Australian Society of Exploration Geophysicists

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PREVIEW

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Doug Morrison, circa 1963 – 64, transcribing analogue data to maps at Aero Service Corp. See ASEG news/Committees for more information.

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Editor's desk

This issue, the third issue of *Preview* since the "Rona" upended our lives, is a bumper issue – especially for those of you who have gone back into lockdown.

Our "best of" series, marking the 50th anniversary of the establishment of the Australian Society of Exploration Geophysicists, continues with a selection made by Professor Michael Asten. Michael is a longstanding and distinguished Member of the ASEG, who was instrumental in setting up the Shanti Rajagopalan award for the best student paper published in *Exploration Geophysics*. Shanti was the Editor of *Exploration Geophysics* from 2000-01, but sadly her life was cut short in 2001.

We also have a second feature, a review of 2.5D AEM inversion written by Rod Paterson at Intrepid Geophysics. This review sounds a timely warning about non-expert interpretation of CDIs and 1D inversions. Geoscience Australia's Exploring for the Future Programme has acquired, and presumably, given an extension of funding, will continue to acquire a truly staggering volume of AEM data. Contractor CDIs and GA in-house 1D inversions are being released with the data, and some of your geological colleagues might need reminding that these products should be interpreted with care. Rod's paper might help with that.

As if two features weren't enough, we have a third! Ken Witherly was prompted by Richard Schodde's PDAC 2020 talk to reflect on the past and future of exploration geophysics. A thought provoking analysis.

But wait, there is more, John Stanley and Phil Schmidt have written a tribute to Ron Green. No, he is not dead, but turning 90. A fine age and fine tribute from former students who are grateful for his guidance. Happy Birthday Ron!!

Also, David Denham (*Canberra observed*) considers the good, the not-so-good, the bad and the very bad in Canberra politics. Mike Hatch (*Environmental geophysics*) is intrigued by geophysics being carried out by archaeologists in the UK. Terry Harvey (*Mineral geophysics*) urges geophysicists to go that extra mile when reviewing and reprocessing legacy data. Mick Micenko (*Seismic window*) is pleasantly surprised by AI. Tim Keeping (*Data trends*) alerts readers to planning for a new petrophysical sampling guide, and calls for input to the formulation of a universal passive seismic data format, and Ian James (*Webwaves*) provides guidance on the use of the ASEG YouTube channel.

Enjoy!

Lisa Worrall
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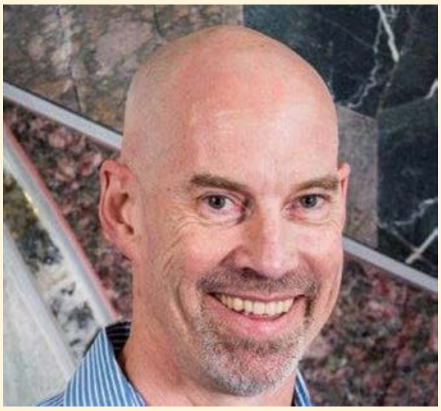
The editor exploring the art of the "selfie" whilst exploring Queensland - as per the Queensland Premier's instructions.

President's piece



So to the second President's Piece of my term. The two themes of this Piece are vacancies in some the ASEG's critical committees and, echoing Ian James' *Webwaves* column in this issue, webinars. In early July, at the time of writing, the COVID-19 pandemic continues to dominate daily life. While some parts of Australia are looking forward to resuming normal life, others are revising expectations.

Eagle-eyed readers of *Preview*'s inner front cover may notice three vacancies in some of the ASEG's many committees. Active involvement in these committees can be a rewarding way for Members to contribute not only to their professional development, but also to that of their colleagues. The Education and International Committees, as well as the Young Professionals and Near Surface Special Interest Groups, all need motivated leaders to take them to the next level. The Young Professionals group, in particular, is an excellent opportunity for recent graduates to improve their visibility in the industry. If you would like to help with any of these groups, please contact Leslie Atkinson (fedsec@aseg.org.au) for more details.

The ASEG continues to address the absence of face-to-face state branch technical meetings through webinars. After our successful online AGM, we made the decision to host webinars so that it would be easier for people to stay engaged. Registration is open to Members and non-members alike, and corporate partners and sponsors of state branches are acknowledged before each session. Recorded webinars are uploaded to the ASEG's website (https://www.aseg.org.au/aseg-videos), as well as to the ASEG's YouTube channel (https://bit.ly/2ZNglaZ), to ensure a wider audience than would be possible either at a branch technical night or at a conference.

The ASEG also sees these webinars as an opportunity to publicise the ASEG and exploration geophysics. At the time of writing, 13 webinars have been hosted. Figure 1 shows attendance by country for all webinars. As might be expected, the majority of participants are from Australia, with a small degree of participation from the ASEG's international cohort. Two Members have attended all webinars. The most popular webinar to date has been ex-ASEG President Marina Costelloe's talk "Mentoring through change, a perspective" followed closely by Indrajit Roy's talk "Computations methods in geophysics". As might also be expected, interest in webinars somewhat follows that of regular branch meetings. General interest topics are better subscribed than more niche topics. However, overall, attendance rates are high and Members generally out number non-members.

For readers who are wondering about the effort involved in presenting a webinar, and are undecided about whether to present one, I offer the following. Personally, the experience was not too dissimilar to a conference presentation, but with some advantages. I found an initial discomfort talking at a screen, but this wasn't too far removed from

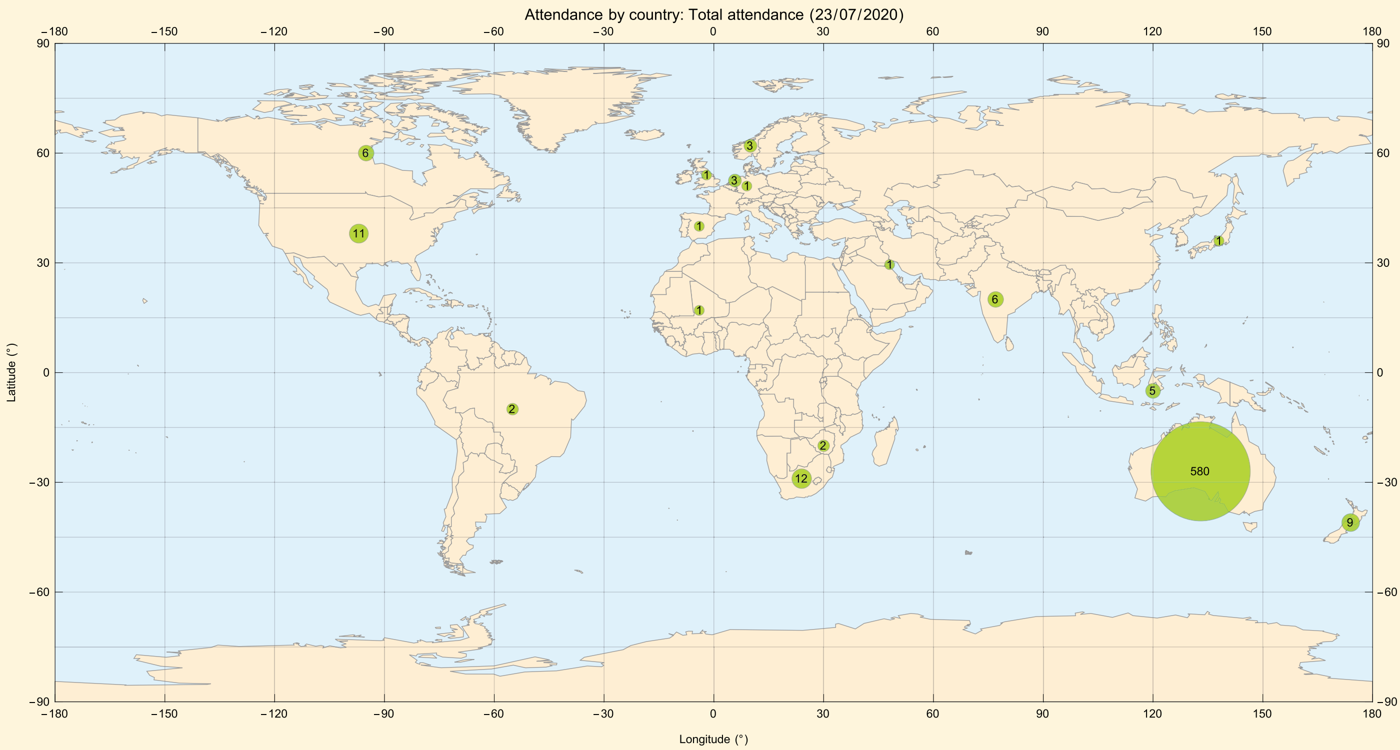


Figure 1: *Attendance at all ASEG webinars. Numbers indicate number of attendees from a particular country. While most attendees are from Australia, roughly 12% are not. This percentage is slightly lower than the ASEG's proportion of international Members, which is 15%.*

ASEG news

the initial discomfort looking out over a sea of faces at a conference. In any case, initial discomfort fades quickly into the presentation, which may be longer than that at a conference, and therefore contain more detail. I suggest that post-talk questions in webinars offer advantages over those at conferences because there are fewer restrictions for time. Personally, it was a rewarding experience.

