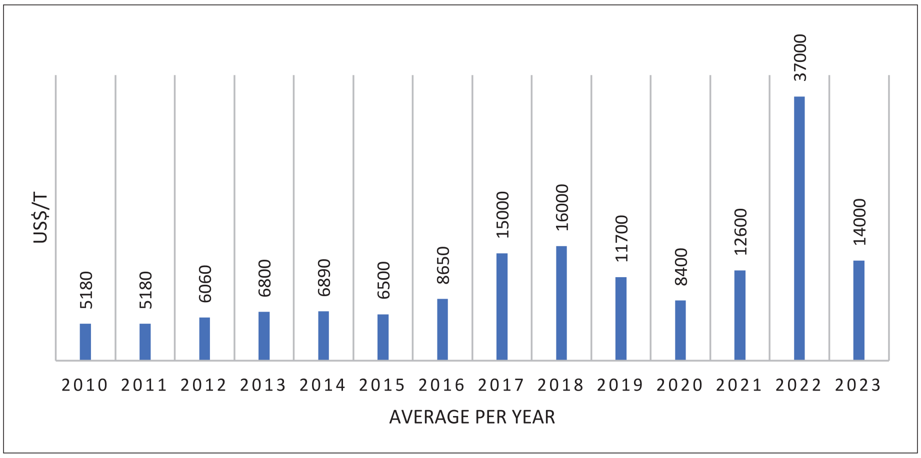


**Figure 4.** *The average price of lithium carbonate between 2010 and 2023 in $US/t. See text for more details*

Australia, Latin America & Caribbean, North America, and Papua New Guinea. Newmont was founded in 1921 and has been publicly traded since 1925. It paid A$26.2 bn for Newcrest, which had a market capital of about $22 bn at the time of the takeover.

Meanwhile, Brookfield's reported bid of $18.7 bn for Origin was unsuccessful. Even though the market capital of Origin was $14.8 bn when the final bid was made. For those who do not know, Brookfield is a Canadian multinational company that is one of the world's largest alternative investment management companies with over US$725 bn of assets under management in 2022. It focuses on direct control investments in real estate, renewable power, infrastructure, credit and private equity (according to Wikipedia).

## Approval of the Barossa gas project – the power of lobbying

Santos operates the depleting Bayu-Undan gas field, which is approximately 530 km northwest of Darwin in the Timor-Leste controlled resource area and it plan to develop the Barossa gas field which is approximately 300 km north of Darwin (*see* ***https://www.thesaturdaypaper.com.au/news/environment/2023/12/16/emails-reveal-labor-caved-santos***). The Carbon Capture and Storage (CC&S) plan was to pump the $CO_2$ from the Barossa field to the Bayu-Undan field.

There are two problems with this plan. Firstly, if the Barossa field is treated as a new field, then it should supply offsets for $CO_2$ and secondly, the facilities are not in place to pump the $CO_2$ from Barossa to Bayu-Undan.

Santos set about lobbying hard. It argued that if Barossa did not proceed, then the Darwin LNG project would have to be mothballed and Government would consequently forgo royalties, Australia's reputation would be damaged in Japan and Korea (where two the joint venture partners are situated) and there would be hundreds of job losses. These were strong arguments by a very effective lobbyist, and the legislation to allow Santos to proceed with Barossa without an effective CC&S plan has been passed.

We will just have to wait and see what transpires as this field is developed.

**HENDERSON BYTE:**

## Seismic Swifties - how the performance of a pop star is recorded on a seismograph

Thanks to a seismograph being well-positioned relative to Seattle's football field, in January 2011 the reaction by the audience to a Seattle Seahawks touchdown could be observed as a seismic event. In July last year a stronger event was recorded on the same seismograph as a result of the performance of Taylor Swift to an audience of 70 000 so-called "Swifties". One of her songs appropriately included the words "shake, shake, shake, shake".

The seismograms were studied by Jacqueline Caplan-Auerbach, a geology professor at Western Washington University, who presented her findings to the American Geophysical Union meeting in San Francisco in December 2023. One event was magnitude 2.3. Generally, the signals were stronger for the Taylor Swift event than for the Seahawks' events, possibly because the Swifties were more coordinated than football fans.

In attempting to determine if the responses came from the music or the audience response, Dr Caplan-Auerbach isolated two sets of signals, one in higher frequencies (30-80 Hz) and one in lower frequencies (1-8 Hz). From the situations at the time, the higher frequencies were clearly from the music itself, while the lower frequencies changed with the tempo of the songs and the audience reaction to them. This was distinguished from any resonance of the building itself. Fortunately, this is different from a situation in Gothenburg in 1985, when the movement of the audience resonated with the clay foundations of the building, forcing further concerts to be banned in that location.

Much of the above information was provided by *The Economist* magazine of December 16, 2023 (p 64-65) under the sub-heading of *Terpsichoseismology* (!).

As Taylor Swift is booked to perform in Melbourne in February 2024 to an audience of 100 000, and in Sydney that same month to a capacity crowd of 80 000, we'll be searching for the nearest seismographs. Watch this space!

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# Education matters

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## Exploring the frontier of online education

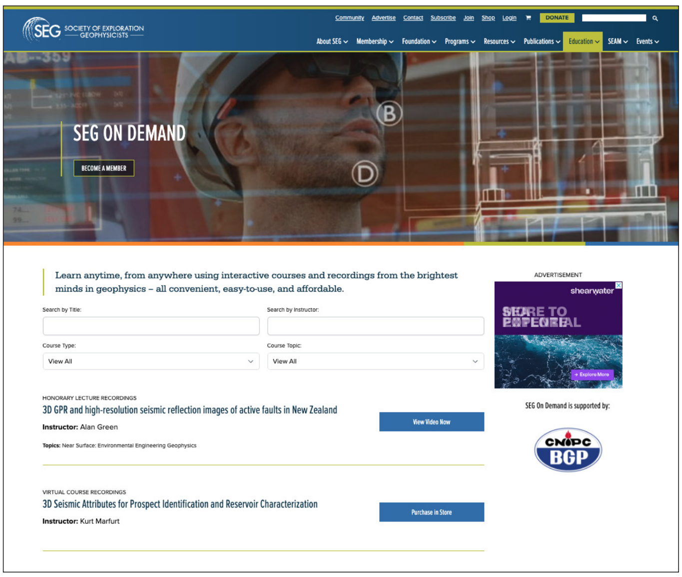
This month, I'm exploring the wealth of online educational and professional development opportunities focused on geophysics, energy, and mineral resources available through professional societies and online education platforms. Let's kick off with a look at our sister societies' websites.

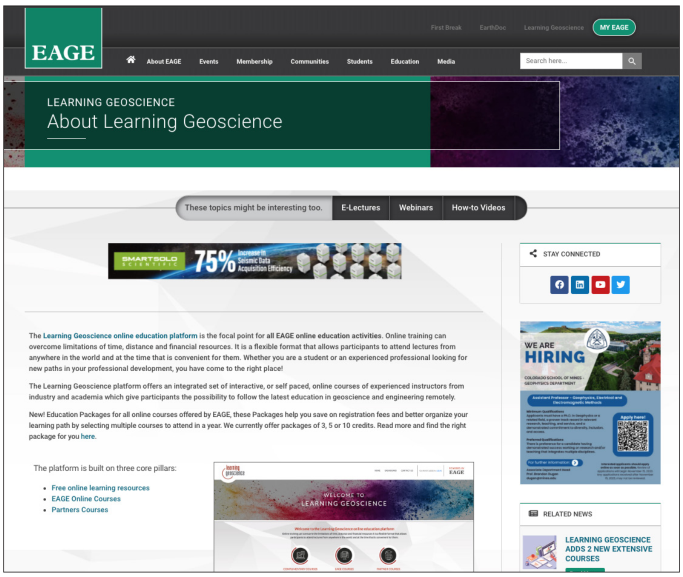
**SEG on Demand** provides complimentary access to Distinguished and Honorary Lecture Recordings. Engage with sessions like "3D GPR and high-resolution seismic reflection images of active faults in New Zealand" by Alan Green, "A brief history of depth... and time seismic imaging" by Samuel Gray, "A journey through time in search of Arabian giants – Oil/gas fields, recording channels, and petabytes" by Peter Pecholcs, "Beyond Physics in Geophysics" by John Castanga, or "Digital rock under stress" by Maxim Lebedev. While annual meeting technical programme recordings are available for purchase for a few dollars, virtual course recordings mirror the full price of attending a one or two-day DISC (download the list here: link). Explore Knowledgette for additional resources from sister societies like AAPG, SPWLA, CSPG, and PESA.

**EAGE's Learning Geoscience** website offers a plethora of resources, including free E-Lectures, Student E-Lectures, and How-to-Videos. The 100 E-lectures cover diverse topics such as seismic acquisition, imaging, reservoir characterization, rock physics, and data science. A highlight is the entertaining How-to-Videos guiding you through tasks like submitting an abstract, presenting to a live audience, chairing a session, and getting published. EAGE members enjoy free access to Distinguished Lecture Programme Webinars, along with self-paced online short courses covering various geoscience topics and addressing the challenges and opportunities of energy transition. Flexible educational packages of 3, 5, and 10 credits are also available.

Venturing beyond society websites, a visit to the **edX online education platform** with search terms "Energy" and "Minerals" yields a staggering 536 results for "energy" courses. The AI-powered assistant, Xpert, assists in narrowing down relevant courses such as "Why Move Towards Cleaner Power" from "Managing People with Power Skills" and "Unlocking the Power of Generative AI with ChatGPT for Higher Education". The platform features a tempting array of free courses on sustainable energy from prestigious institutions like MIT, Delft, Harvard, and Imperial College, all accessible at any time. While there are fewer courses on Minerals and Mining compared to Energy, Australian Universities, especially Curtin University and the University of Queensland, play a significant role, contributing about half of these resources. Explore reservoir geomechanics courses from Stanford University, 120 "earth science" courses covering environmental science, and 21 "geoscience" courses. Language diversity is also notable, allowing you to enjoy courses in your native language or use educational courses to learn foreign languages.

In the vast landscape of online education, various sites offer substantial amounts of interesting and relevant materials for continuous education and professional development. If your preferred sites aren't mentioned, feel free to share your favourites, and drop me a line for a collective exchange of recommendations among readers.



# Environmental geophysics

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## Fibre-optic cable based systems for data collection

Welcome readers to this issue's column on geophysics applied to the environment. For this issue, I am learning about fibre-optic cable based systems often set up to collect seismic, temperature or even static strain data – sometimes called DAS, DTS and DSS systems. I got interested in this subject when Professor Roman Pevzner from Curtin University came to Adelaide to give his SEG Honorary Lecture titled "Surface and Borehole Seismic Monitoring of $CO_2$ Geological Storage". My original idea when I saw Roman's presentation was to show some examples of work done by the group at Curtin that Roman's is part of, along with some other work that Eddie Banks is doing at Flinders University and be done with it. But the deeper I go the more I find, and the harder it is for me to find my way out. So back to my original plan…

In his talk, Roman opened a window onto an area of research/instrumentation that is interesting to me (I guess I had heard of it before but hadn't appreciated it); *i.e.* Distributed Acoustic Sensors (DAS) and Distributed Temperature Sensors (DTS) using fibre-optic (FO) cable as both the sensor, as well as the "wire" (the signal medium). A very brief introduction to the concept follows; for more you should start with the Silixa website (https://silixa.com/resources/downloads), and then the references in the other papers that I mention here. Briefly, fibre-optic cable is laid out to measure temperature distribution or acoustic properties of a medium – often the FO is placed in a borehole, and also, often, is cemented into place so as to be part of a permanent monitoring system. Laser pulses are transmitted along the FO cable, with some of the energy backscattered to the source when various properties of the FO vary. For example, the FO may be set up to sense changes related to seismic events, *i.e.* both naturally sourced, as well as induced. In this case the cable acts much like a high-resolution seismic string. To measure temperature along the FO, more complex interaction between the transmitted light and the fibre itself are measured, again producing backscatter. Positions of scattering events (whether acoustic information or temperature) along the FO line are measured based on time-of-flight calculations for the pulse and the returned scatter. Event types are separated by frequency of the return signal. Higher frequency information is related more to seismic events, while the phenomena associated with temperature variation are lower frequency. To give us an idea of resolution, one paper (Banks *et al.* 2022) stated that temperatures along the FO were generally accurate to within 0.1°C (calibrating to known temperatures at the time that the readings were taken), and approximately 0.5 m positional resolution along a 110 m long cable. The seismic events measured by the group at Curtin are in boreholes more than 1500 m deep.

For the work that the Curtin group have been doing in the $CO_2$ sequestration space, they have been using DAS setups to collect vertical seismic profile data (VSP) in five instrumented wells over an approximately 7.3 km$^2$ area in the CO2CRC's Otway International Test Centre (Yurikov *et al.* 2022, Isaenkov *et al*. 2022, Pevzner *et al.* 2023). The wells were all instrumented to at least 1600 m depth, with two stages of liquid $CO_2$ injection into one of these wells, the first at ~4 kt in December 2020 and the second at ~12 kt in early 2021. The DTS instrumentation ran nearly continuously for the duration of the study, so data were collected in at least three "modes". The most conventional mode was run as a 4D VSP survey, where the source was a vibroseis truck, shaking the earth at ~3400 sites over the course of three distinct surveys – one immediately before injection, the second after the first injection and the third after the second injection. These results are summarised in Yurikov *et al*. (2022). The second data collection mode (slightly less conventional) was based on the use of nine surface orbital vibrators (SOV) at discrete locations around the test site as sources (Isaenkov *et al*. 2022). And then finally, passive seismic data sets were collected continuously as well (Pevzner *et al.* 2023).

Needless to say, imaging these gas injections in a briny aquifer at 1500 m depth is a tough ask. The best results are when the full 4D VSP surveys were performed, as vibroseis trucks were used as sources at so many sites. This produced a good ground coverage with pretty good multi-fold seismic data sets, so SN ratios were relatively low. But this survey takes by far the greatest amount of effort and cost as running the vibroseis systems required a lot of time, effort and personnel. **Figure 1** shows some of the best results taken from the Yurikov paper, showing differences between survey results for data collected during the pre-injection survey (M6), post 4 kt injection (M7), and 12 kt injection (M8).

The results using the SOVs as transmitters were not quite as good as when using the vibroseis trucks. Relatively, obviously, both the fold and the lateral coverage of the data are much lower (nine transmitter sites vs. ~3400). It is important to note here though that while coverage is lower, the surveys using the OVs as sources could, once procedures were refined, be run remotely (including much of the data processing). **Figure 2** shows the evolution of the plume as measured using the nine SOVs – the data are limited to the data tracks as determined by the sensors in each well and the location of each SOV. Note that while these data sets are limited spatially, they were collected nearly continuously so the development of the injection "bubble" can be observed before during and after injection (along with reactivation of an old injection event).

The natural source results used ocean-generated Rayleigh waves as the source for the study (Pevzner *et al.* 2023) was also tested. These waves are present over much of the Earth, but are characterised by wavelengths of many kilometres. The results of the use of natural source information to

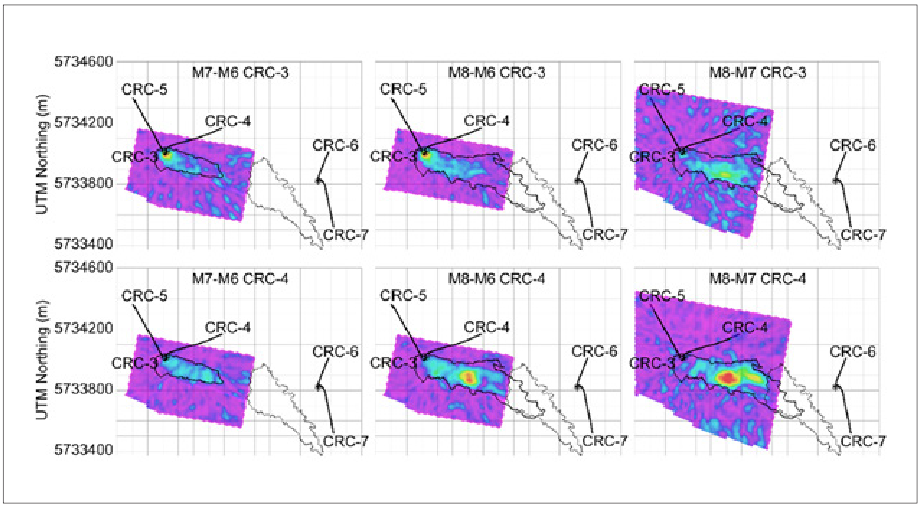


**Figure 1.** *RMS amplitude attributes of the time-lapse differences computed at the target horizon for two of the observation wells from the 4D VSP. M6 is the pre-injection survey, M7 shows the results after injecting 4 kt, and M8 shows the results after injecting another 12 kt. The black solid contours outline the modeled plume extent while the black dashed line shows the extent of an earlier injection trial (not discussed here). Modified from Yurikov et al. (2022).*

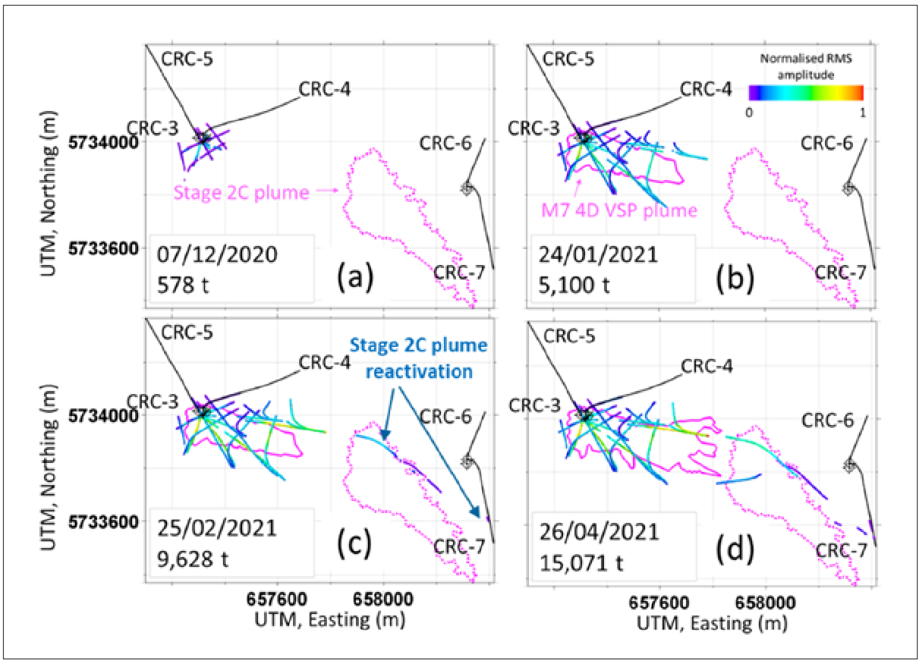


**Figure 2.** *Evolution of the $CO_2$ plume captured by the continuous offset VSP monitoring. The colour code shows the normalised RMS amplitude of the time-lapse signal at the well/SOV transects. The date and the amount of injected gas are displayed for each vintage. The dashed pink contour shows the spatial extents of the earlier plume detected by the 4D surface seismic. The solid pink contours show the extent of the Stage 3 plume as detected by the multi-well 4D VSP. Note, that for each well/SOV transect, only the area with a time-lapse signal (as detected by an interpreter) is displayed. Modified from Isaenkov et al. (2022).*

characterise the extent of the injection was the most ambiguous, with at least some response in the data attributable to the injection event, but with the conclusion that it was pretty much impossible to quantify results with present understanding of how ocean-generated Rayleigh waves are affected by lateral heterogeneity in the area of interest. Interesting nevertheless, as if this could be refined, information about $CO_2$ movement could be collected with no transmitters at all.

On a different note, it is interesting to look at what Banks *et al*. (2022) were doing with similar equipment, but with a completely different research goal. This team, based both in Australia (Flinders University) and New Zealand (University of Canterbury and private industry) are interested in groundwater – surface water interactions in general, and in particular, in a river system in New Zealand that has been an ongoing study area for some time so is otherwise well-instrumented. In the study reported on here, they used an Active Distributed Temperature Sensor (A-DTS) setup. In their approach, hot water is used as a tracer to track water motion around the OF. This meant cementing in a copper wire heat source adjacent to the OF string to use as a heat source, so local heat flux could be estimated along the OF string and use that information as a proxy for water velocity, which then provides information about water flux from the losing river system to the groundwater. They concluded that this approach gave them higher detail information about flux than is available using more conventional methods like differential flow gauging.

So, this was not the usual shallow environmental technique or issue that I usually address in this column, but nevertheless is an area of research and data collection that should be of interest to all of us as we work on our ability to image the near surface. I'll be watching this space for sure.

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# Minerals geophysics

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## Form and substance

Whenever I'm discussing geophysical interpretation with geologists my emphasis is on the petrophysical property involved: magnetic susceptibility for magnetics, density for gravity, electrical conductivity for electromagnetics, etc. Our approach then is to try and relate geology to the interpreted geophysically-derived values and distribution of the petrophysical property in the sub-surface. This typically involves questions like "What likely rock types are both dense and magnetic?" and, perhaps more hopefully "Could this relatively shallow flat-lying conductor be mineralisation related – perhaps enhanced weathering or even a secondary enrichment blanket?".

In this piece I'd like to take a closer look at electromagnetics and electrical conductivity; in particular, two strongly conductive minerals the properties of which and their distribution in geology (respectively the 'substance' and 'form' of my title) impact on the use of electromagnetics in mineral exploration. For the most part, neither mineral is an exploration target in its own right, but both have associations of economic significance.

In very simplistic terms, the electromagnetic geophysical technique utilises electromagnetic generation, then subsequent electromagnetic detection, of transient electrical currents flowing within a conductive target body. Plate-like target bodies have the optimum shape. Key properties of the target body are the conductivities of constituent minerals, electrical connectivity, and size, more specifically for plate-like targets, areal extent and thickness. The generated transient electrical currents must be of sufficient strength, duration and extent to create a quantifiable secondary electromagnetic field. As a further consideration the strength of the electromagnetic response is proportional to conductance (conductivity x thickness). A thin extremely conductive plate can generate the same response magnitude as a thick plate of moderate conductivity.

### *Pyrrhotite*

Pyrrhotite is a common iron sulphide mineral of variable composition $Fe_{(1-x)}S$ where x = 0 - 0.17. The variable deficiency in iron is responsible for its variable magnetic properties, but that is not our concern here. Unlike most of the common metallic sulphide minerals (pyrite, chalcopyrite, galena, etc.) which are semi-conductors, pyrrhotite is a metallic conductor with significantly higher electrical conductivity (see Pearce *et al*. 2006 for background detail). In mineral exploration, the value of pyrrhotite detection comes from its association with ore minerals, as for example in some VMS polymetallic, SEDEX zinc and magmatic nickel deposits.

In electromagnetic exploration, the impact of pyrrhotite can go beyond its strong electrical conductivity. In many cases the nature of the distribution of pyrrhotite within the mineralisation enhances the electrical connectivity, rendering the body more amenable to electromagnetic detection. Stories, in some cases perhaps apocryphal, of drilling a strongly conductive electromagnetic target only to find 20 cm of massive pyrrhotite as the potential source, are commonplace. Certainly, in my experience the first choice of the possible source mineral for a particularly conductive target is pyrrhotite. And in exploration for magmatic nickel deposits, there are the additional bonuses of the layered nature of the deposits and the presence of metallically conductive pentlandite $(FeNi)_9S_8$. No wonder electromagnetics is the go-to geophysical exploration technique there!

### *Graphite*

Graphite is a naturally occurring crystalline form of carbon comprising stacked layers of graphene. Graphite is strongly electrically conductive, much more so parallel to the graphene layers than perpendicular to them. In mineral exploration, apart from direct detection in the search for massive graphite deposits, the value of graphite detection comes from its presence in metamorphosed sedimentary sequences which may, for example, host strata-bound zinc deposits, and from its occurrence in disruptive structures. Systematic mapping of both these features will aid geological understanding.

In electromagnetic exploration, the impact of graphite, too, can go beyond its strong electrical conductivity. In metamorphosed sedimentary units, both layering and associated pyrite (particularly in the case of units associated with strata-bound zinc deposits) contribute to enhanced electrical connectivity and conductivity. Conductance comes into play too, in that a lower conductivity due to the somewhat disseminated nature of the conductive minerals can be compensated for by unit thickness. Systematic detailed mapping of these units at a sub-regional scale is feasible with airborne electromagnetics; favourable sites for mineralisation, notably fold closures, may thus be highlighted. In disruptive structures, the distribution and platy nature of graphite can enhance the electrical connectivity within the structures, rendering them more amenable to electromagnetic detection. Again, mapping of these structures with electromagnetics can contribute to the overall exploration programme.

So there you have it. In mineral exploration the electromagnetic technique targets the petrophysical property electrical conductivity ('substance'). And the very nature of the geological distribution ('form') of two minerals of high electrical conductivity enhances the effectiveness of that technique. Substance and form - there's a nice symmetry there.

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Wikipedia https://en.wikipedia.org.>wiki> graphite, pentlandite, pyrrhotite

# Seismic window

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During the appropriately named Christmas break, I managed to fall on a concrete cricket pitch while bowling to my seven-year-old grandson and broke some bones in my hand. As a result, my keyboard skills are somewhat compromised, so I have picked one of my favourite columns from the past for reproduction in this issue.

Since this article was first published in 2013 (*Preview* **163**), I have noted an increase in the number of reports that include a section describing the polarity of the seismic displays, which is encouraging.

I hope you enjoy reading this blast from the past!

## The demise of ASEG polarity

I would like to dispatch to the annals of history the term ASEG polarity or Australian SEG polarity when referring to seismic data displays. There is no ASEG polarity standard.

Seismic data polarity is a common source of confusion for many interpreting geophysicists (Simm and White 2002), including me. As a joint venture representative, I attend meetings and presentations with several companies and to fully understand the presentation material it is necessary to confirm the display polarity because it determines how an increase (*e.g.* intrusives) or decrease (e.g. gas sand) in acoustic impedance appears.

The only definition of normal or standard polarity I know is given in the SEG *Encyclopedic Dictionary of Applied Geophysics* (Sheriff 2002). Here is an excerpt from the online version (https://wiki.seg.org/wiki/Dictionary:Polarity_standard), "… for a zero phase wavelet, a positive reflection coefficient is represented by a central peak, normally plotted black on a variable area or variable density display. This convention is called **positive standard polarity**…" (an increase in acoustic impedance produces a positive reflection coefficient). There is also a definition for minimum phase wavelets but I will stay with zero phase because most seismic processing aims to output a zero phase wavelet – a symmetrical wavelet with a maximum value at zero time.

The SEG Dictionary also describes dual polarity displays as "Troughs may be colored red and peaks blue or black, or some other combination of colors may be used." This is more like a suggestion but is an extension of the polarity definition – if the peaks are coloured black a contrasting colour, commonly red, was used to colour troughs.

The SEG positive polarity definition makes sense because an increase in impedance produces a positive reflection coefficient which is displayed by a positive number or black peak. With this definition the mathematics is consistent and AVO analysis and seismic inversion is simpler with no need to swap sign.

But in Australia and Europe the opposite convention is often used. The correct name for this convention is SEG negative standard polarity, not ASEG polarity. The SEG polarity standard is quite clear and is illustrated below (**Figure 1**) along with the polarity conventions used by an Australian operator, an international operator working in Australia and a European service provider. To confuse interpreters even further Operator A displays AVO (**Figure 2**) and inversion results with the opposite polarity to their display of standard seismic data. They do this to avoid the situation shown in **Figure 3**. Even industry leaders Schlumberger (2013) have no consistent usage, with their excellent web-based Oilfield Glossary correctly describing positive polarity while their Petrel software defaults to something else.

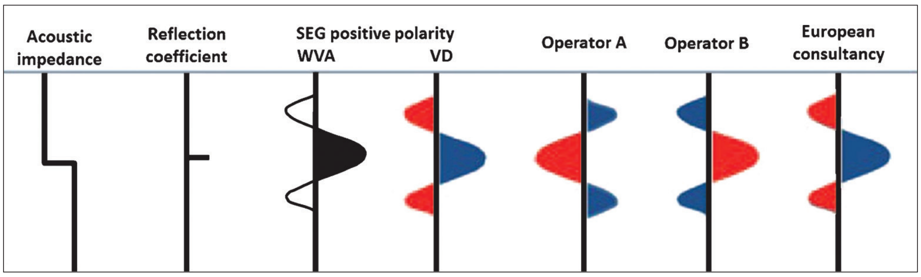


**Figure 1.** *The SEG positive polarity standard for zero phase wavelets. From left, an increase in acoustic impedance produces a positive reflection coefficient that is displayed on wiggle variable area displays as a black peak or blue on a variable density colour display. The three right wavelets illustrate the variety of conventions used by three companies operating in Australia. Only one uses the SEG standard.*

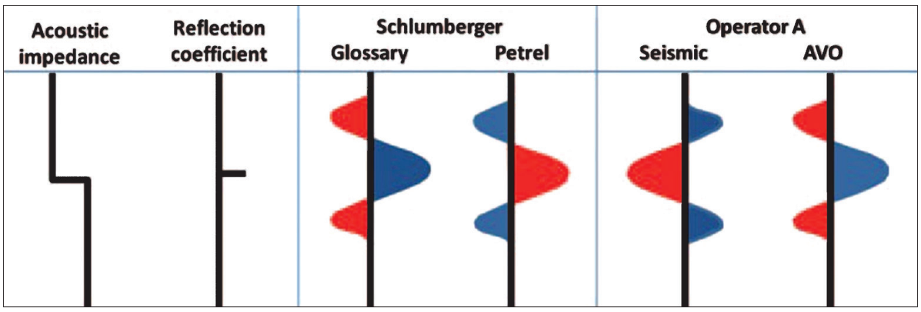


**Figure 2.** *Even companies with well-defined standards have internal variation. The Schlumberger glossary of oil field terms (internet) correctly describes the SEG standard, but their interpretation software (Petrel) defaults to something else. A major operator uses SEG negative polarity for seismic displays but reverts to SEG positive polarity for QI and AVO displays.*