It may be that future webinars proceed in a manner similar to the Geological Survey of Queensland's Sustainable Minerals Series (https://bit.ly/3gMdSdc) where free-ranging post-presentation discussion from 'the floor' is encouraged. Because they are broadcast to a wide audience, webinars represent an opportunity for your work to reach those unable to attend conferences or technical nights. They are also an excellent opportunity to improve on your future presentations, because you get to watch and critique your own recording.

To summarise, the ASEG views webinars are so successful that, when the COVID-19 pandemic eases, we would like branches to host and record them as a matter of course. If you are interested in presenting your work to a large audience, please contact Kate Robertson (president-elect@aseg.org.au) or me (president@aseg.org.au) for more information.

David Annetts
ASEG President
president@aseg.org.au

Executive brief

The Federal Executive of the ASEG is the governing body of the ASEG. It meets once a month, via teleconference, to deal with the administration of the Society. This brief reports on the monthly meeting that was held in June 2020.

Finances

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

Year to date income: $168 477

Year to date expenditure: $130 637

Net assets: $1 113 425

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

Membership

As at 1 July, the Society had 831 financial Members, compared to 906 at this time last year. The ASEG currently has five Corporate Members, including three Corporate Plus Members. A huge thanks to all our Corporate Members for your continued support in 2020. Don't forget to have a look for our Corporate Members on the contents page of *Preview*, and to support them as much as you can. It is great to see our Society's Members also taking advantage of the savings gained with the 5-year membership options. Please remember early and mid-career Members can join the ASEG Young Professionals Network at www.aseg.or.au/about-aseg/aseg-youngprofessionals.

Social media

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

Online events

The current circumstances have prevented monthly face-to-face meetings at state level, so the ASEG has continued with the webinar series. There have been some really interesting talks. These are all recorded and available for viewing at the ASEG website or on our YouTube Channel. The Federal Executive is looking at the possibilities for returning to face-to-face meetings in those states where it is safe to do so. So, keep a look out for notifications from your state branches to see what is coming soon, and get out there and reconnect with your colleagues.

With 2020 marking the ASEG's 50th year, the committee has lots of interesting events and promotions coming in the year ahead. It's not too late to renew, so remind your friends and colleagues, and renew today.

If there is anything you wish to know more about, please contact Leslie at fedsec@aseg.org.au.

Leslie Atkinson
ASEG Secretary
fedsec@aseg.org.au

Welcome to new Members

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

First name	Last name	Organisation	State	Country	Membership type
Fatemeh	Amirpoorsaeed	Monash University	VIC	Australia	Student
Flynn	Cameron	University of Adelaide	SA	Australia	Student
Josh	Grattage	Camborne School of Mines, Exeter University	Staffordshire	United Kingdom	Student
Pooya	Hadian	Curtin University	WA	Australia	Student
Tavis	Lavell	GBG Maps	VIC	Australia	Active
Bhavik	Lodhia	Imperial College London	Leicester	United Kingdom	Active
Behnam	Sadeghi	University of Sydney	NSW	Australia	Active
Nathan	Wake	University of Sydney	NSW	Australia	Student

ASEG Research Foundation: Looking to the future

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 29 years, and has spent nearly $1.5 M dollars with the support of the ASEG and tax-deductible donations made by ASEG Members, supporting companies and others. This year, thanks to the generous support of the ASEG ($45 000) and Members, we have been able to award grants to four new projects; one BSc, one MSc and two PhDs.

With the financial year just over, I take this opportunity to thank those of you who made donations and look forward to your continued support. This is one way in which we can all back the future of our profession.

At our meeting held during the AEGC conference in Perth last year, the members of the Foundation discussed the composition of the current committee. Many of us have served in our current roles over many years so, with an eye to the future, it was resolved to invite new people to join. It was our combined view that the membership of the Foundation should gradually evolve to reflect the change in the makeup and needs of our profession and, as a consequence, the ASEG.

As a consequence, I am very pleased to welcome eight new members of the ASEG Research Foundation committee. The overall spread of their skills and experience will complement our makeup and help to set us with a view to the future. We welcome:

Mike Haederle, General Manager, Western Australia, with Rio Tinto Exploration. Mike has had a long career with Rio Tinto firstly as a geophysicist, and then in broader exploration roles in Australia and overseas.

Ian James, Senior Geophysicist, HiSeis. Ian has extensive experience in field seismic data acquisition, data processing and interpretation and the innovative application of seismic in non-petroleum applications.

Asmita Mahanta, Manager, Technical Services & Data Integration (Geoscience WAIO), BHP Iron Ore. Asmita has extensive experience with BHP across a number of areas including mineral exploration in India, the Falcon implementation team, and BHP Iron Ore where she is part of the brownfields exploration team that substantially expanded iron ore resources. She also led the development of innovative downhole technologies for the rapid assaying of iron ore blast holes.

Joe Cucuzza, Consultant. Joe had extensive experience in industry as a geophysicist before joining AMIRA International, becoming Managing Director in 2012. He retired from AMIRA in 2019 and has re-joined the Foundation committee.

Roland Hill, Head of Innovation and Geophysics, MMG. Roland has an extensive career in minerals exploration over many years in Australia, and many other parts of the world.

Chris Wijns, Group Geophysicist, First Quantum Minerals. Chris had a distinguished academic career followed by extensive mineral exploration experience. He is still very much involved with academia and research through various advisory boards and the AMIRA board.

Tania Dhu, Manager Geophysics and Remote Sensing, Northern Territory Geological Survey. Tania has extensive geological survey experience with both the Geological Surveys of South Australia and the Northern Territory covering all aspects of their geophysical, remote sensing and other activities.

Sharna Riley, Senior Geophysicist, Resource Potentials. Sharna specialises in the use of magnetic, gravity and passive seismic in gold exploration.

In my view, the experience, contacts and age spread of our new members enhances the makeup of the current committee and I welcome them all. An obvious shortcoming is a lack of people involved in the petroleum industry. If you are one of these and would be interested in joining us let me know. Still around half of the proposals for support we receive annually are petroleum based.

I thank all the members of the Foundation for their support and contribution over past year. In particular Doug Roberts, Secretary, and Peter Priest, Treasurer. Also, special mention to the heads of the subcommittees, John Denham, Petroleum, Bob Musgrave, Minerals, and Koya Suto, Environmental and Engineering. In addition, special thanks to Bob Smith and Steve Mudge who rolled up their sleeves to help identify new members for the Foundation.

No matter how the world appears to be changing some things never will. Most important of these will be a need for up and coming bright people to carry our profession forward. The ASEG Research Foundation is helping to take care of our future.

Phil Harman
ASEG Research Foundation Chair
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ASEG History Committee: A history of geophysical data and image processing in Australia

The ASEG History Committee has completed a report on the history of geophysical data and image processing in exploration geophysics in Australia. The report has been compiled from contributions made by over 20 computer software developers and users of the software. Their memories have resulted in a total of 34 companies and organisations being individually featured, and they are listed in time zones from the earliest developers in the 1960s to the late 1990s.

The report is not intended to be a detailed description of all developments in data processing over recent decades, but to high-light, historically, the major stages in the foundational developments and the principal achievements. It also recognises those persons primarily responsible for various contributions, including some of the pioneers whose legacy lives on in their ground-breaking achievements.

The report focuses on data processing chiefly for hard-rock geophysics, where innovation was necessitated in the early years by the lack of available products from elsewhere in the geophysical surveying industry. In stark contrast was the continually evolving range of software then available for processing of soft-rock geophysical data. In particular, because there was a strong emphasis on airborne acquisition of data in Australia, the unique types of airborne geophysical surveying conducted, such as low-level flying, required specialised products.

This project was first suggested to Roger Henderson, Chair of the History Committee, by Steve Mudge in December 2016 as a project to commemorate the 50th anniversary of the ASEG in 2020. The report, which is the culmination of three and a half years of compiling and editing by

An early photo of Doug Morrison, circa 1963 – 64, transcribing analogue data to maps at Aero Service Corp. On the desk at the back is an aerial photographic slotted template cutter for producing base maps.

Roger Henderson, Peter Gidley and Steve Mudge is now available on the ASEG website in the History section (https://www.aseg.org.au/history/).

The history begins in the early 1960s, when slide rules, mechanical calculators and mathematical tables were being used. Analogue devices such as 'graph rectifiers' to transcribe analogue records to maps followed, and then came the arrival of electronic devices with memory and programmable calculators. A particular breakthrough came in the early 1970s with the advent of the digitizer. Data reduction software was created next, along with contouring software to display the data. The emergence of numerically powerful desktop machines in the 1970s, and availability of interactive colour display systems in the 1980s, determined the timing and efforts of many developments.

Some contributions to this project were in the form of small essays. While often informal, after extraction of the historical information these contributions have been preserved, unedited, in a second volume of "Attachments". Both volumes have illustrations of some of the early computers and digitizing equipment. In particular, Doug Morrison's 'story', as the first of the attachments is called, also includes an example of early hand contouring.

A companion article that also discusses this evolutionary period is "Fifty Years of Potential Field Modelling" by Dave Pratt, 2002, *Preview* **99**, pp 16–19.

Roger Henderson
ASEG History Committee Chair
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ASEG Branch news

Western Australia

Greetings from Perth and WA! It's been fairly quiet here, and there is not much to report. At least one thing is for sure; the various webinars on geophysics we've all been seeing for free have been darned good and informative.

I'd like to take the opportunity to remind Members that the Western Australia branch of the Australian Society of Exploration Geophysicists (ASEG WA) is offering awards to eligible students studying geophysics or a related scientific discipline. The aim of the program is to promote and encourage geophysics-related research and education in Western Australia. Due to the impact of the pandemic on general infrastructure, the application deadline has been extended to 31 August 2020. Please pass this information onto anyone that might benefit! Full details are on our ASEG webpage.

Todd Mojesky
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Australian Capital Territory

Well, a quick run to the end of financial year saw the ACT Branch enjoy webinars hosted by other states. July was an action-packed back-to-back set of presentations covering change; firstly in mentoring in an uncertain work environment and then in the use of mathematical derivatives.

On July 14 **Marina Costelloe** spoke to an enthusiastic crowd on "Mentoring through change, a perspective", aimed at geoscientists at all stages of their career covering shared leadership challenges, what we can to do more of, and less of, where to go to for help and how you can make the most of new opportunities for your workplace, your teams and for you in your own leadership sphere.

This was followed the next day by a presentation from **Dr Indrajit G. Roy**, speaking on "Computation methods in geophysics". Indrajit brought his experience over 27 years across both seismic and non-seismic studies to geophysical data acquisition, processing, modelling and interpretation. The talk focussed on mathematical derivatives and the challenges of robust and precise estimation, how to minimize errors, and provided insight into many of their applications.

You may have seen the recent Geoscience Australia Exploring for the Future virtual roadshows (webinars) and the new data delivery system, please visit the new website https://www.ga.gov.au/eftf with links to the data portal for news and updates.

Marina Costelloe
actpresident@aseg.org.au

New South Wales

We trust all ASEG Members are virus free and hopefully finding heaps to do as we all wait for the "new normal" to happen . . . .. although, as we type this, the borders between NSW and Victoria are being closed . . . .so who knows when that will be.

Over the last couple of months, we have had a couple of speakers who gave their presentations online. In May **Simon Williams** from GBG Australia gave a talk about "Geophysical characterisation for the dredging of the Marine Industry Park, Darwin". Simon walked us through the various geophysical methods that were used to characterise the geology and geotechnical challenges for the dredging of the access channels for a proposed development site. Imagine doing a survey with crocs around! Many questions were asked and answered.

In June **Claire Mallard** from the University of Sydney gave a talk entitled "Coupling surface evolution and mantle dynamics: two examples of the interplay of tectonics, eustasy and surface processes". Claire spoke about how a new numerical simulation package was used to link surface evolution with lithospheric-scale thermo-mechanical models. Claire walked us through an example looking at the 40 Ma evolution of the South African landscape.

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Queensland

The cancellation of all face-to-face events continues for the QLD ASEG, like other branches, although it has been good to see an increase in the number of online webinars and Zoom forums to keep people connected and up to date. The Federal ASEG, and the GSQ and their collaborators, deserve a special mention for a number of these. The GSQ webinars supporting exploration in the North West Queensland Minerals Province were particularly interesting.

We put out a call in February for anyone interested in standing for a branch committee position in 2020. April passed without an official AGM and the current committee of Ron, James and Roger has continued to serve. If anyone is interested in getting more involved with the QLD ASEG, we invite you to get in touch.

For those of us in QLD, it has started to feel like life is returning to the new normal with our move to stage 3 restrictions from 3 July, and we hope that Members impacted by earlier restrictions are able to continue with their important work. At the same time, we acknowledge there is a long way to go, and the safety and health of all Members and the communities in which we operate should always take the highest priority.

In recognition of restrictions lifting, and in celebration of the ASEG's 50th Anniversary, the QLD branch is planning a Social Trivia Night, tentatively on Tuesday 18 August. More details to be made available to Queensland Members closer to the time, and it is of course contingent on restrictions allowing it to go ahead. We hope it will be a great opportunity for Members to meet up face-to-face for the first time in six months.

Ron Palmer
qldpresident@aseg.org.au

South Australia & Northern Territory

Face-to-face branch meetings are still suspended but, as we are seeing restrictions start to ease, we are hopeful that we will be able to resume technical meetings at some point in the second half of 2020.

Hopefully, also, you have found the ASEG webinars of interest. Don't forget, recorded webinars are uploaded to the ASEG's website (https://www.aseg.org.au/aseg-videos), as well as to the ASEG's YouTube channel (https://bit.ly/2ZNglaZ)

Stay safe!

Kate Robertson
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ASEG news

Tasmania

All Tasmanian face-to-face branch meetings are currently on hold. When restrictions are eased, it is expected that meetings will resume in the CODES Conference Room, University of Tasmania, Hobart. 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 also 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.

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Victoria

"Knock knock". "Who's there?"

No one, because we're isolating … again. Well, Victorians are at least, anyway. While the rest of Australia and its upstanding citizens exuberantly reclaim the magnificence of their freedom, Victorians are wallowing in their own self-pity after being forced into lockdown once more. The Victorian community of Jehovah's Witnesses must be salivating at the thought of knowing that EVERYONE will be at home.

Is it OK to laugh at coronavirus jokes and memes? I mean, does anyone remember the last time when we didn't have to wash our hands for 20 seconds, 57 times in one day? I can vaguely remember. Do you? It's good to see that the Australian Government continues to hand out money for nothing. It's not a matter of simply printing more money when needed, as any economist will you tell. At the rate we are 'borrowing' from future generations, your children's children will still be paying the price for our financial dependence. Can you imagine the day when you'll have to explain to your grandchildren how a guy eating a bat soup led to a toilet paper shortage in Australia? Really? If you needed 1440 rolls of toilet paper for a 14-day quarantine, you probably should have been seeing a doctor long before COVID-19. These 'sufferers' of the pandemic will unfortunately endure varied levels of respiratory failure, but at least their backsides will be clean!

I read there's now a 'Where's Wally' coronavirus edition. For the first time in 30 years, it's super easy to spot Wally due to social distancing measures. I kid you not, but where's the fun in that? I recently visited a bank with my elderly father. Now picture this. Two guys. Wearing masks. Walking into a bank. When we approach the female teller, I say "we're here to rob the place". She said she suddenly felt an overwhelming sense of relief. Ka ching!

So, I've been researching Netflix a lot lately and it turns out every disaster/apocalyptic movie starts with the government ignoring a scientist. Astounding! Armageddon, Outbreak, I Am Legend, The Day After Tomorrow, Contagion, Deep Impact, 2012, Interstellar, Waterworld, The China Syndrome, and even the animation Wall-E to name but a few. The movie "The Core" gets a special mention here because the government allowed a prize-wining geophysicist to conduct deep-seismic experiments that led to the destabilisation of the Earth's core. Now get this, they enlisted the help of another geophysicist (as well as other scientists) to save the Earth. Kind of like fighting poison with poison, I suppose. See? Not all geoscientists get a bad rap

OK, in actual branch news, I am saddened to inform our Members that your incumbent president, **Seda Rouxel**, will be relinquishing her role before spring. Seda has been involved with the Victorian ASEG since she was branch Secretary in 2014 and 2015 before being appointed your President in 2016, a role she has performed meticulously since. Seda and her family will be moving hemispheres and a little closer back to home (in France) to start the next chapter of their life's journey. I want to take this opportunity to thank Seda for her amazing contribution to our great Society, and to wish her well and prosperity in her future endeavours. Thank you so much, Seda. Reluctantly, I have agreed to be your acting President upon Seda's departure. No more flippant, wisecrack remarks from me. I promise I will be 'presidential'. Pfffffffft … as if.

Well, once again it's Day Two of isolation. I found a young lady sitting on my couch yesterday. Apparently, she's my wife. She seems nice. And finally, once scientists discover a vaccine for COVID-19, I don't want to see any of you anti-vaxxers inline waiting to get a jab.

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ASEG national calendar

Date	Branch	Event	Presenter	Time	Venue
All ASEG Branch face-to-face meetings have been cancelled until further notice. Branches are now hosting webinars. Registration is open to Members and non-members alike, and corporate partners and sponsors of state branches are acknowledged before each session. Recorded webinars are uploaded to the ASEG's website (https://www.aseg.org.au/aseg-videos), as well as to the ASEG's YouTube channel (https://bit.ly/2ZNglaZ). Please monitor the Events page on the ASEG website for information about upcoming webinars and other on-line events					

A tribute to Ron Green

Ron Green

This year, 2020, we celebrate 50 years of the Australian Society of Exploration Geophysicists. We also celebrate the 90th birthday of Ron Green, one of the Society's founding members, and a person who through lateral thinking and a unique approach made pioneering contributions to several facets of our science. Ron also mentored many geophysicists who have gone on to make their own careers in geophysics.