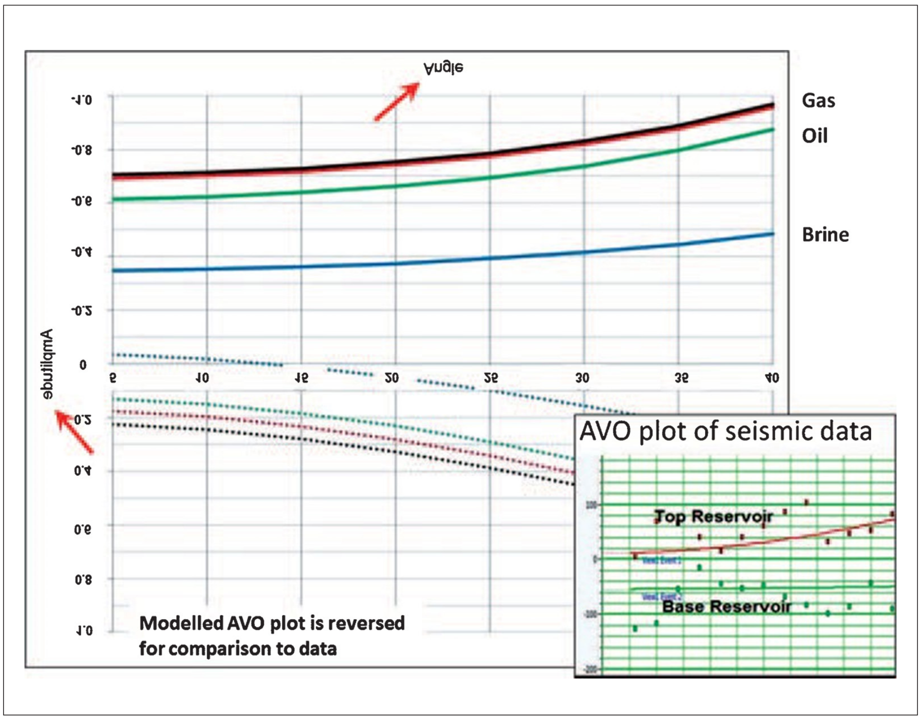


**Figure 3.** *Example of AVO modelling results presented by an Australian operator. For comparison the display of modelled results has been inverted to account for the negative polarity convention of the seismic data (lower right). Inverting the graphical display to match the measured seismic response results in unreadable text (arrows).*

**Figure 3** is an example of AVO modelling from a recent prospect presentation that I attended. This company displays seismic data as SEG negative polarity (an increase in impedance is displayed as a trough) while their seismic modelling results are displayed with SEG positive polarity. To enable the modelled and actual curves to be compared directly one of the displays has been flipped. In this case the model display was flipped and the curves can be compared, but the text and labels are difficult to read.

So what has brought about this confusion?

We can blame it on computers – the introduction of digital recording brought about the need to define polarity, and this led to the SEG polarity standard being published in 1975 (Thigpen *et al.* 1975). This document provided details of tests and standards for seismic acquisition and included this text "… An increase in acoustic impedance … recorded as a negative number on tape…". I understand this was a pragmatic decision because most manufacturers at the time wired their sensors in this way. But the standard was for acquisition standards and did not contain a definition for displaying the data on paper or computer screens. About 1988 John Denham (Chief Geophysicist BHP) queried the authors of the 1975 standard and they replied confirming that the standard did not include displaying the recorded data for interpretation. It was not until the mid-90s that the later editions of the SEG Encyclopaedic Dictionary defined polarity without any fanfare – the definition just appeared. The intervening gap of approximately 20 years was plenty of time for various companies to implement their own polarity definition. Generally, the US went for SEG positive, and Europe and Australia went negative or reverse polarity.

There are a number of reasons for the negative polarity convention becoming common place. Here are three. Probably the simplest reason is that a negative number on tape is simply displayed as a trough on paper. The second reason harks back to seismic refraction records. Refraction seismic uses first arrivals which are refracted along a boundary across which the seismic velocity (impedance) increases and commonly refraction instruments were wired to display first arrivals as a deflection downwards. This convention carried over into seismic reflection records. All very technical, but my favourite explanation is an anecdote from the days when seismic interpretation was drawn on paper sections using coloured pencils to pick reflectors which were most commonly at major increases in acoustic impedance. If the increase in impedance was displayed as a trough (an unfilled wiggle deflecting to the left) the coloured pencil line was easier to see. This convention also had the added bonus that the coals (common in the Gippsland and Cooper Basins) were displayed as black peaks and hence looked 'coally'.

This brings me back to my opening – for consistency we should all be using the SEG positive polarity standard and terms such as ASEG or Australian polarity should be replaced with the correct term SEG negative polarity. Unfortunately, I haven't seen any evidence of willingness in the industry to move in this direction and there will be more confusion when 4D seismic and shear wave data becomes more commonplace.

Finally, I'll finish with an extract from a Schlumberger Petrel users guide. The polarity and colour conventions described in Petrel manuals are "…the default color scale displays troughs as 'cold' blue colors and peaks as 'hot' red and yellow colors. This appears to be against another popular convention used, whereby positive amplitudes are usually displayed in blue tones…. Whatever convention is chosen, it is up to each user to make this clear in any resulting map or display showing amplitude related information." Thanks for that – this is exactly why the confusion continues.

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# Data trends

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## Tools for getting to know Big Data

The Big Data/Machine Learning world likes big comma separated text files (csv) as the simplest exchange format. The resultant spreadsheets can be too big for MS Excel™ and can crash when being imported into MS Access™.

The Geological Survey of South Australia offer files for Machine Learning such as a 20 GB csv of geochemistry (https://dem-sdp.s3-ap-southeast-2.amazonaws.com/index.html), which is not easy for mere mortals to explore. The file has over 61 million lines (25 GB in RAM) of one chemical value per line plus various other numbers and text. I wanted to use the csv file to generate a shape file of point locations and associated chemical values.

The (free) Python programming language is a favourite tool in data science teaching, and the process described below used the Pandas dataframes (Python Data Analysis Library), similar to the Matlab™ Cell Array. After a week of trawling the StackOverflow forums I hope to introduce this process to the world of "data wrangling".

First, I loaded the csv file and dropped half the columns, saved and reloaded the file so only 9 GB of RAM was now required for processing (**Figure 1**). My intent was to flatten this very vertical dataset by moving each unique chemical name into its own column. The easiest way to do this is to use the *pivot_table* command, which converts values in one column into separate columns and fills the rows with values from another column. The parameters of interest are:

- **index = ['SITE_NO', 'LONGITUDE_GDA94', 'LATITUDE_GDA94', 'DH_DEPTH_FROM']** combinations become row ids and appear in the new table
- **columns = ['CHEM_CODE']** – unique names entries will have a column created
- **values = ['VALUE']** or **['UNIT']** – the numbers to fill each new chemical column (or left empty)

I reassigned numbers in *VALUE* column to columns made with names in *CHEM_CODE*. Then ran again with *UNIT*. The resulting tables *t1* and *t2* are identical except *t2* has unit names where *t1* has numbers.

The two new tables have the same chemical names for columns. Luckily the pivot operation creates layers of column names and we can combine the unique chemical names with whatever name was used with values=<column>. In this case either VALUE or UNIT.

Some "pythonic" wizardry is required to combine the name layers. Thanks to the Stackoverflow website (https://stackoverflow.com/questions/14507794/how-to-flatten-a-hierarchicalindex-in-columns) there is an answer looping backwards over

```
Import Pandas as pd
Import csv

# Open large file, drop columns by name and save smaller file
fpath = "D:\\ sarig_rs_chem_exp.csv"
df = pd.read_csv(fpath, delimiter=',', header=0, low_memory=False)
cols =  ["SAMPLE_SOURCE_CODE",…,"CHEM_METHOD_CODE"]
for col in cols:
   df = df.drop(col, axis=1)

fpath = "D:\\chem_cutdown.csv"
df.to_csv(fpath, sep=',',header=True,quotechar='"')

# reload the smaller dataset
fpath = " D:\\chem_cutdown.csv"
df = pd.read_csv (fpath, delimiter=',', header=0, low_memory=False)

# Flatten the dataframe
t1 = df.pivot_table(index = ['SITE_NO', 'LONGITUDE_GDA94', 'LATITUDE_GDA94', 'DH_DEPTH_
FROM'], columns='CHEM_CODE', values=['VALUE'], aggfunc='first')
t2 = df.pivot_table(index = ['SITE_NO', 'LONGITUDE_GDA94', 'LATITUDE_GDA94', 'DH_DEPTH_
FROM'], columns='CHEM_CODE', values=['UNIT'], aggfunc='first')

# Rename columns by combining 'UNIT' and 'Ag' into 'Ag_UNIT'
t1.columns = ['_'.join(col).rstrip('_') for col in [c[::-1] for c in t1.columns.values]]
t2.columns = ['_'.join(col).rstrip('_') for col in [c[::-1] for c in t2.columns.values]]

# Combine the 2 dataframes and sort alphabetical
t3 = pd.concat([t1, t2], axis=1)
t3.sort_index(axis=1, inplace=True)

# separate the t3 dataframe into several csv files
fpath = "D:\\"
sCols = t3.columns.tolist()
n = len(sCols)
nCols = 50
i = 0
j = i + nCols + 1
while i < n:
   sHeadings = sCols[i:j+1]
   fName = sHeadings[0] + "_" + sHeadings[-1] + ".csv"
   t3.to_csv(fpath + fName, sep=',', header=True, columns=sHeadings, quotechar='"')
   i = j + 1
   j = j + nCols
   if j > n - 1:
      j = n - 1
```

**Figure 1.** *Python code to open csv text file, flatten data and split into multiple csv out files.*

the different name layers. The two tables now join easily using the concat command. The rest of the job is just reordering alphabetically so values and units are next to each other and split into csv files consisting of 50 columns and 250 MB each.

A shape file of 2.7 m points was created without crashing, but this is not the best answer (**Figure 2**). The pivot operation is really for generating financial statistics so it only picked the first value encountered and ignored any other occurrences of the same chemistry at the same xyz coordinates. Many numbers are text with a < or > symbol so personal processing preference is required there. The next step will be to explore other ways to view and use the full dataset.

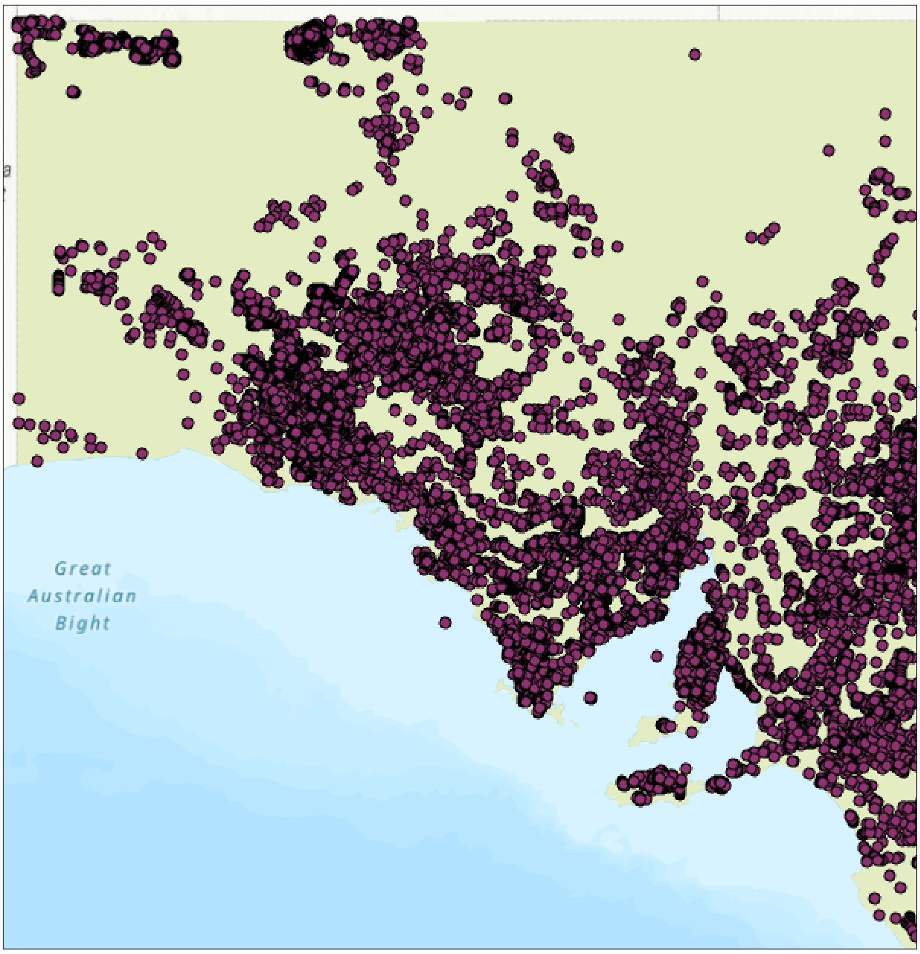


**Figure 2.** *ArcGIS shape file showing the location of 2.7 million geochemical data points in South Australia with chemical values in the table.*

# Webwaves

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## Google for nonprofits - including the ASEG

The ASEG's status as a not-for-profit society for the promotion of science confers a number of benefits to the organisation. Recently, thanks to the efforts of Gokul Venu Sreebindu on the Web Committee, we have now been verified and approved for Google for Nonprofits.

This means we will be able to setup Google Workspace for Nonprofits at no charge. This enables us to generate an unlimited number of email addresses at the @aseg.org.au domain at no cost, in addition to a host of other benefits as discussed and outlined here https://support.google.com/nonprofits.

The move to Google Workspace will involve a complete migration of ASEG communications to Google. This process will start in early 2024 and will be communicated in advance to Members so we can cut over during a brief, planned email outage. The benefit of migrating the ASEG email accounts (56 and counting) includes the ability to easily create additional accounts for specific events or content, such as CAGE and MAG, at no additional cost. Additionally, SPAM and phishing issues that have been present in some volunteer accounts should be reduced with the improved filtering capabilities in the Google product.

## Website refresh update

In 2024 there promises to be significant change in the digital presence of the ASEG, with the new website now close to being ready. This has previously been discussed in the *Webwaves* column in *Preview* **224** and **225**.

One of the key aims of the new website is to provide a cleaner, simpler experience. **Figure 1** shows the Publications section on the homepage of the new ASEG website highlighting *Preview*, the ASEG Newsletter and *Exploration Geophysics*.

Along with the website relaunch, we are replacing our membership database. This is an essential part of the refresh and will simplify website login and other friction points on the website.

One aspect of the new website that is currently being worked on is the Contractor Database. In practical terms, the connected nature of the website and the membership database means that each contractor needs an entry in the ASEG "Members" database. To avoid incurring ongoing membership cost for each contractor, it is being suggested that each ASEG Member could add a Contractor to the membership database, thereby restricting Contractor entries to ASEG Members and Corporate Members. It seems reasonable to expect that a geophysical contractor that wishes to be advertised on the ASEG website has an ASEG Member in their employ. While this is somewhat frustrating compared to the existing Contractor Database, the net benefit of the integration for the Society is positive.

## Next Steps

Keep an eye out for communications from the ASEG about the email migration and website update taking place in the first quarter of 2024.

As with all transitions, there are likely to be some teething issues. Please be patient in the early days of the new website and email webmaster@aseg.org.au while we iron out issues and deploy updates.