Background: Pioneering continental drift

Ron Green was born in Brisbane on 22 July, 1930. Following secondary school Ron was paid a Public Service salary by the Commonwealth (Department of Supply) to attend the University of Queensland (UQ). The federal government department selected all course work with emphasis on mathematics, physics, electronics and geology. No failures were tolerated. Ron did not fail, and on graduation was employed by the Commonwealth of Australia on a permanent basis. Ron graduated with a BSc (Hons Physics) in 1953 and his thesis was entitled: "The electron density in the F2 ionosphere layer".

Ron commenced his PhD studies in 1955 in the nascent Department of Geophysics in the Research School of Physical Sciences at the Australian National University (ANU). John Conrad Jaeger had been appointed the Foundation Professor of Geophysics in 1952. Previously Jaeger had lectured in mathematics at the University of Tasmania and had attended a series of lectures presented by Professor Sam Carey (1998 ASEG Gold medallist). Jaeger was inspired by Carey to focus his new Department of Geophysics on "the physics of the crust and interior of the Earth". It is probably pertinent that at about this time (1952 - 53) Carey was appointed Visiting Reader in Jaeger's new department. In late 1954 Jaeger also appointed Edward (Ted) Irving as a Research Fellow to commence a systematic study of rock magnetism in Australia

Ron was Ted Irving's first PhD student. Ron had worked on magnetic surveys in WA at the Bureau of Mineral Resources (BMR), Canberra, between 1953 and 1955. He recognised the heterogeneous magnetisation of rocks, and how this fact was not consistent with a simple induction model. Ron was, therefore, well placed to begin doctoral studies on rock magnetism. Ron's contacts in the BMR were very useful at times, with BMR field geologists generously providing oriented field specimens from remote localities. Their assistance was greatly appreciated and gladly acknowledged.

One of Ted and Ron's first findings was that at the time the Jurassic Tasmanian dolerite was intruded, Tasmania was very close to the South Pole. The opportunity to carry out research on the Tasmanian dolerites and to test the predictions of Wegener's continental drift hypothesis was one of the main reasons Ted had agreed to come to Australia. Their finding was opposed to the conventional polar wander interpretation of results from Europe and North America, and was probably one of the main factors behind Sam Carey's "Continental Drift Symposium" in Hobart in 1956. Earth science thinking in the southern hemisphere was well ahead of thinking elsewhere. It is hard to appreciate now just how ground-breaking this early work was and, although not as widely recognised as it should be, how very influential on research directions globally.

While Ted was a geologist and Ron a physicist/mathematician, they complemented each other perfectly and managed enormous progress in a very short time period. Ron also worked closely with Jaeger, especially on the cooling history of a massive Tasmanian dolerite sill, where they demonstrated geomagnetic secular variation during the Jurassic period. Jaeger was already well known for his work on heat flow and the cooling of solids.

By 1957 the "polar wandering" path of Australia from Early Proterozoic times to the Late Tertiary had been constructed. Laughably (now) Ted and Ron's manuscript was rejected by the *Journal of Geophysical Research* (JGR). Their paper "Polar movement relative to Australia", was published in the first issue of the *Geophysical Journal of the Royal Astronomical Society* (Irving and Green, 1958). To reconcile the European, American and Australian paths, relative motion between the continents must have occurred. With remarkable accuracy a rate of 50 mm/year was determined for the northward drift of Australia. See also a review by one of us (PWS) of "The Continental Drift Controversy" by Henry R. Frankel (*Preview* **163** p. 29). It is also noteworthy that Sam Carey had a manuscript rejected by *JGR* at about this time.

In the late 1950s, while still pursuing his PhD research, Ron took up a lecturing position in Carey's department at the University of Tasmania. Ron graduated with a PhD in geophysics from ANU in 1961. The title of his thesis was "The Palaeomagnetism of some Kainozoic & Palaeozoic rocks".* Also in 1961, the year Ron joined the SEG, he participated in the voyage of the *R.V. Argo* from Fremantle to Hobart. The cruise established that there was no continuation of the Darling Fault through the oceanic floor, and that there were mirror-image magnetic anomaly stripes paralleling the '50°S degree' ridge. All these findings supported continental drift.

In 1967 Ron was appointed to the UNE at Associate Professor level, and tasked with establishing an independent

* Editor's note: Cenozoic, meaning "new life," is derived from Greek kainós "new," and zōḗ "life." The era is also known as the Cænozoic, Caenozoic, or Cainozoic. The name "Cenozoic" (originally: "Kainozoic") was proposed in 1840 by the British geologist John Phillips (1800–1874).

Department of Geophysics. Some students remember that Ron began his lecture on continental drift warning that the theory was controversial, and that the student should ask him/herself, the question "Do I agree with that statement or do I disagree with it? If you agree you will remember it, and if you disagree make a note to check it out - get some numbers you can rely upon". Also, Ron liked questions from students. If a student asked a silly question, his standard reply was "I am glad that you asked that, it gives me an opportunity to clear up a common misunderstanding".

With hindsight, and now knowing all the facts, Ron's students are quite rightly dismayed he never received the recognition he deserved and made a full professor while at UNE! However, in 1980 Ron was awarded DSc from UQ for "Geophysical Investigations". He is now a retired FIEAust, CPEng, College ITEE and a committee member of Engineering Heritage of SA.

The focus of the new Department of Geophysics at UNE.

What ambitions did Ron have for his new department? In 1967 there was an emerging boom in mineral exploration in Australia, but geophysical technologies to assist in near-surface exploration for minerals were all being developed in the formerly "glaciated environments" of Canada and Sweden. They were failing in our ancient, deeply weathered, ferruginous and highly conductive crustal environments. ANU had already established pre-eminence in crustal geophysics and continental drift. So Ron identified different priorities. These were directed towards producing graduates that were equipped to become geophysical "problem solvers", capable of advancing any branch of geophysics. He would establish the first specialised department in Australia to encompass both global and applied geophysics, with an emphasis on applied.

The department Ron established primarily targeted post graduate activities. While geophysical subjects, including crustal and inner Earth physics and near surface exploration and mapping, were taught at 3rd year undergraduate level, Ron focussed his attention upon an Honours year course, complemented by Masters and PhD programmes. He recognised that to solve future problems in geophysics, students primarily had to have a solid understanding of physics and mathematics. While the application of geophysics may well have been to assist geological investigations for which a knowledge of geological subjects was an advantage, knowledge and understanding of maths/physics was imperative. For most students it was not practical to major in physics, mathematics and geology, and while learning physics and maths was best facilitated in a university environment, geological insights could be acquired through work experience and fieldwork. So, Ron made the call, the pre-requisite for his Honours Geophysics degree was maths and physics with geological subjects listed as optional.

Ron's Honours degree course had four main components:

- Graduates in physics were to be given bridging coursework specifically in the application of their undergraduate studies to a crustal/geological environment.
- Their undergraduate studies were to be supplemented with an intensive course in the Fourier transform and its data and signal processing applications.
- Students were to write up a geophysical topic researched from published literature.
- Students were to conduct applied research into a geophysical problem.

Those students who may have done the bridging geophysical coursework as an undergraduate were encouraged to replace this component with geological subjects.

Many of the applied research topics undertaken by his students were exploration and instrumentation oriented. But Ron recognised that the New England environment also presented a unique opportunity, and that was to develop a geophysical observatory for crustal studies, deep underground in a nearby disused gold mine at Hillgrove. Within three years of establishing his department, Ron had negotiated access to a suitable mine tunnel and was developing a laboratory for the measurement of crustal tilt and strain.

As the mineral exploration boom accelerated in the 1970s, industry required graduates capable of applying geophysical methods to exploration. Earth science schools that included a geophysics capability were soon established in other universities, while existing schools where geophysical subjects were being taught became more oriented towards meeting this demand. In contrast to Ron's model, this demand was generally perceived to be most readily met by offering geophysical exploration courses to students majoring in geology. Both models were successful! There was a place in the exploration industry for geologists knowledgeable about, and familiar with, geophysical tools. But with few exceptions, these staff were constrained to a textbook application of off-the-shelf technologies with limited opportunity to advance these technologies when shortcomings were encountered. And, in the Australian environment, there were many challenges encountered. Ron's students, in fact, excelled in exploration as they were invariably part of a team effort that benefitted from the input of a strong physics-based understanding of the geophysical response from complex geological structures. No real-world geological environment can be represented by simplified models taught from textbooks. As Ron's students subsequently proved, a training in problem solving with a sound grounding in the fundamentals of the physical sciences was a base from which almost anything could be achieved. Those of his students working in mineral or oil exploration very quickly rose to high and successful positions. Others excelled in the application of geophysics to regional, environmental and archaeological mapping, palaeomagnetic and global crustal studies, instrumentation development, geomechanics, project and resource management, education and even resource industry stock broking. In the first ten years, Ron's department saw 30 students graduate with Honours.