These initiatives also represent cost savings for the society: Google for Nonprofits offerings will remove our annual expenditure on email hosting; certainly something that I, as a Scotsman, can get behind.

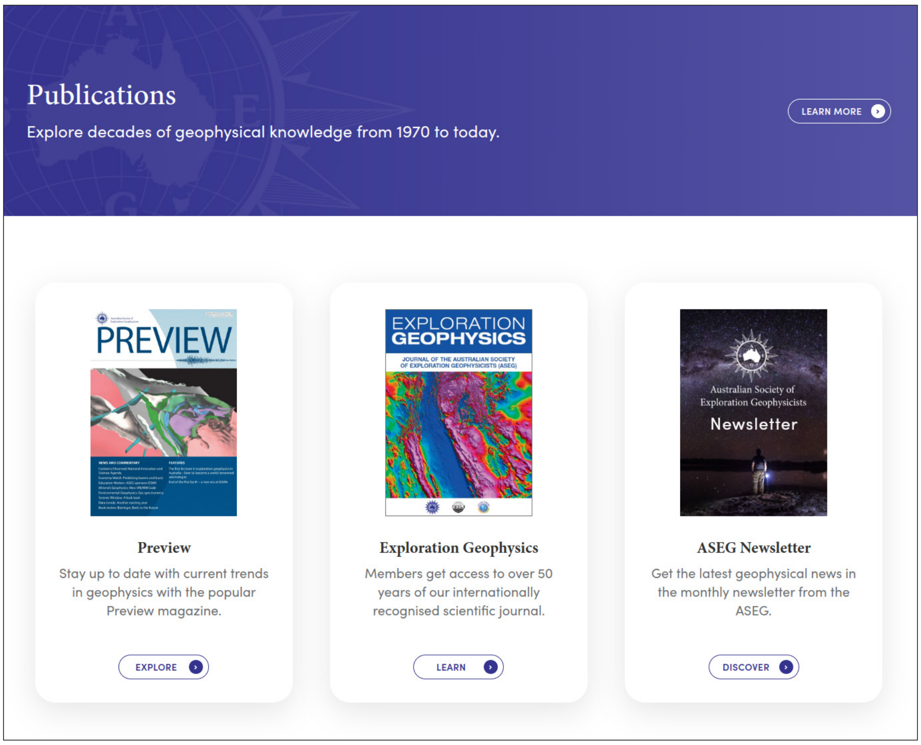


**Figure 1.** *Publications section on the homepage of the new ASEG website.*

# Discovery and geophysics of the Khamsin iron oxide - copper - gold deposit, Gawler Craton, South Australia

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## Introduction

The Khamsin iron oxide - copper - gold (IOCG) deposit occurs some 95 km SE of Olympic Dam and 10 km NW of the Carrapateena Deposit (see **Figure 1**). Initial estimates (ASX, 2014) indicate that it comprises 202 Mt of 0.6% copper, 0.1 g/t Au and 1.7 g/t Ag. The objective of this article is to present observations that led to its discovery and to discuss the results of transient electromagnetic (TEM) surveying data carried out later.

## Geology

The deposit occurs at the basal unconformity under 460 to 680 m of mostly sedimentary cover. Disseminated mineralisation occurs within the Khamsin Breccia Complex, which is a polymictic granite-hematite-carbonate breccia surrounded by altered granite and some dykes within the *c.* 1856 Ma Donington Suite granitoid, towards the eastern margin of the Gawler Craton of South Australia.

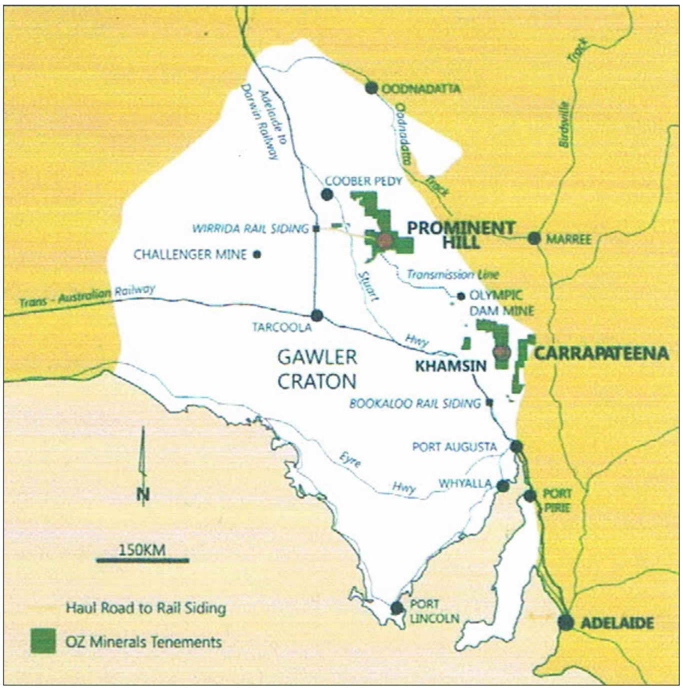


**Figure 1.** *Location Map.*

## Early work

The Khamsin prospect, formerly known as 'Salt Creek', exhibits a double peaked gravity high of about 1½ to 2 mGal, approximately coincident with a 60 nT residual magnetic ovoid. In 1977, hole PSC4 was drilled by Australian Selection Trust Pty Ltd located on the weak magnetic anomaly, as part of a larger percussion stratigraphic drilling campaign, and hole SASC2 is a diamond drilling extension of this hole into basement. Basement at 517 m was found to comprise "altered biotitic granite" with sericite, chlorite and hematite alteration, and anomalous copper was noted in the basal conglomerate above the unconformity. Gravity data was collected as part of the 'Bowen Anomaly' survey in 1983, using a variety of station spacings. Early models of the Khamsin gravity anomaly used two separate bodies to simulate the two peaks.

In 2005 Teck Australia Pty Ltd joint ventured into the Carrapateena project with RMG Services Pty Ltd (the discoverer of Carrapateena) and shortly after holes KH001 and KH002 were designed to test a density model that used two dense model bodies to simulate the double gravity peak. KH002 indicated minor copper grades at the 457 m deep unconformity. After a change in drilling technique and then access, OZ Minerals drilled DD12KMS003 in 2012 intersecting 600 m of hematite, siderite and chlorite altered breccias associated with the eastern gravity peak. Further drilling discovered the best grades and hematite breccias are associated with the western gravity peak.

## Gravity and magnetics

In 2007, following the acquisition of the tenement by TeckCominco in 2006, one of us (LV) recommended the collection of detailed gravity (200 x 200 m) data. The new data led to the recognition of the NS linear gravity low, interpreted as a low density palaeochannel in the cover and passing over the deposit, as an alternate cause for the double peaked gravity anomaly. When the palaeochannel was included in the density model it was found that the response of a single contiguous dense ovoid could replicate the data and still simulate the double gravity peak.

The detailed data yielded the images shown in **Figure 2** (topography), **Figure 3.1** (Bouguer gravity) and in **Figure 3.2** (residual gravity, created by smoothing the Bouguer gravity to estimate regional trends and forming the difference). **Figures 4.1** and **4.2** show the aeromagnetic data and a residual magnetic

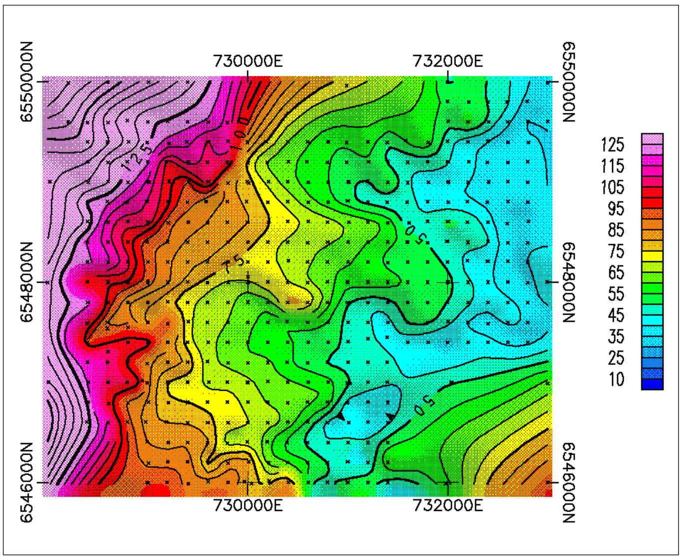


**Figure 2.** *Gravity station elevations. Coordinates are MGA Zone 53 and colour bar units are metres (AHD).*

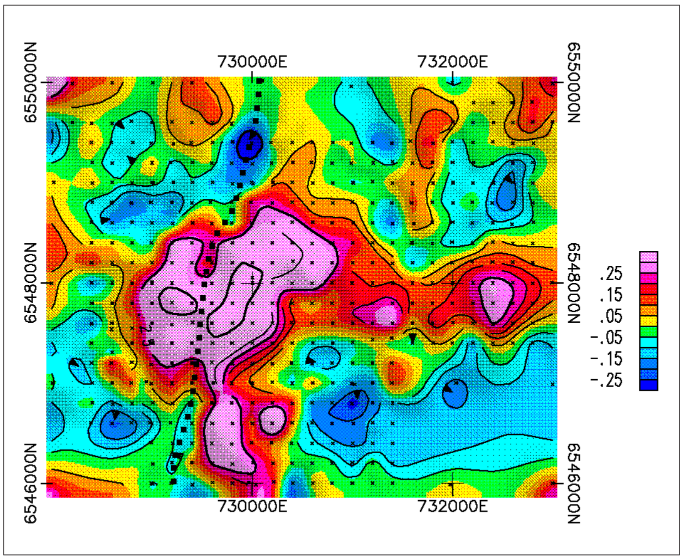


**Figure 3.2.** *Residual gravity image.*

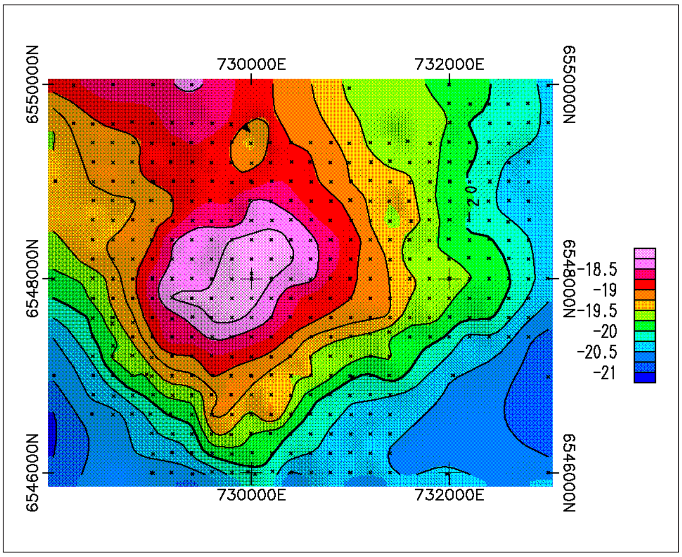


**Figure 3.1.** *Variable density Bouguer gravity map.*

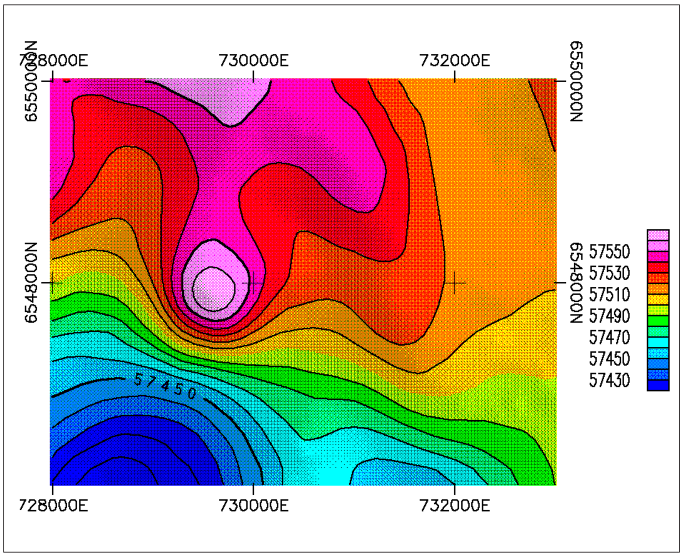


**Figure 4.1.** *Total magnetic intensity with flight lines.*

image respectively. These images, which still exhibit the double gravity peak and small magnetic ovoid, show the data used to constrain the model discussed below. For gravity and magnetic images, colour bar units are mGal and nT, respectively.

## *Selection of a gravity image*

**Figure 3.1** shows the Bouguer gravity map that was used to constrain the model discussed below, but comments on how it was selected may be useful.

In addition to other corrections to the observed gravity (Blakely 1995), the Bouguer correction is an attempt to account for extra (or deficient) mass under the gravimeter when the survey line crosses a hill (or a valley). This correction requires knowing the density of the hill, which is never available and must be estimated. If under corrected, as when the correction density is less than the unknown true hill density, the final gravity image tends to *mimic* the topography, while

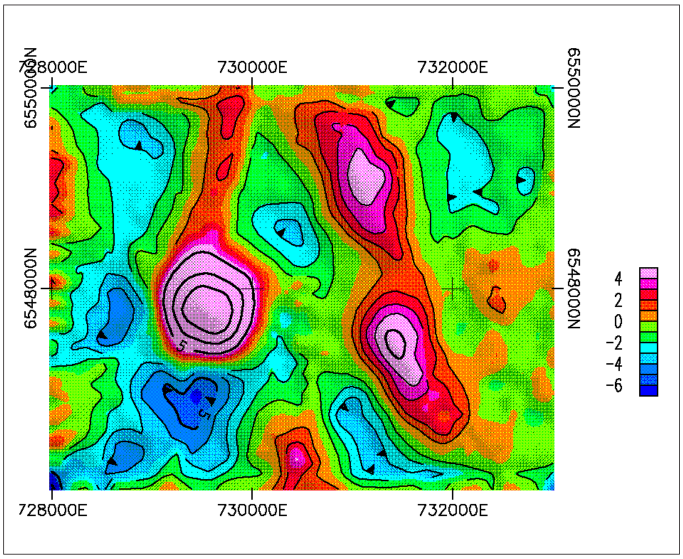


**Figure 4.2.** *Residual aeromagnetic map.*

overcorrection causes the gravity to *mirror* it. For large areas comprising many surface rock types, the industry-standard density of 2.67 g/cc is widely accepted, but for small areas a different value may be optimum, since an inappropriate correction density can yield false gravity anomalies. The gravity data from Khamsin was reduced using several correction densities in the range from 1.9 to 2.67 g/cc (not shown) and the method of Freund (1960) was used to show that the density that minimises the gravity *vs*. elevation covariance for the data sets shown in **Figures 3.1** and **3.2** is 2.27 g/cc.

All Bouguer correction densities showed similar robust gravity anomalies (including the double peak) in the central part of the area, with the similarities presumably due to the bland topographic gradient seen in that part of the image. However, there were indications of minor local covariances that were both positive and negative suggesting that no single correction density would be optimum throughout the entire area. One final test was carried out using the method of Rimbert *et al*. (1987) wherein the covariance at a point being corrected is calculated using only points within a selected radius, and the Bouguer correction is then applied at the given point using the local covariance minimizing density. The result is shown in **Figure 3.1**, which yields slightly smoother contours than images using a single density, covariances are in the -0.02 to +0.02 range, and covariance minimising densities generally increase from west to east. However, it must be noted that coincidental correlations can occur between topographic features and subsurface density inhomogeneities that cannot be predicted; consequently, none of covariance minimisation methods are immune from the generation of false anomalies.

## *Density and magnetic susceptibility model*

Forward modelling with the almost arbitrary body shapes permitted by the method of Talwani (1960, 1961) was used to develop a density and magnetic susceptibility model whose calculated responses are fair simulations of the data. The *MagGravJ* method (Hanneson 2003), which, among other things, permits calculation of the gravity response of non-magnetic material separately from the gravity response of magnetic units, was used to assess the model bodies for concentrations of three gross categories; namely, magnetite, hematite+sulphides, and a barren lithology unit, in this case, felsic rock. This can be advantageous in the search for IOCGs and amounts to a *joint* interpretation of the two data sets.

The dotted line in **Figure 3.2** traces a narrow residual gravity low running across the image and beyond the limits of the area. It invites speculation that a palaeochannel with relatively low-density infill passes over deeper dense rocks, which, in turn, overlie a deeper magnetic source, and that the supposed palaeochannel could be the cause of the double gravity peak. With this as an overall strategy, a new model was begun using first a shallow, low density flattened rope-like body to simulate the supposed palaeochannel at the north and south ends and passing through the central gravity high. It was then found that a single dense contiguous ovoid feature immediately overlying a magnetic vertical pipe-like body (the classic IOCG scenario) could simulate the gravity and magnetic data.

While the earlier models that used two bodies to simulate the double gravity peak suggested a disappointing prognosis for IOCG mineralisation, the single dense ovoid gave reason to test between the peaks – which yielded significant grades.

Plan views of the evolved model are shown **Figures 5.1** to **5.3**, where magenta-coloured bodies are dense and non-magnetic, and greenish bodies are magnetic. Long, narrow, pale pink bodies have negative density contrasts thus plotting outside the phase diagram (Hanneson 2003), and of these, unlabelled bodies 119, 115 and 111 follow the dotted line in **Figure 3.2** to simulate the linear gravity low. **Figure 6** is a cross-section along line 6547800N, where the solid blue profile shows the magnetic data, and the magnetic model response (dotted blue) is barely discernible because of the accuracy of the simulation. Likewise, the gravity response of the model (dotted red) is an accurate simulation of the gravity data (solid red). As a numerical experiment, the single-peak gravity response (also dotted red in **Figure 6**) arises when the Body 115 simulating the palaeochannel is removed from the model by giving it a zero-density contrast.

The model benefited from knowledge that Hole KH002 intersected basement at 457 m, but the funnel shape used for the dense non-magnetic top is not a strict requirement of the data. Other shapes could simulate the data as well; however, the shape used was inspired by a similar shape in a notional cross section for Olympic Dam (Haynes *et al*. 1995, p298). Often, when a model is constrained only by the ambiguous geophysical data, a small dose of "geological credibility" can make a model geologically more believable and may also reduce the perceived risk that the model could be invalid. Furthermore, splaying the top out along the known unconformity depth allowed incorporation of the fact that minor sulphides were intersected at the unconformity in hole KH002. See **Figures 5.1** and **6**.

A NNE linear magnetic high (body string 39 to 50) can be seen in **Figure 4.2**, however the cause of this feature which is well-defined in the east-west aeromagnetic flight lines seems to be west of and much deeper (800 m) than the interpreted palaeochannel although both could be following an earlier fault structure that in some way controls the magnetic lineament.

The density/susceptibility model contains over a hundred bodies; most are of no perceived economic significance but were included to improve the data simulation. Many bodies plot on the Magnetite Line (left margin of coloured area) of the phase/scatter diagram in **Figure 7** and, in fact, these bodies were chosen to plot on the Magnetite Line but only after their responses were seen to simulate, and therefore to be permitted by, the local magnetic and gravity data. They are interpreted geologically to represent minor accumulations of magnetite within a (felsic) matrix that has the same density as the country rocks, except to say that deep body 28 in **Figure 5.3** is part of this group and is interpreted to represent felsic rocks with about 5 percent magnetite. It suggests deeper more reduced rocks expected for the standard IOCG model.

Other bodies like the greenish string (bodies 50 to 39) in **Figure 5.3** were chosen to plot on the dashed green Gabbro Line, and while simulating the data, they have the properties expected for mafic rock with minor magnetite. Magenta coloured bodies plot on the zero-magnetite baseline to the right of the Gabbro Line and are judged to represent non-magnetic rocks that are denser than barren mafic rock; they are depicted in **Figure 7** and **Table 1** as having the properties of felsic rock with some tens of percent of material like hematite+sulphides and no magnetite.

Body 115, which simulates the interpreted palaeochannel, is poorly constrained by the data. Assuming unconsolidated in-fill, it was assigned a density contrast of 1.95 – 2.65 = -0.70 g/cc (compared

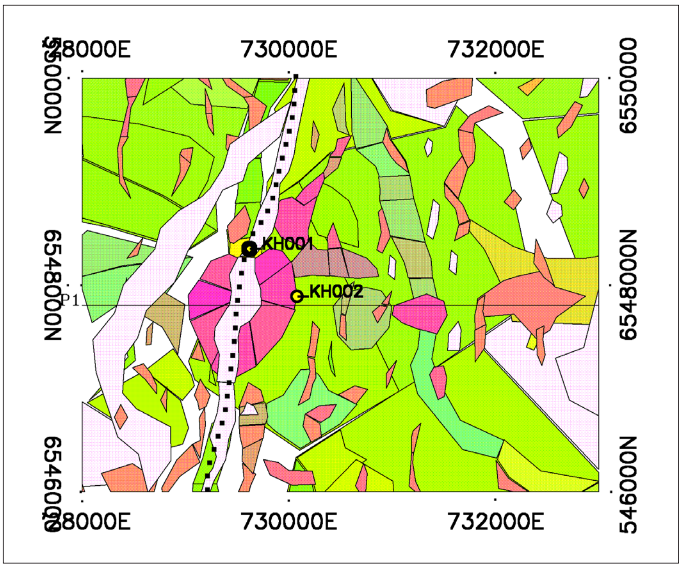


**Figure 5 .1.** *Model body tops. Yellow dots are drill collars.*

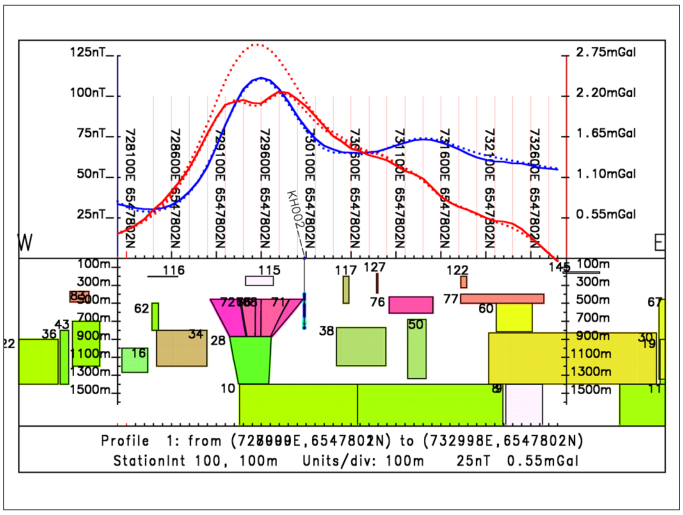


**Figure 6.** *Cross-section along EW line P1 in Figure 5.1. Profiles: gravity=red; magnetics=blue; solid=data; model response=dotted. The dotted red single-peak gravity response occurs when body 115 has zero density contrast.*

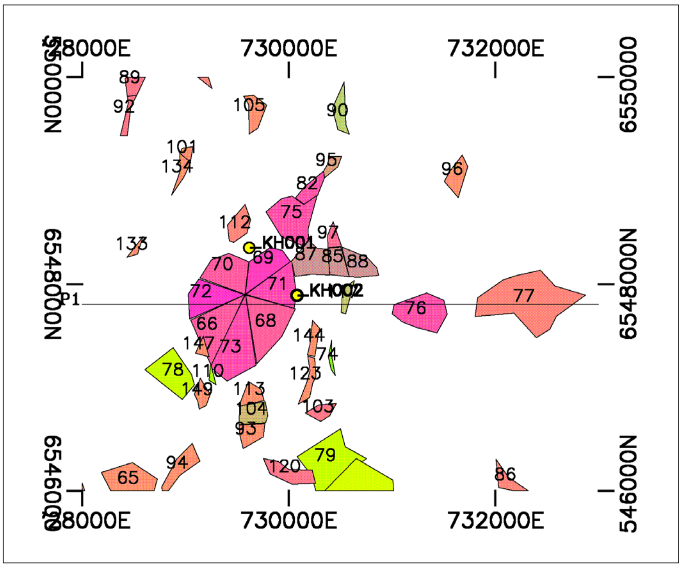


**Figure 5.2.** *Model depth slice: 460 m*

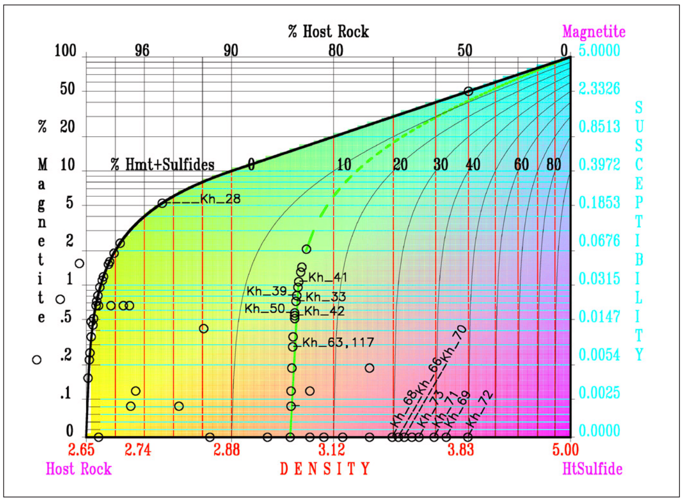


**Figure 7.** *Phase/Scatter diagram with body numbers for bodies and groups of bodies thought to have economic significance.*

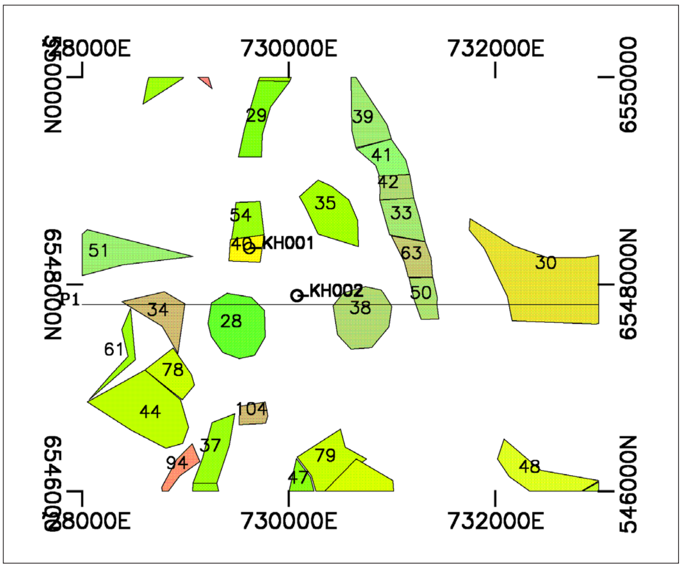


**Figure 5.3.** *Model depth slice: 871 m.*

to the host rocks), which, with a thickness of 100 m, adequately simulates the dip in the gravity profile. Alternatively, semi-consolidated material with, say, a -0.35 g/cc contrast and a 200 m thickness would also work, while the depth estimate could also be affected by a failure of the 200 m spaced gravity stations to capture the true shape of the double peak. **Table 1** gives more details.

## Transient electroMagnetics

### *Preamble*

Early workers in the 1970s era of the Olympic Dam discovery believed that the sulphides within the hematite breccia ore would be too widely disseminated and too poorly connected to be sensed by transient electromagnetic (TEM) prospecting systems, which were, and still are, used effectively to assess profiles of the late time channels for bumps that might indicate nickel-rich pyrrhotite and/or other high conductance ores. We refer here to such TEM effects as *Local Magnetic Induction* (LMI)

**Table 1. Bodies of the density/susceptibility model discussed in the text.**
App%Mt and App%HtS mean apparent percent magnetite and apparent percent hematite+sulphides respectively.

| Body (m) | Depth | Depth extent | Mag Sus (SI) | Density (t/m**3) | App%Mt | App%HtS (Felsic) | Tot Mass (t) | Centroid | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | E | N |
| **Deep magnetic ovoid** | | | | | | | | | |
| 28 | 870 | 530 | 0.194 | 0.123 | 5.21 | 0 | 3.62E+08 | 729485 | 6547589 |
| **Dense non-magnetic bodies making up the funnel-shaped ovoid** | | | | | | | | | |
| 66 | 457 | 411 | 0 | 0.73 | 0 | 31.06 | 1.48E+08 | 729249 | 6547561 |
| 68 | 457 | 411 | 0 | 0.7 | 0 | 29.79 | 1.56E+08 | 729819 | 6547591 |
| 69 | 457 | 411 | 0 | 1.01 | 0 | 42.98 | 6.57E+07 | 729797 | 6548204 |
| 70 | 457 | 411 | 0 | 0.76 | 0 | 32.34 | 6.87E+07 | 729400 | 6548141 |
| 71 | 457 | 411 | 0 | 0.93 | 0 | 39.57 | 7.29E+07 | 729937 | 6547949 |
| 72 | 457 | 411 | 0 | 1.17 | 0 | 49.79 | 1.14E+08 | 729193 | 6547877 |
| 73 | 457 | 411 | 0 | 0.84 | 0 | 35.74 | 2.44E+08 | 729478 | 6547342 |
| **Other dense bodies with economic potential** | | | | | | | | | |
| 75 | 440 | 300 | 0 | 0.8 | 0 | 34.04 | 1.50E+08 | 730068 | 6548643 |
| 76 | 430 | 180 | 0 | 0.8 | 0 | 34.04 | 8.39E+07 | 731270 | 6547713 |
| 82 | 380 | 400 | 0 | 0.8 | 0 | 34.04 | 5.15E+07 | 730222 | 6548920 |
| 85 | 350 | 160 | 0.005 | 0.6 | 0.19 | 25.34 | 2.18E+07 | 730467 | 6548215 |
| 87 | 330 | 180 | 0.005 | 0.6 | 0.19 | 25.34 | 5.20E+07 | 730207 | 6548237 |
| 88 | 320 | 250 | 0.005 | 0.6 | 0.19 | 25.34 | 4.93E+07 | 730710 | 6548165 |
| **Bodies that simulate the interpreted palaeochannel** | | | | | | | | | |
| 111 | 200 | 50 | 0 | -0.5 | - | - | 2.07E+07 | 729297 | 6546412 |
| 115 | 200 | 100 | 0 | -0.7 | - | - | 5.66E+07 | 729495 | 6547658 |
| 119 | 200 | 80 | 0 | -0.5 | - | - | 5.45E+07 | 729909 | 6549146 |

anomalies, where the induced currents in a target can persist until after the decay of the currents induced in the host, at which time they become apparent. In vector displays of the scatter currents on the target, they have a toroidal (or vortex) form, and plate-in-free-space codes can be used to interpret the last few channels (possibly stripped of host effects) of the decay. Thus, the early workers were essentially correct as far as their understanding of TEM theory went - because no one seems yet to have demonstrated LMI responses over a known IOCG occurrence.