In the 1970s the exploration industry was hampered by the lack of instrumentation capable of exploring through ferruginous and highly conductive regolith. Indeed, this very Australian problem was the driving force behind the establishment of the CSIRO Division of Mineral Physics under Dr Ken McCracken (1989 ASEG Gold Medallist) in 1972. At the same time, it was recognised that the per-capita cost of educating the relatively small number of post-graduate students in Ron's department, of giving them training access to the latest exploration equipment and of funding their research projects, was quite high. To address both these problems, a proposal for a "Geophysical Research Institute" (GRI) was put to Ron. The concept behind this proposal recognised that the department had students capable of problem solving in the exploration and instrumentation arena. It also recognised that the industry had specific problems it wanted solved, and they had field sites where these problems were being encountered. In addition, industry had state-of-the-art commercial instrumentation that was unaffordable for teaching purposes. If industry and the university were to work together exploration technologies could be advanced, and useful graduates familiar with the latest technologies could be produced, most economically, with the research and field work funded by industry. Moreover, none of Ron's small staff of two had had exploration experience in industry, and by working on collaborative projects the industry sponsor could provide invaluable co-supervision. The proposed GRI would be a benefit to all parties, and Ron recognised this instantly, giving it his full support. Within four years, Ron's department had 20 well-funded and fully supported post graduate students. During this time Ron had independently established a wonderful relationship with the Indonesian Resources Ministry, and many outstanding students came from this Indonesian source.

Sadly Australian universities were not as engaged with industry in 1978 as they are today, and the GRI was condemned within the university as "a threat to academic freedom". Conveniently, Ron's 20 post-graduate students were attractive bait to an overstaffed Geology Department next door. In business parlance a "takeover" was inevitable, and an Earth Sciences Department resulted. The GRI was permitted to continue independently, but was to be self-sufficient and, at least initially, not to be involved with students. It was a strange transition period, and soon afterwards the UNE was to boast that it had led the way in integrating academic and industry needs. After just 15 years Ron's department was taken away from him, but in that time he had achieved a lot, and the accomplishments of his students speak for themselves.

In 1986 the ASEG inaugurated the Grahame Sands Award for "Innovation in Applied Geoscience". Nearly half (six) of the first 14 Grahame Sands Award recipients were graduates of Ron's department.

Ron's students respected him, called him their "Prof", and are forever grateful for the guidance he gave them in their education. Thanks Ron and congratulations on your longevity and great contributions to Australian and global geophysics!

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Vale: Margaret Sites Sheriff (1925 – 2020)

Margaret Sheriff

Many ASEG Members will be saddened to learn of the death of Margaret Sites Sheriff on May 24 2020.

Margaret was born in Salina, Kansas on November 28, 1925. She was raised in Salina and attended Kansas State University for two years, studying chemistry. She moved to Oak Ridge, Tennessee in 1944, obtaining a job with the Manhattan Project in order to save enough money to finish college after the war. In Oak Ridge Margaret met Robert E. Sheriff, another Project employee. They married on October 13, 1945.

After the war Margaret and Bob moved to Ohio, Bob's home state, to finish their educations at Ohio State University. Margaret completed her BS in Geology, Phi Beta Kappa, in 1947, and then worked as a chemist for Bechtel Labs while Bob finished graduate school. In 1950, after Bob received his PhD, Margaret and Bob moved to southern California where Bob began his career with Standard of California (Chevron). Bob's career took them from California to Florida, back to California, Trinidad, Western Australia, back to Louisiana and, ultimately to Houston, Texas in 1970.

Margaret was instrumental in supporting Bob with his geophysical writing, serving as first editor, and even writing the first draft of Bob's book *A First Course in Geophysical Exploration and Interpretation* by transcribing tapes of his lectures and notes. After their six children were grown, Margaret joined Bob on his many US and international trips to teach geophysical short courses; these trips took Margaret and Bob all over the world, including Australia, from the 1980s through the 2000s.

Margaret and Bob endowed several SEG Scholarships for international students wishing to continue their studies in geophysics at the University of Houston. They also established the endowed Faculty Chair in Applied Seismology, an endowment in Applied Geophysics, an endowed Professorship in Sequence Stratigraphy and an endowed Professorship in Geophysics at the College of Natural Sciences and Mathematics of the University of Houston.

Margaret was widowed in 2014 (Bob's obituary was published in *Preview* **174**). She and Bob were a remarkable couple with an astonishing legacy.

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Exploration geophysics: Past performance and future opportunities

Management guru Peter Drucker is credited with the statement "you can't manage what you can't measure." In the exploration world the most important outcome of our efforts is the discovery of new economic resources, which we expect will often involve the creative use of the best of minds and science. However, documenting these outcomes is often seemingly relegated to 'campfire' stories that change with both the passage of time and who is telling the story. While no one would suggest that the key players in a discovery should be denied their 'bragging rights', after the parade has passed by the industry is often left with only partial information as to how the discovery was made, and what could be considered the key elements of thinking and process that lead to the successful outcome.

While the observations and opinions of a number of 'students of discovery' were reviewed in Witherly (1993), the author is not aware of any generally accepted template that could be used to capture what goes into a successful exploration program. Based on Witherly (1993), a summary of the key factors commonly identified are outlined below.

Critical success factors:

- Confidence
- Flexibility
- Focus
- Technical competence
- Sense of urgency
- Serendipity

Supporting success factors:

- Effective structure
- Good communications
- Leadership
- Strategic plan
- Consistency of support

Other factors:

- The prospector myth, which is persistent and our industry's version of the hero's journey. Rose (2003) defines this succinctly: "the prospector myth is the image of the courageous lone prospector who struggles against Mother Nature, sceptical associates and financial hardships before succeeding, finally, through persistence, faith and luck to achieve vindication, fame and wealth". While the oil industry has worked hard to expunge, or at least control, the prospector myth (Rose and Citron 2000, and Rose 2003), the minerals business is still seen to embrace or at least tolerate this belief, which is seen as a major impediment for the profession to evolve in a meaningful and effective way.
- Technology. Interestingly, in the Witherly (1993) assessment, none of the pundits mentioned 'technology' as a critical factor expected to drive exploration success.

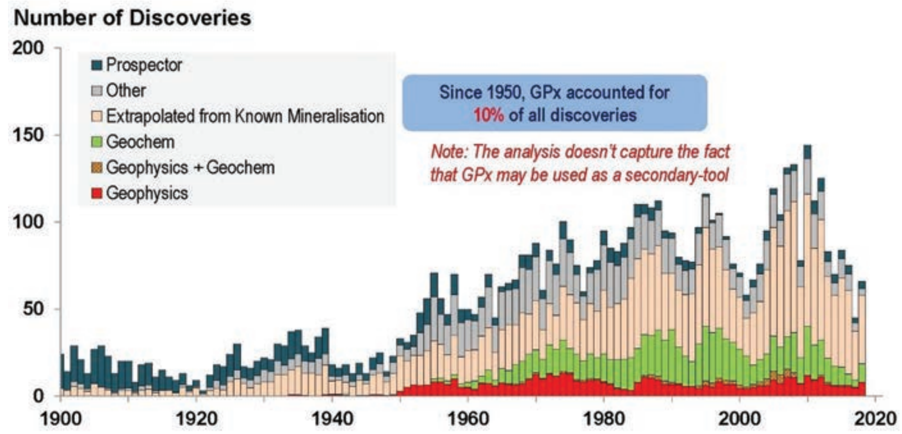

Figure 1: *Primary search method used at the project-scale for all significant non-bulk mineral discoveries in the World from 1900-2018. Source: Schodde 2020.*

Past performance

As part of the recent PDAC programme in Toronto, Canada, Richard Schodde (Schodde 2020) assembled an assessment of global discovery outcomes that provides a detailed review of the key factors leading to minerals discovery. The 2020 study drew upon a review Schodde presented in 2014 (Schodde 2014), but expands on that review to examine the role of geophysics based on commodity and location. He used the outcomes from the discovery of 3710 non-bulk deposits[1] since 1900, and extracted the contributions of six factors that contributed to decision making at the "Project-Scale" (defined as the scale at which leases are staked), and the "Prospect Scale" (the scale at which the first drilling is undertaken). These factors are:

- Prospector
- Other
- Extrapolation from known mineralisation
- Geochemistry
- Geophysics and geochemistry
- Geophysics

[1]Excludes satellite deposits in existing Camps

At the project scale (Figure 1), geophysics contributed approximately 10% to the global discoveries. Geochemistry appeared to make a strong showing in the period of 1985-2010, but declined in recent years. The "extrapolation from known mineralisation" has grown in importance, which could be an indication of the increasing emphasis on brownfields exploration. At the prospect scale (Figure 2), geophysics has a much stronger contribution, with responsibility for over 20% of discoveries. At this scale, as at project scale, geochemistry made a significant contribution from 1985-2010, but its role has diminished in recent years.