With the advent of more powerful mainframe computers in the 1960s and 70s, came the efforts of workers like Hohmann (1975), Weidelt (1975), Lajoie and West (1976), Hanneson and West (1984) and Walker and West (1991) who produced codes that solve the plate-in-conductive-host problem. They simulate, in the frequency domain, currents that flow in both the conductive host and in plate-like targets, the latter sometimes having conductances that can range over several orders of magnitude. The improved understanding was quickly extended to the time domain (Rai 1982) with Fourier transform algorithms like YVESFT (Holladay 1981) that yield the impulse response, and, in Holladay's implementation, also carry out the convolution operation that converts the impulse response to that of any practical transmitter current waveform.

Nabighian (1979) devised an important analytical solution for the time domain currents in a homogeneous halfspace due to a circular current carrying loop at the surface. After current shut-off, it predicts horizontal circularly symmetric E-field loops, initially under the transmitter loop with donut-shaped magnetic flux linkages that diffuse slowly downwards and outwards, in a phenomenon he aptly named a *smoke-ring*.

Host currents of the smoke-ring tend to get diverted into conductive inhomogeneities (as a path of least resistance) and are diverted around features that are less conductive than the host, in a process called *Galvanic Current Gathering* (GCG). Vector displays of GCG currents on a plate-like scatterer show filaments flowing from the upstream end (as defined by the direction of host current flow in the host) to the downstream end of the conductor. If the currents in the host are subtracted off the current flow pattern, then the residual currents have return currents that are outside the plate as illustrated diagrammatically by West and Macnae (1982) and McNeill *et al.* (1984).

The enhanced (or depleted) currents of this electrical effect radiate their fields back to the surface where they alter the local field being measured, and the effect (at the target) is a maximum when the smoke-ring sweeps past. The donut-shaped magnetic flux linkages carried with the smoke-ring induce LMI vortex currents at the same time, but these don't become the dominant current form unless the target is conductive enough that they persist until the E-fields of the smoke-ring have dissipated sufficiently. Also, GCG effects saturate at low plate conductances because they cannot gather more current than is flowing in the host and do not highlight high conductance features as well as LMI effects. One further complication is that LMI currents in a confined target decay exponentially, which is faster than the $t^{-3/2}$ power-law decay of the fields in the semi-infinite host. Consequently, GCG effects dominate again at very late times, although this may be later than the last channel.

The complex 3-dimensional interplay of the electric and magnetic effects in a semi-infinite medium with inhomogeneities does not make for easy conceptualisation. While geophysics students are usually taught about magnetic induction, it seems that the GCG phenomenon is often ignored so that graduates may be prone to entering the exploration workforce ill-equipped to understand, and maybe disinclined to believe, that important information can reside in the early and mid-times, and not just in the late times, of TEM datasets.

## *Conductivity-depth images*

During or shortly after the development of comprehensive modelling codes, workers like Macnae and Lamontagne (1987), Fullagar (1989), Smith *et al.* (1994) and others, began creating conductivity-depth images that transformed inscrutable profiles of TEM channel amplitudes into intuitively credible Conductivity-Depth Images (CDIs) for the earth under a given survey line. Such images are not models, but they provide a more effective way of viewing TEM data because of the knowledge imparted about the existence and approximate locations of conductive or resistive features that could be of interest.

By way of a numerical experiment, the upper half of **Figure 8.1** shows profiles of the modelled responses of five flat-lying plates in a 0.022 S/m halfspace for the in-loop prospecting system discussed below. The lower half shows a CDI derived from the profiles, which uses Nabighian's theoretical descent rate of the smoke-ring maximum to assign an apparent depth to the apparent conductivity for each reading (while holding in reserve one final depth adjustment factor). Algorithms by Hanneson and West (1984) and Holladay (1981) were used to generate the profiles shown in **Figure 8.1**.

In consideration of the overall process, there must be time for the field disturbance caused by transmitter shut-off to diffuse to target depth, excite scatter currents on the target, and for the anomalous scatter currents to radiate their fields back to the surface (similar to the notion of a two-way travel time in seismic processing). In consideration of this, the CDI in **Figure 8.1**, results from a final adjustment factor of 2.0, and while it places the apparent conductivity highs at about the right lateral location, the highs are slightly deeper than the known depths of the plates. Nevertheless, this image is reassuring because bumps (and troughs) in the channel amplitudes correspond to relative conductivity highs (and lows) in the image. Every fifth channel is annotated to make clear how each point on a profile relates to its corresponding point on the CDI. Plate 1 at 90 m depth exhibits a bump in Channel 1 (0.10ms) because the measurement post-dates the arrival of the smoke-ring at the target (plus the return of the scattered fields). Plate 2 is resistive (negative conductivity contrast) and exhibits a conductivity low. Plates 3, 4 and 5 are deep enough that the smoke-ring travel time (multiplied by 2) is later than Channel 1 so that the shallowest conductivities approximate the intrinsic conductivity of the host. This last effect is called *early-time blanking* and has been mentioned by Rai (1982) and others.

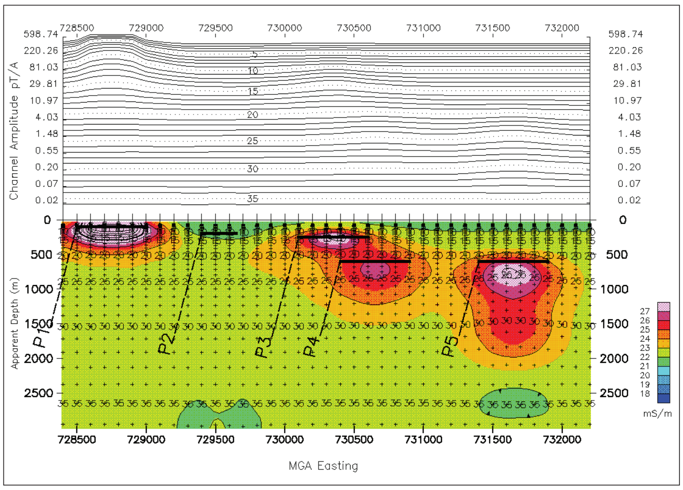


**Figure 8.1.** *CDI derived from profiles of model response at 36 measurement times. Apparent conductivity highs and lows relate to bumps and troughs in the images.*

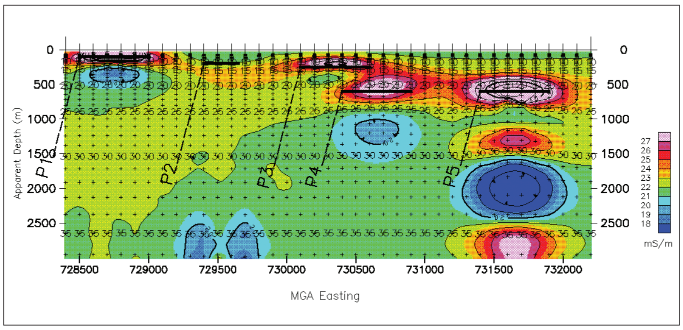


**Figure 8.2.** *Using the integrated conductance over all shallower depths to estimate a mean conductivity encountered by the descending smoke-ring places the maximum apparent conductivity high at the plate – at least for the shallowest plate at a given location. Profiles are the same as in Figure 8.1.*

Interestingly, for a given point on the image, integrating all shallower conductivities seems to give a better estimate for the effective conductivity of the path followed by the smoke-ring, so that when the new descent rate and the time are used to assign a depth, the location of the maximum conductivity high is much closer to the known depth of a plate in the model, but unfortunately the one-to-one correspondence between highs in the image and highs in the profiles is no longer evident. See **Figure 8.2** (for which the profiles are the same as in **Figure 8.1**).

Plate 5 has a high enough conductance (1000 S) to generate an LMI anomaly that persists at least until Channel 33. It exhibits a deep (1200 to 2000 m) conductive lobe in **Figure 8.1**, but is grossly misrepresented in **Figure 8.2**.

**Figure 9** simulates a fixed loop survey for a 200 x 200 m loop above the left edge of the plate and helps explain what is happening on the plate at station 731400E in **Figure 8.1**. It shows the secondary Hz profiles (all channels: yellow) with **H**sec vectors near the red horizontal Plate 5. At 0.87 ms, the **H**sec vectors **circle the entire plate** from which can be inferred a bundle of gathered, unidirectional (GCG) current filaments flowing into the page. At 53.0 ms, the **H**sec vectors have a **dipolar form centred on the plate** and are caused by closed horizontal loops (or vortex) of magnetically induced current on the plate. It is safe to conclude that Plate 5 exhibits GCG effects at mid times and LMI effects at late times. Both phenomenon occur at the plate but the CDI algorithm places the LMI apparent conductivity high at great depth because it is not dominant until after the dissipation of the host currents at late times (early workers would have recognised the Plate 5 anomaly in Channels 25 to 33 in **Figure 8.1** as an LMI anomaly to be stripped of any remaining background host response and interpreted using a plate-in-free-space code).

## *Early TEM tests for IOCG mineralisation*

A single line of 200 m coincident loop SIROTEM data (5 Hz base frequency) was collected in the early days at Olympic Dam, but it was concluded that the last channel (50 ms) was not late enough to "see" the basement. Esdale *et al.* (1987, 2003), however, assure us on the basis of IP/Restivity surveying, that the ore exhibits higher electrical conductivity and polarizability than the country rock. Hart and Freeman (2003) come to the same conclusion for Prominent Hill based on down-hole and surface surveying. Finally, a single (unpublished) line of in-loop TEM (1.6 Hz base frequency; last channel at 148 ms) was read by TeckCominco at Carrapateena, for which a CDI showed rocks with elevated conductivity starting near the known depth of mineralisation. Consequently, a similar prognosis would seem reasonable for the mineralisation at Khamsin.

## *Khamsin TEM data*

### Survey design

In 2018, subsequent to the Khamsin discovery, OZ Minerals Ltd. carried out TEM surveying to determine if IOCG mineralisation generates recognisable responses in CDIs for the area. Theoretical responses were used to assess depth penetration and target sensitivity for the, by then, known conditions at nearby Carrapateena. Based on the results, the selected field system was a Geonics Ltd transmitter to generate fields with an exponential-on ramp-off bipolar current waveform, a 1 Hz base frequency and a ramp-off duration of 750 microseconds. A SMARTem receiver collected in-loop B-field measurements binned into 36 time channels ranging from 0.094 to 225.8 ms. Transmitter loops of 200 x 200 m size were deployed with 100 m stations along 200 m spaced lines.

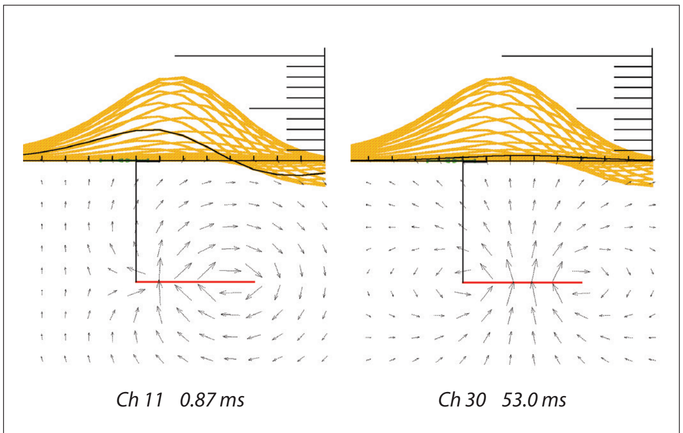


**Figure 9.** *Profiles of $H_z^{sec}$ due to currents on 500x500m red plate at 550m depth with vector display of $H^{sec}$. Even numbered channels are shown in yellow. Black profiles show Channels 11 and 30. Scale bar ranges from 0 to 1 pT/A.*

### Data CDIs and depth slices

The Khamsin survey data were converted to apparent conductivity and apparent depth for all stations and all times using the method described for **Figure 8.2** (but using a depth adjustment factor of 2.3 to distribute the error between shallow and deeper features). Interrogating the resulting metafile then permitted the generation of the depth slices shown in **Figures 10.1** to **10.4** and CDIs for all east-west lines, of which one, L6547800N through the centre of the deposit, is shown in **Figure 11**. Profile amplitudes in **Figure 11** use a *sinh* scale suggested by James C. Macnae (c.1987, *pers comm.*), which transitions smoothly from linear at low values to logarithmic at high values. Of the CDI schemes reported above, the one described here is not necessarily the best; rather, it is the only one available to us.

### Plate-in-host model

The modelling code that produced **Figures 8.1** and **8.2** was then used in an attempt to simulate the profiles and a CDI for Line 6547800N using the same specifications that were set for the survey equipment. The result is shown in **Figure 12.1**. The model comprises flat lying (non-interacting) plates in a host environment judged to be similar to that at Khamsin. Early models yielded CDIs, which, upon comparison with the data CDI (**Figure 11**), gave visual indications of how the model had to be modified and/or expanded to better simulate the data. The computed response of the thin plates shown in **Figure 12.1** is the best model found so far, and while it remains an imperfect simulation of the data profiles and the data CDI, there are enough similarities to make it worthy of further consideration. As stated above, a CDI is not a model; the model, now offered as an interpretation of the data, is the 0.025 S/m halfspace and the nine plates shown in the lower half of **Figure 12.1** and described in **Table 2**.

### Interpretation of the CDIs

Forward modelling is an arduous, computationally intensive task, but if it can be agreed that the above model for L6547800N is reasonable, then with little further effort, the depth slices and the CDIs generated from the full dataset can be taken as a qualitative, or at best, a semi-quantitative interpretation of local electrical structures (with due regard for the misrepresentations of any LMI anomalies).

**Figure 10.1** shows a near ubiquitous conductive layer at about 100 m depth. At 450 m depth, **Figures 10.2** and **11** suggest that the part of the ovoid not covered by the conductive layer exhibits an apparent conductivity high at about the unconformity depth, but a similar claim for the 600 and 900 m depth slices (**Figure 10.3** and **10.4**) is less convincing.

The interpreted palaeochannel, which was so disruptive to the gravity, seems also to disrupt the mid-level depth slices (**Figures 10.2**, **10.3** and possibly **10.4** in the far north) and appears as a linear conductivity low following the same dotted line shown in **Figure 3.2**. While interpreting this feature as a palaeochannel might seem reasonable as long as only the geophysical data was available, subsequent drilling suggests a normal fault with a slight downthrown eastern side. Porous Whyalla sandstone units are in contact on either side of the interpreted fault, and, to the east, at least, these rocks contain hypersaline water. For the linear feature to appear resistive would seem to require low salinity water sealed off from the saline waters in the shallower (?) sandstone, and, if the 900 m deep conductivity low seen in **Figure 10.4** is real, then a fault

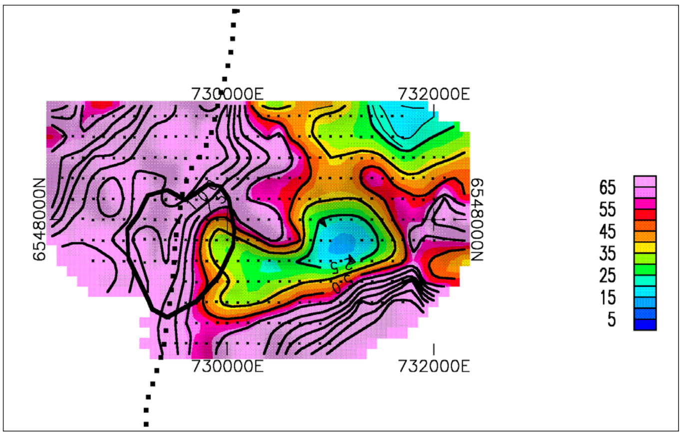


**Figure 10.1.** *CDI depth slice: 100m. Units are mS/m. The black outline indicates the dense ovoid in Figure 5.2.*

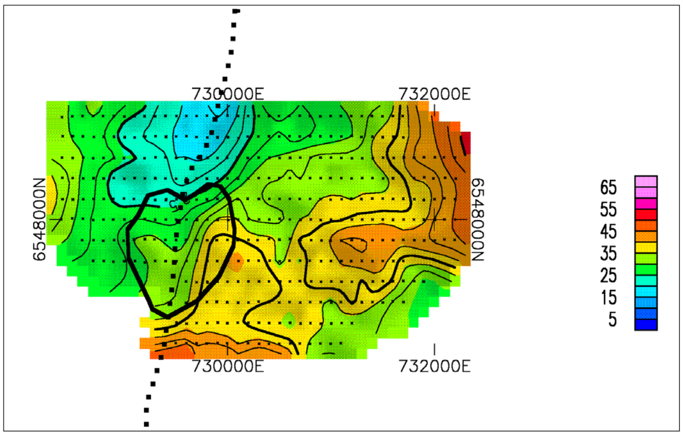


**Figure 10.3.** *CDI depth slice: 600 m.*

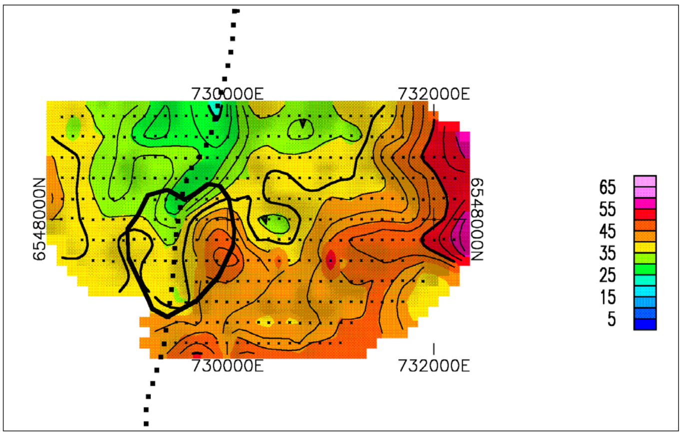


**Figure 10.2.** *CDI depth slice: 450 m*

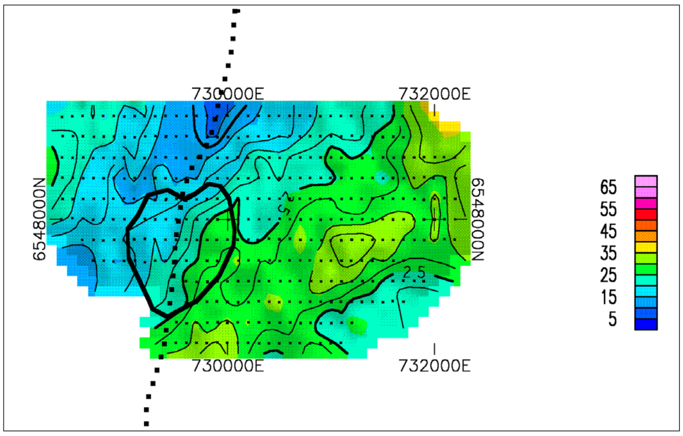


**Figure 10.4.** *CDI depth slice: 900 m*

might seem more probable than a palaeochannel at that depth. Interpretations will no doubt converge as more information becomes available. This feature seems not to have been drilled, and, if the low conductivity means weakly saline or even potable water, it might represent a resource of value to local pastoralists and/or for mine development.

The lobe of elevated conductivity associated with Plate 9 in **Figure 12.1** (near 730000E, 450 m depth) seems to be about all that we can expect from the ore at Khamsin under such difficult survey conditions. In an early model a single plate covered the lateral extent of the ovoid in **Figures 5.2** and **Figure 10.2**, but when divided into Plates 5 and 9, the small separation, with resistive Plate 7, was found to replicate better the dip in conductivity that follows the linear gravity low.

A numerical experiment shown in **Figure 12.2** indicates that if Plate 1, used to simulate conductive cover, is eliminated then Plates 5 and 9, used to simulate the vicinity of the ovoid, would both be revealed in the CDI. It seems safe to conclude that a conductive zone in the cover is masking the TEM response from a significant portion of the deposit.

Visual inspection of drill core suggests rock of relatively low porosity (to the exclusion of conductive brines?) with sulphide disseminations – a situation often recognised as causing polarization effects in TEM data (Flis *et al.*1987, Hodges and Smith, 1997). The response of Plates 5 and 9 in the model seems

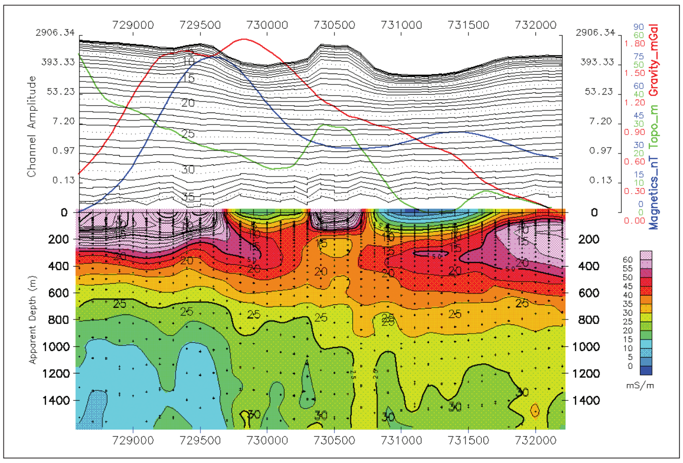


**Figure 11.** *Channel amplitudes and CDI for Line 6547800N with profiles of gravity (red), magnetics (blue) and topography (green).*

to require a dispersive conductivity in order to generate the low (blue) values under them in **Figure 12.2**, but the effect is insufficient when compared to the data. This may mean that the best combination of Cole-Cole parameters has not yet been found, or, that the deeper country rocks under the deposit are less conductive. When Plates 5 and 9 in **Figure 12.1** are made non-polarizable ($m$=0) the conductivity low beneath them disappears (not shown).

Plate 4 in **Figure 12.2** seems not to require polarization properties to simulate the data – possibly because galvanic currents associated with its higher conductance are suppressing or overwhelming any polarization effects. Plate 4, however, deserves mention because it is almost coincident with a minor magnetic high and a flattening of the gravity gradient seen in **Figure 12.1**, and it might represent dense, magnetic and conductive mineralisation that has not yet been tested.

The plate-in-host model may not be the best for the present purpose, but it is the only code to which we have access that includes the full effects of the conductive host on the response of a target body. **Figure 8.1** hints that the anomaly attenuation due to increasing depth-to-top, is rapid (compared to potential field anomalies), and it might be argued that it is the upper surface in contact with the cover rocks that would dominate the response of a block-like body. The thin plate model could therefore be better than what might be expected. However, the thin plates create a dilemma for resistive bodies. Setting the plate conductance to zero in a 0.025 S/m halfspace yields a weak conductivity low in the CDI; however, this might not be enough to simulate some resistive features. Normally one would simply increase the plate thickness but since this option is not allowed by the thin plate model, we have had to dip into the non-physical region of negative conductances to simulate some features in the data.

## Conclusion

An important step in the discovery of the Khamsin deposit was recognition that the double peaked gravity anomaly could be caused by a low density palaeochannel within the cover rocks and passing over the source of the central gravity high. It led to the development of a model comprising dense and magnetic ovoids arranged so as to suggest the classic IOCG scenario, while still simulating the data, and thereby elevating the geological credibility of the model to a point where drilling between the peaks seemed worthy of the risk. Gravity and magnetics are well established techniques in the search for IOCGs; however, the Khamsin experience indicates that explorers need to be alert to features that can disrupt the apparent coincidence of gravity and magnetic anomalies.

It seems that part of the deposit can be seen in the conductivity depth-slices and cross-sections – at least when the gravity and magnetics hint at where to look in the images. This at least leaves room for optimism in applying TEM in the search for IOCGs elsewhere.

We believe that the joint interpretation of magnetic and gravity data remains the most important method in the search for IOCGs. However, a qualified success at Khamsin suggests that TEM can

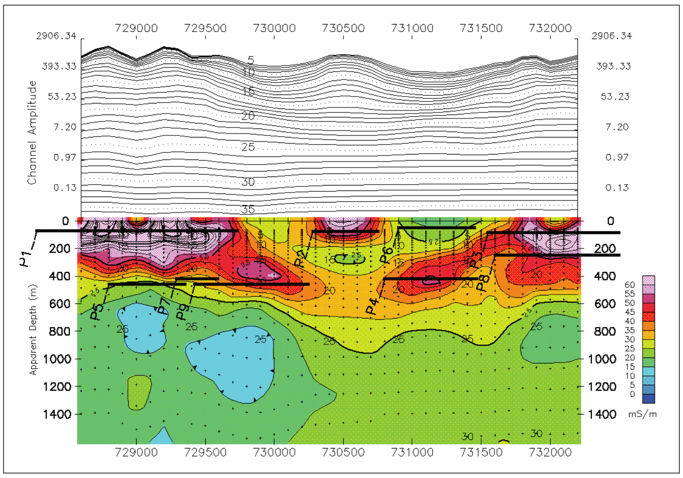


**Figure 12.1.** *Response of nine flat-lying plates in a 0.025 S/m halfspace.*

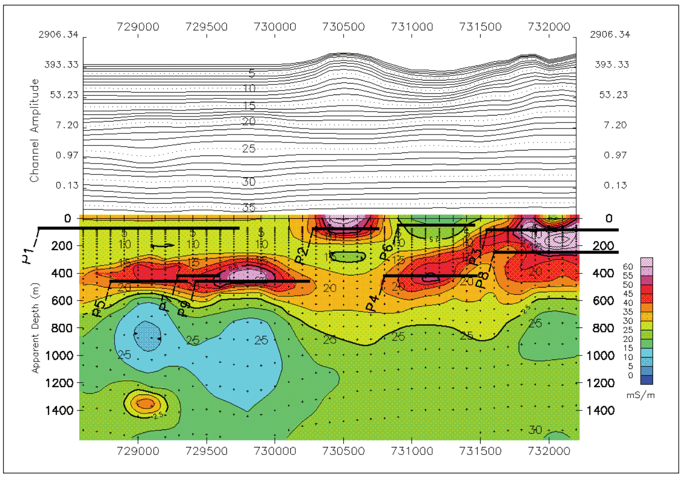


**Figure 12.2.** *When Plate 1 is given zero conductance, the full extent of Plates 5 and 9 are evident.*

**Table 2. TEM model with non-interacting plates in a non-polarisable 0.025 S/m halfspace.**

| Plate | Length | Width | Depth | Dip | Sig-P | Cole-Cole Parameters | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | S | *m* | *tau* | *c* |
| 1 | 1500 | 1450 | 70 | 0 | 8.0 | 0.0 | 0.001 | 0.25 |
| 2 | 400 | 470 | 75 | 0 | 5.0 | 0.0 | 0.001 | 0.25 |
| 3 | 900 | 950 | 85 | 0 | 6.0 | 0.0 | 0.001 | 0.25 |
| 4 | 500 | 670 | 420 | 0 | 62.0 | 0.0 | 0.001 | 0.25 |
| 5 | 1500 | 550 | 460 | 0 | 11.0 | 1.4 | 0.008 | 0.25 |
| 6 | 400 | 550 | 50 | 0 | -0.98 | 0.0 | 0.001 | 0.25 |
| 7 | 1300 | 300 | 420 | 0 | -30.0 | 0.0 | 0.001 | 0.25 |
| 8 | 900 | 900 | 250 | 0 | 8.0 | 0.0 | 0.001 | 0.25 |
| 9 | 1500 | 820 | 460 | 0 | 12.0 | 1.1 | 0.005 | 0.25 |

be used as a third independent (and non-invasive) method to assess electrical properties for base metal sulphides, in order to further reduce risk in the risky endeavour of mineral exploration.

## Acknowledgements

The authors thank Jim McKinnon-Matthews, OZ Minerals, for managing aspects of the efforts needed to produce this report, and the authorities at OZ Minerals Ltd, now BHP, for generous funding of the TEM work and for permission to publish the results.