Gold and base metals

Schodde (2020) shows that geophysics plays a larger role in the discovery of base metal deposits than gold, but deposit styles that contain both gold and base metals are likely to be targets for some explorers, and they can be expected to utilize the best technology available to pursue their prize.

Canada and Australia - similar but different

When geographic location is considered, Schodde 2020 shows that Canada and Australia are the heaviest users of geophysics and, correspondingly, the greatest beneficiaries. This is seen as driven by two components; both are relatively mature terrains that require explorers, on average, to look deeper for new resources. Schodde (2020) observes, however, that below 300 m, the performance of geophysics drops off

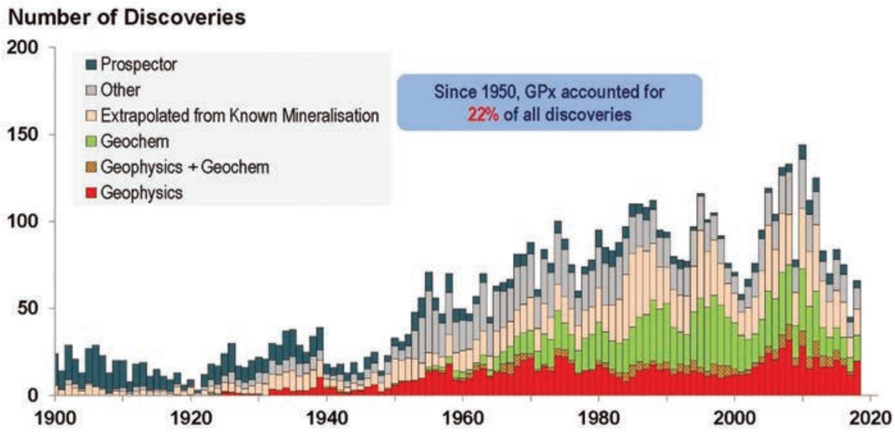

Figure 2: *Primary search method used at the prospect-scale for all significant non-bulk mineral discoveries in the World from 1900-2018. Source: Schodde 2020.*

and exploration plays become more purely drilling dominated. Maybe this is because Australia was an early adaptor of the minerals system approach (many explorers outside Australia are still unfamiliar with the term), which emphasizes the importance of good regional assessment work at project scale, and Australian Commonwealth and state agencies have invested heavily in a variety of regional pre-competitive geophysical data sets (McKenzie, Witherly and Ronacher 2019). The Australian industry has also invested in innovative drilling technology to enable targets at depth to be tested at far lower cost than conventional wire-line or rotary drilling technology (Hillis 2015).

In the context of the value of regional data sets, two recent papers; Betts *et al.*, (2020), and Woodhead (2020), and an earlier study, Betts *et al.* (2017), examine how regional geophysical data can be better used to define areas of high prospectivity. While this style of assessment can benefit from complementary mapped geology, this geophysically-driven approach is almost essential when deposits are expected to be located beneath cover.

Technology

Schodde (2020) also refers to changes in exploration technology since the 1940s (Figure 3). This work was originally presented by Rowe and Craske (2018). Schodde notes that the period from the inception to maturity (point at which the technology is in routine use) can be quite long, often 20 years or more. With underlying changes in the demographics of the industry, many of the new technologies, especially those designed to aid in processing and interpretation of complex datasets, are being under-utilised. Figure 4 from Witherly (2016), shows an estimate of the distribution of geophysicists working in the minerals exploration industry. The number of company employees engaged with the end use of survey data, i.e. its application to exploration programmes to locate or define new resources, has declined significantly over 20 years. Arguably as well, there are more datasets available and the processing software has become more complex.

For reasons poorly understood, since 1990 many new acquisition and processing technologies have been introduced into the market place, but neither at the individual level (i.e. airborne gravity gradiometry or Heli-TEM) or

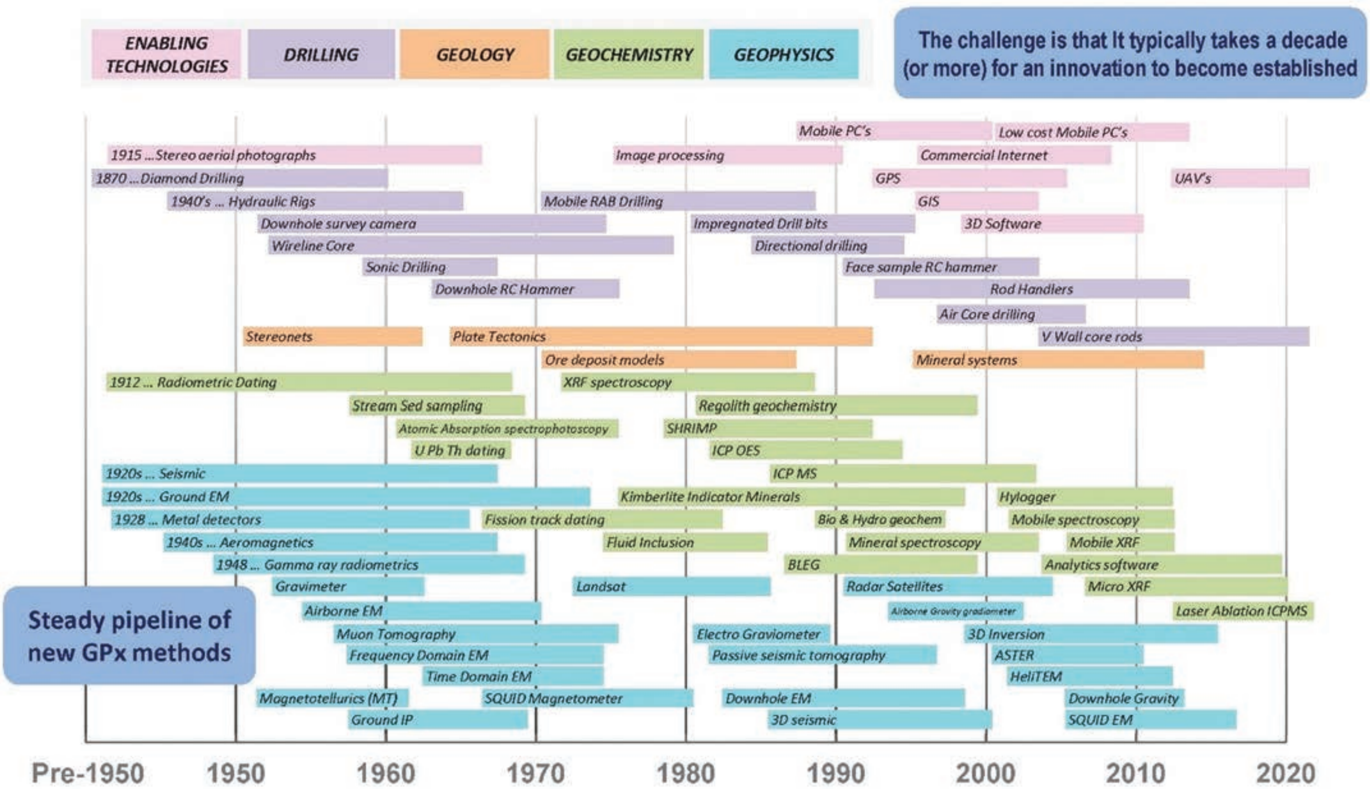

Figure 3: *Time line for 72 key technology innovations developed for minerals exploration. Source: Rowe and Craske 2018 modified by Schodde 2020.*

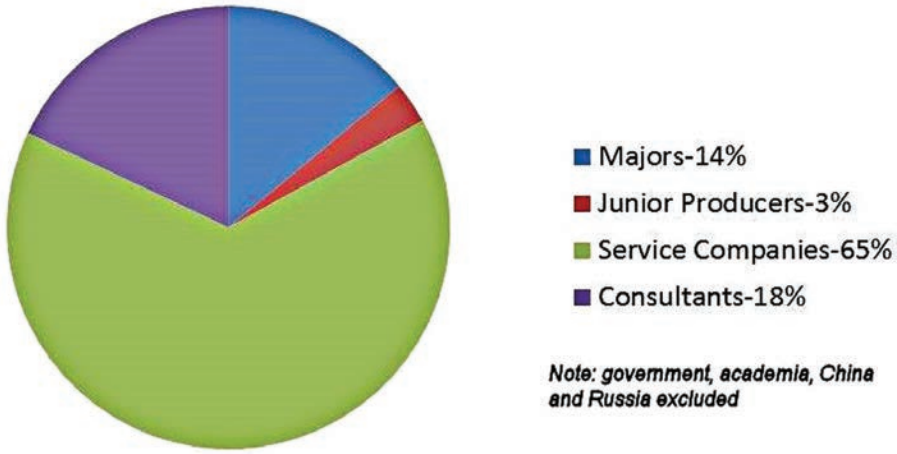

Figure 4: *Industry employers of minerals geophysicists. Approximately 1000 geophysicists were counted. Source: Witherly 2016.*

collective level (i.e. 3D modelling of all data types) do these technologies appear to have had any impact on countering the decline in discovery of either the number or quality of many deposit types. For the discoveries that have been made, it is hard to determine whether 'traditional' technologies should get the credit, or if newer technologies have made the difference.

This raises questions that have significant implications for the industry going forward. Unfortunately, there does not appear to be any forum that engages the developers of new technology, the end users and their clients where such issues can be addressed. Two anonymous senior geoscientists have offered comments about this; one remark is delightfully brief, the other a more sombre remark that, on its own, could inspire a workshop or even a conference built around examining the issues raised.

Comment 1: "We can see deep but things are fuzzy … "

The wish to be able to explore deeper in exploration is aligned with the idiom 'be careful what you wish for'. And like many things, once you have it, you "own it" and it requires you to be able to use the capability effectively if credibility is to be maintained. The last piece of my colleague's line, "but things are fuzzy", means there is considerable risk associated with trying to define and then test targets when exploring at greater and greater depths.

The reverse can be demonstrated that in the era when one technology, airborne EM, contributed significantly to the discovery of many deposits in Canada (Witherly 2000); drill depths were much shallower (Figure 5 in Witherly and Allard 2010), with the majority of drill holes less than 100 m. When deeper exploration depths are pursued not only are the geophysical surveys and analysis more expensive, but the drill testing is more costly as well.

Comment 2: "Despite lots of new geophysical systems and improved technology being available in the past 20 years, discovery rates are not climbing. I think this underlines that we can now measure and detect far more things than we can understand geologically. While the information is not recorded, I'm guessing that, as an industry, we are drilling far more false positive anomalies these days, partly because we can now detect them, and partly because we can make them look so good with 3D inversions and glossy isosurfaces. So, the efforts going forward need to be directed at relating geophysics to mineralogy and its alterations, from field results with drill hole logging to theoretical studies."

As noted above, the focus of the profession has changed over time, and there are now far fewer geophysicists whose responsibility is the processing and analysis of exploration data. The irony is that the industry arguably has a far better range of high-quality technology than ever before, but fewer people than ever are tasked with developing the means to best use this technology.

Historically, senior members of large mining houses would take on leadership roles, advancing such issues in community forums to help develop pre-competitive capabilities. However, with major changes in companies' support for exploration during the same period as the wave of technology was developed and delivered, most remaining geophysical staff have been relegated to internally focused, tactical roles.

Fiscal support

Schodde (2020) shows that geophysics has struggled over the last two decades to maintain what might be considered a sustainable level of funding from the exploration industry (Figure 6). This has implications from the issue of professional "readiness", to the development of new technology, and the industry's ability to employ newly graduated professionals coming out of universities. In Canada

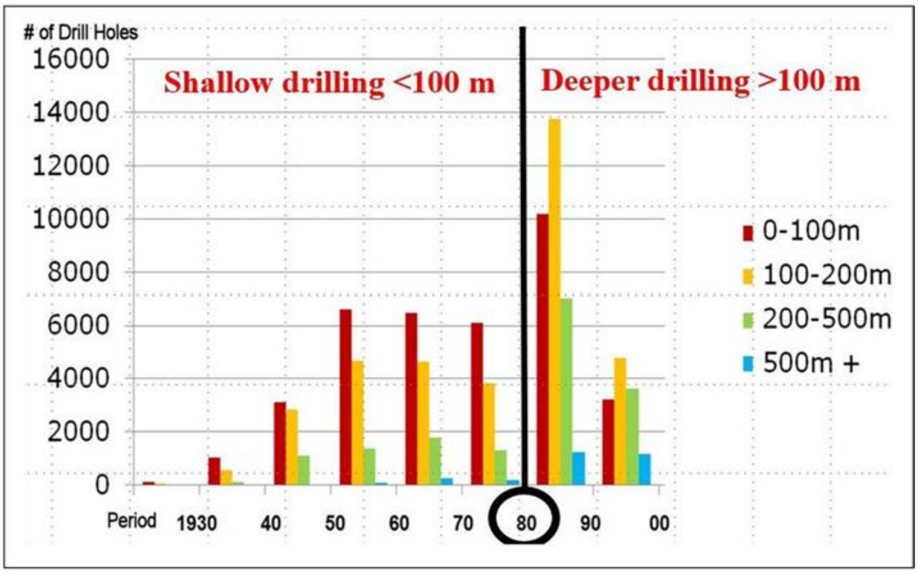

Figure 5: *Drilling depths over time in the Abitibi (Canada). Source: Witherly and Allard 2010.*

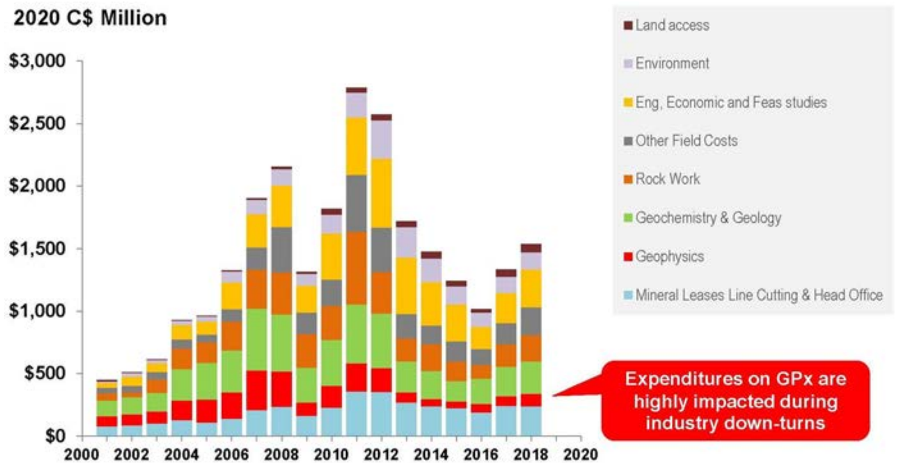

Figure 6: *Mineral exploration expenditure by activity for Canada, 2001-18. Source: NRCan modified by Schodde 2020.*

and Australia the number of schools providing undergraduate programmes in geophysics has declined in the past 20 years, as have the number of students enrolled in these programmes. Meanwhile, a number of professional groups promote their often-generous scholarship programmes for students in geosciences but seldom examine the issue of where these people will find suitable employment once they graduate.

Future opportunities

Schodde (2020) ends his presentation on a positive note, predicting that in the longer term explorationists will need to explore the earth to greater depths, and geophysics can be expected to play a growing role. As no group is explicitly watching to ensure that the geophysical profession/industry is ready for this challenge, it would seem that this state of readiness will be driven more by luck than good planning.

While this is seen as an accurate assessment of the minerals industry, the petroleum industry is going through a similar transformation as the major oil companies fundamentally re-define their use of geoscience professionals. The Society of Exploration Geophysicists has been trying to understand these changes and to provide a plan (House 2018) to help bridge the gap being created as Big Oil withdraws from being a major player in professional development of geoscientists.

Something comparable would seem to be critical for the minerals industry going forward. The Frank Arnott Next Generation Explorer Award (www.frankarnottaward.com) is attempting to address this issue. The NExUS programme (Lilly 2016) in Australia has similar objectives.

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Geoscience Australia: News

Over the last two months the hard-rock geophysical teams at Geoscience Australia have been focussed on the final casting of the new geophysical archive and data delivery system (GADDS), finalisation of Exploring for the Future (EFTF) products, and planning for a new suite of airborne and ground geophysical surveys across Australia. In collaboration with our State agency partners: Western Australia, South Australia, Northern Territory, Queensland, New South Wales, Victoria and Tasmania, new surveys will kick-off shortly across WA (AusAEM20), NSW (Mundi AEM, Cobar Mag/rad), Tasmania (Tas Tiers) and Victoria (Eastern Victoria). Details are presented in Figure 1, and the tables updating survey progress that follow.

2020 GADDS release

After a few minor delays, we have passed GADDS 2.0 to a group of 30 to 50 "power-user" clients for beta testing. While still in the early stages, the new GADDS 2.0 provides:

- An improved graphical/GIS – based interface, facilitating the choice of dataset.
- Superior data selection criteria and data extraction speeds via the National Computational Infrastructure (NCI), with an archive underpinned by netCDF.
- The capacity to clip and ship grids and located data to a user-specified area.
- Enhanced pre-delivery filtering including data age, grid spacing, re-gridding algorithm, survey location, data type, to name just a few.
- Access via the primary GA portal so that most of the other GA-delivered datasets can be easily viewed andextracted.

What won't be readily apparent to users is the amount of data remediation and archive clean-up that was required to build the new system; keeping in mind close to 100 years of geophysical data acquisition, combined with multiple data configurations (line, point, grid, non AWAGs corrected, AWAGs corrected etc.). The clean-up has taken the equivalent of one full-time staff member for 12 months.

Other big changes planned for GADDS are:

- The capacity to ship AEM and airborne gravity/gradiometry located data through the same portal.
- The capacity to select and ship time-series and other multi-dimensional datasets through the same portal.