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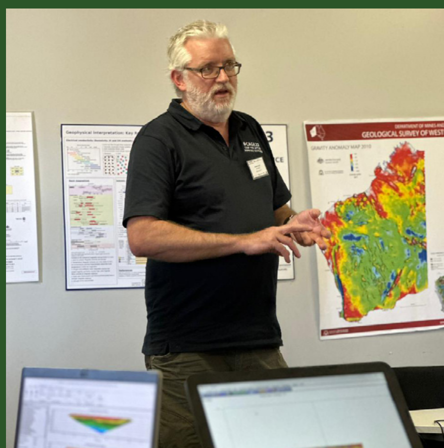
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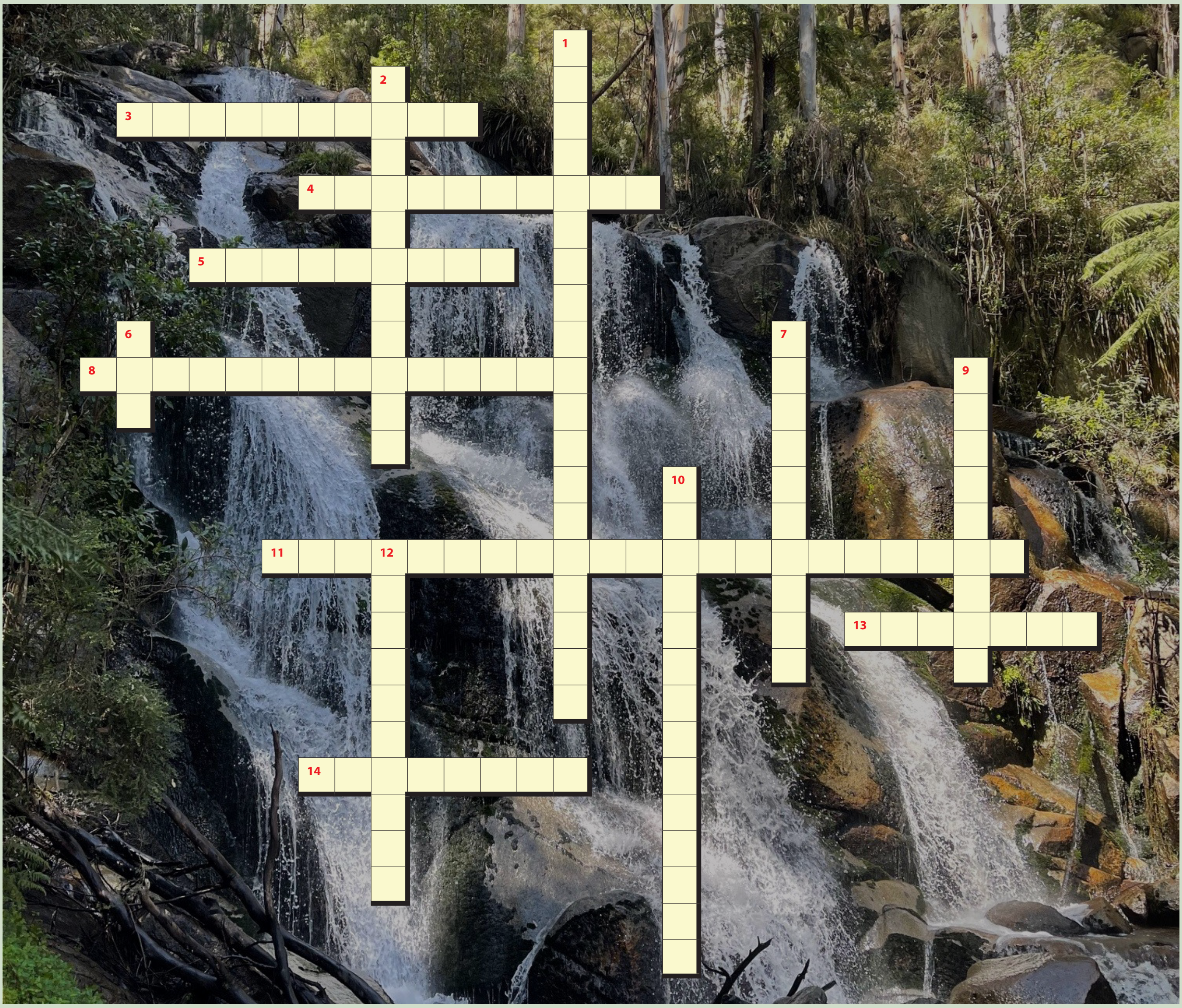
## *Preview* crossword #30

## *I have a beef with you*




### Across

**3.** An American sandwich consisting of ground beef and onions in a tomato-based sauce served on a hamburger bun [6,4]

**4.** Russian dish of sautéed pieces of beef in a sauce of mustard and sour cream

**5.** A classic Italian slow-cooked dish that translates to 'bone with a hole' that is traditionally served with either risotto or polenta [4,5]

**8.** A Mexican dish that translates as 'chilli with meat' [6,3,5]

**11.** This popular US food chain uses Ritz crackers rather than breadcrumbs in this dish [7,7,8]

**13.** A hearty, warming stew of slow-cooked, fall-apart beef in a rich and slightly smoky tomato and paprika sauce

**14.** A well-known Korean rice bowl dish topped with all sorts of seasoned sautéed vegetables, marinated beef (usually) and a fried egg sunny side up

### Down

**1.** A super hearty beef and beer stew from Belgium [10,8]

**2.** A magnificent slow-cooked French dish with hearty vegetables in a rich red wine sauce.

**6.** An extremely popular Vietnamese noodle soup dish

**7.** This English classic has a deeply savoury beef mince filling smothered in gravy topped with creamy mashed potato [7,3]

**9.** All over the world, ground meat rolled into a ball

**10.** An English dish made out of fillet steak coated with pate and mushrooms, wrapped in puff pastry [4,10]

**12.** Salt-cured brisket [6,4]

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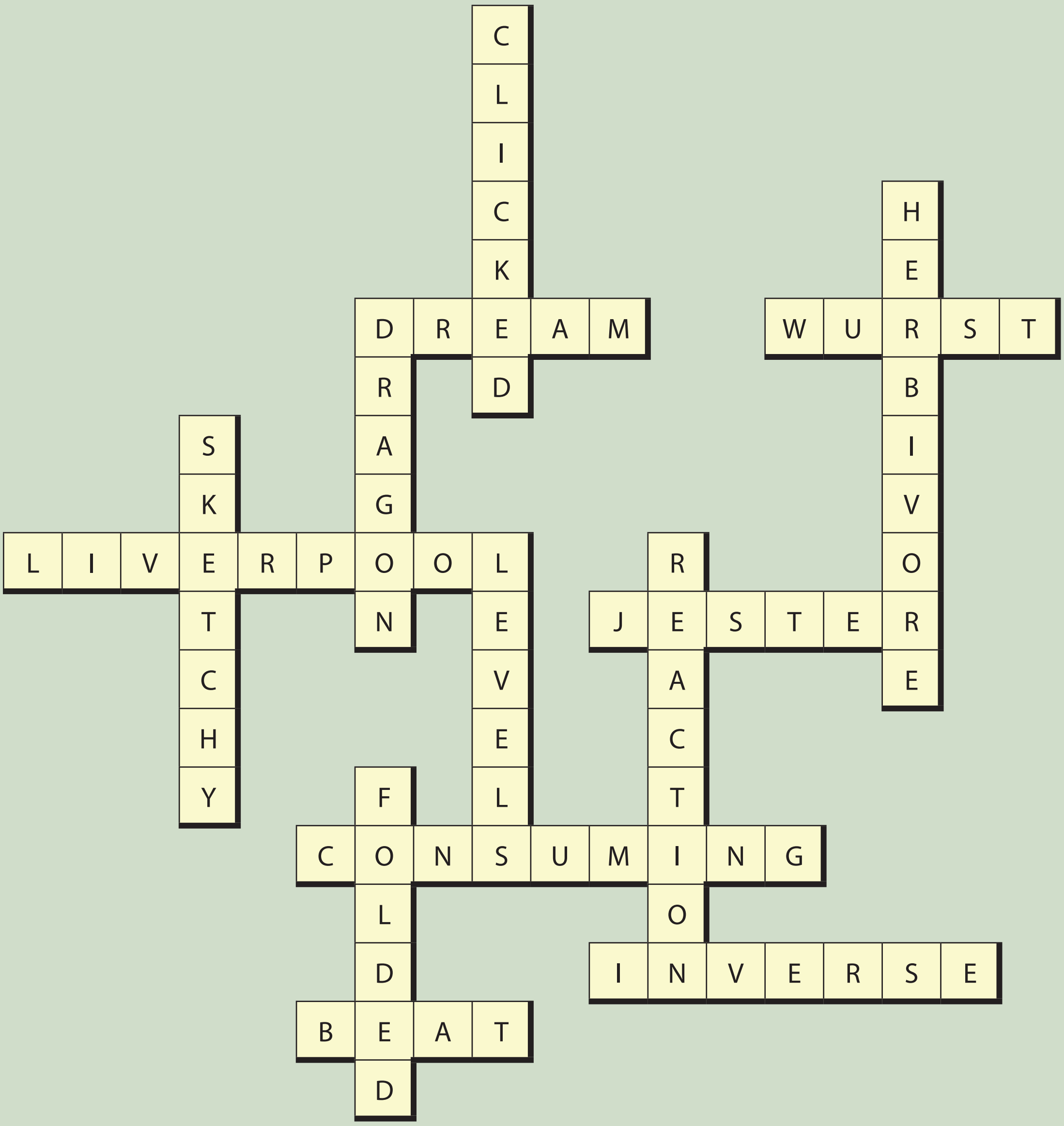
## *Preview* crossword #29 solution

### *What a pun-dle of joy*

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|---|---|
| ❑ Active/Associate (Australia) - $204.60 (incl GST) | ❑ Active/Associate 3 Year Membership (Australia) - $613.80 (incl GST) |
| ❑ Active/Associate (Group IV Countries) - $186.00 | ❑ Active/Associate 3 Year Membership (Group IV Countries) - $558.00 |
| ❑ Active/Associate (Group III Countries) - $55.80 | ❑ Active/Associate 3 Year Membership (Group III Countries) - $167.40 |
| ❑ Active/Associate (Group I & II Countries) - $20.50 | ❑ Active/Associate 3 Year Membership (Group I & II Countries) - $61.50 |
| ❑ Associate-Graduate (Australia) - $102.30 (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 CanPrint so that I can receive copies of ASEG publications. CanPrint will not use the member list for any purpose other than for distributing ASEG publications including *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 of *Preview* delivered to their nominated address (offer does not apply to Student members). In 2024, a fee rebate (approx 15%) is available to members who choose to not receive hardcopy *Preview*.

❑ **Yes, I would like to receive hardcopy *Preview*** ❑ **No *Preview* hardcopy (apply the 2024 fee rebate)**

## 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.

**AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS**
A.B.N. 71 000 876 040

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Phone: +61 2 9431 8691 Fax: +61 2 9431 8677
Email: secretary@aseg.org.au Website: www.aseg.org.au


# Application for Student Membership 2024

## 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 | Title

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 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.

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

❑ **Yes** ❑ **No**

### Section 5 Declaration

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

Signature: ______________________________ Date:

## ASEG CODE OF ETHICS

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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.

# International calendar of events 2024–25

| February | 2024 | | |
|---|---|---|---|
| 14–16 | State of Energy Research Conference (SoERC) 2024<br>**https://www.erica.org.au/soerc2024** | Perth | Australia |
| 25–28 | ASCE Geo-Congress 2024<br>**https://www.geocongress.org/** | Vancouver | Canada |
| 27 Feb–01 Mar | Oshore Technology Conference Asia (OTC Asia)<br>**https://2024.otcasia.org/** | Kuala Lumpur | Malaysia |
| **March** | **2024** | | |
| 3–6 | PDAC<br>**https://www.pdac.ca/convention** | Toronto | Canada |
| 11–13 | Carbon Capture, Utilization, and Storage (CCUS)<br>**https://ccusevent.org/2024** | Houston | USA |
| **April** | **2024** | | |
| 14–19 | EGU 2024<br>**https://www.egu24.eu/** | Vienna | Austria |
| **May** | **2024** | | |
| 7–8 | International Mining Geology 2024<br>**https://www.ausimm.com/conferences-and-events/mining-geology/** | Perth | Australia |
| 6–9 | Oshore Technology Conference (OTC)<br>**https://2024.otcnet.org/** | Houston | USA |
| 13–15 | 6th Asia Pacific Meeting on Near Surface Geoscience and Engineering<br>**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)<br>**https://urtec.org/2024** | Houston | USA |
| **August** | **2024** | | |
| 18–23 | Goldschmidt2024<br>**https://conf.goldschmidt.info/goldschmidt/2024/meetingapp.cgi** | Chicago | USA |
| 25–31 | International Meeting for Applied Geoscience & Energy (IMAGE)<br>**https://www.imageevent.org/** | Houston | USA |
| **September** | **2024** | | |
| 8–12 | EAGE Near Surface Geoscience Conference & Exhibition 2024 | | |
| **October** | **2024** | | |
| 15–18 | ASEG DISCOVER 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.

Advertising and editorial content in *Preview* does not necessarily represent the views of the ASEG or publisher unless expressly stated. No responsibility is accepted for the accuracy of any of the opinions or information or claims contained in *Preview* and readers should rely on their own enquiries in making decisions affecting their own interests. Material published in *Preview* becomes the copyright of the ASEG.

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Single copies of *Preview* can be purchased from the ASEG.

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 April issue is Friday 8 March 2024.

For the advertising copy deadline please contact the Editor at **previeweditor@aseg.org.au**

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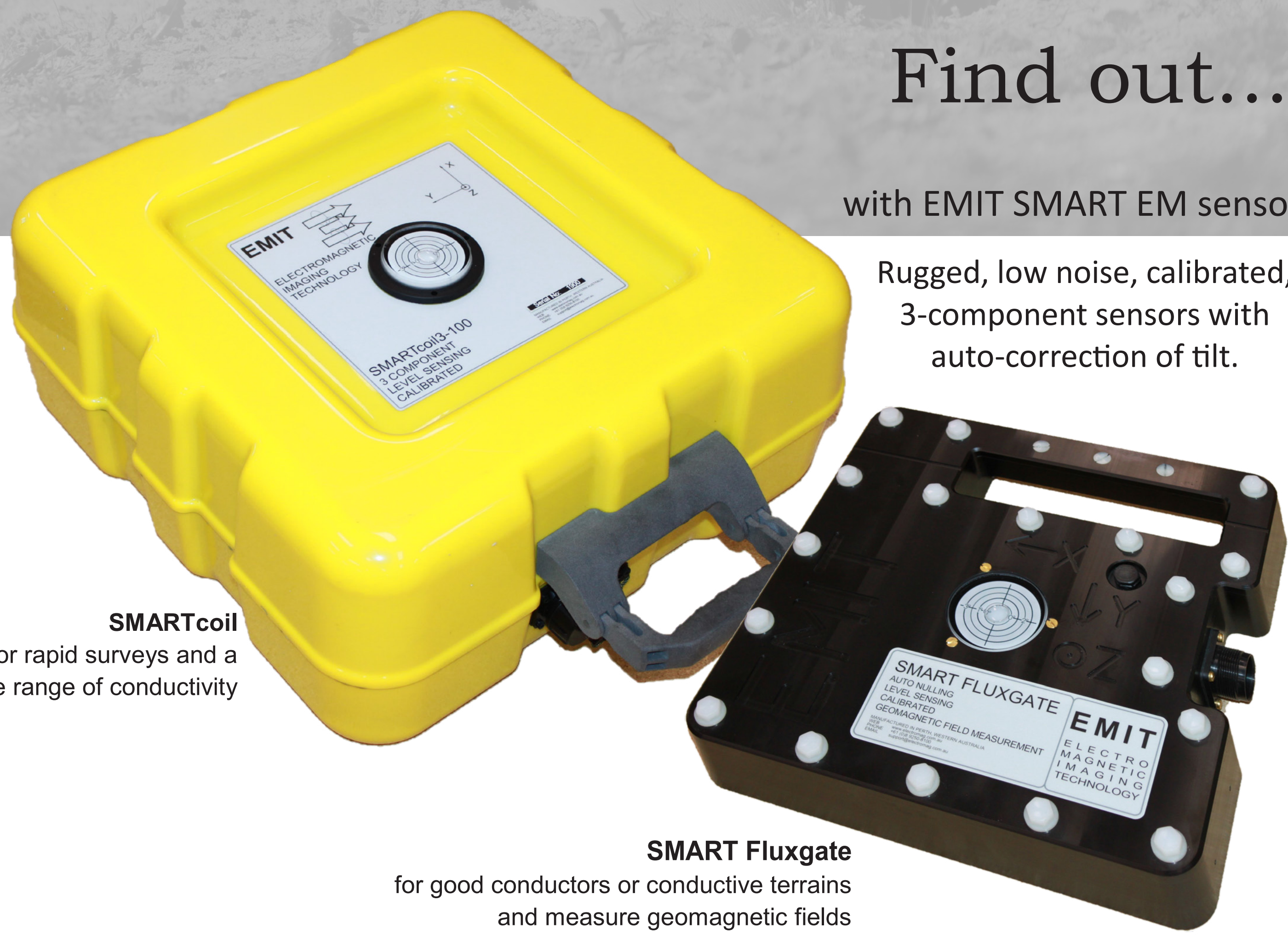


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