After reviewing and implementing the recommendations of beta testers, we will start to work on the enhanced functionality over the next 6 months. Hopefully GADDS 2.0 will be available to the general public by the next issue of *Preview*

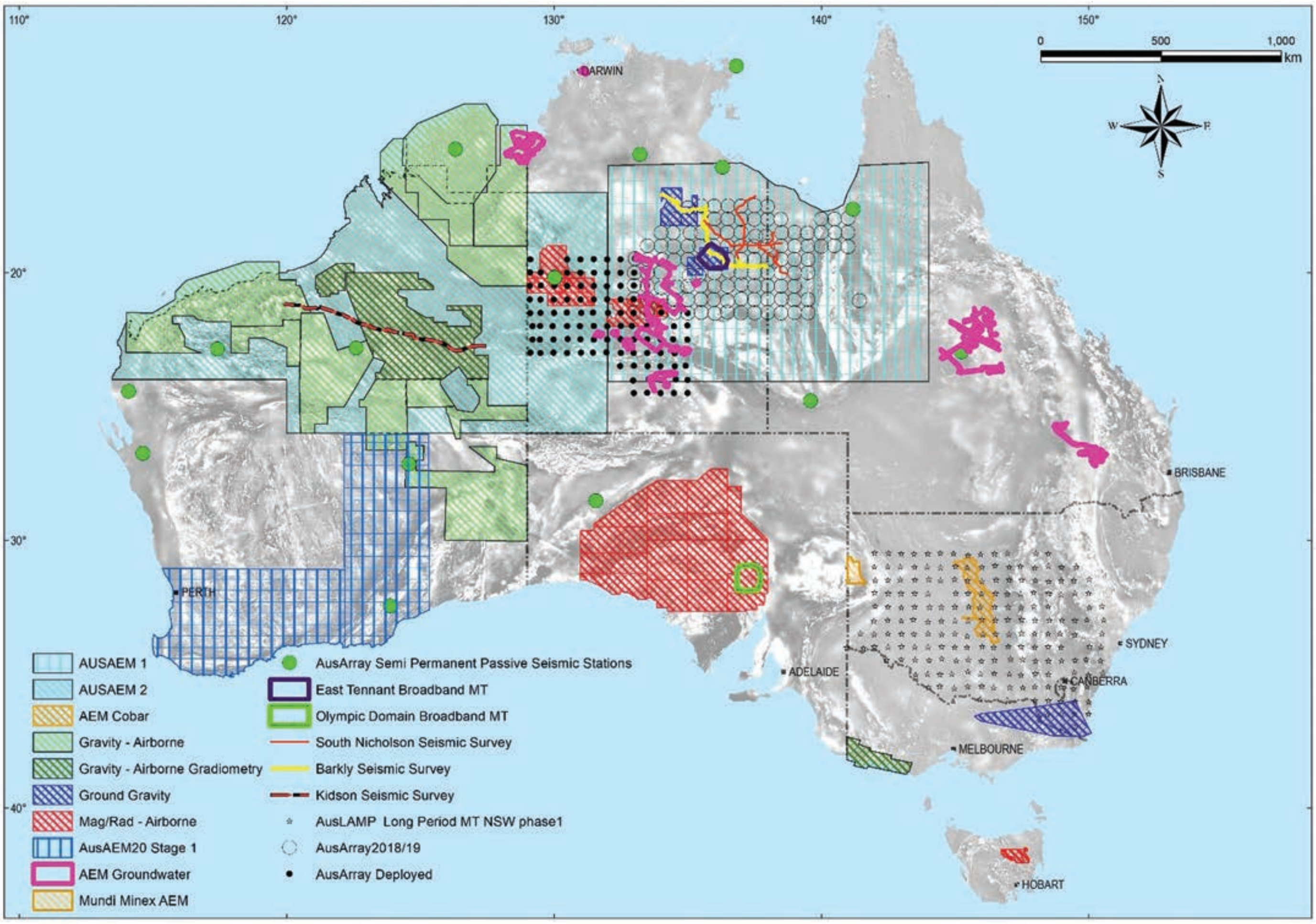

Figure 1. *2018 -2021 geophysical surveys – completed, in progress or planned by Geoscience Australia in collaboration with State and Territory agencies.*

AusAEM2 release

The decision was made to suspend AusAEM2 in March of this year, under the current contract framework, despite the survey being only 72% complete, or having flown approximately 52 000 line km of the proposed 73 000 line km programme (Figure 2). The located data, contractor inversions and GA's inversions were publically released last month, and can be downloaded via GA's electronic catalogue system: https://ecat.ga.gov.au/geonetwork/.

GA's inversion uses an in-house sample-by-sample layered-earth (1D) approach, which is a deterministic regularised gradient-based algorithm that we call GALEISBS (Brodie, 2016). The process simultaneously inverts the vector sum of measured X- and Z-component data to produce a single smooth layered conductivity model. The inversion is initially tuned for data QC purposes, but is then re-seeded for interpretation for either groundwater (shallow lateral enhancement) or mineral (deeper contrasts) applications. More details can be found at Brodie 2016 and Ley-Cooper *et al*, 2019.

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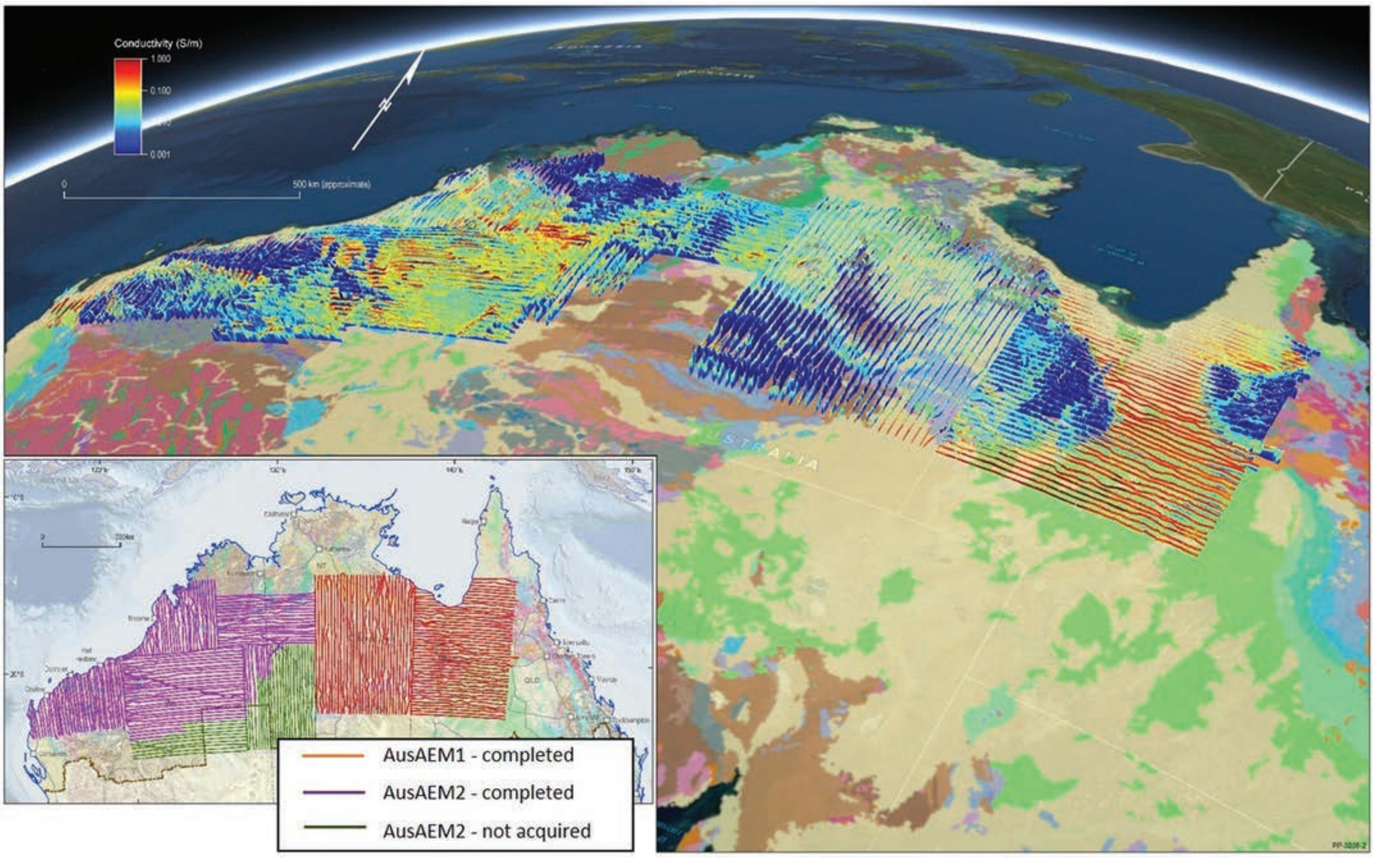

Figure 2. *AusAEM 1 & 2 coverage over Northern Australia, 2020. Background image: 1:1 million scale Surface Geology of Australia underlain by magnetics (greyscale, 0.5 vertical derivative of total magnetic intensity).*

Update on geophysical survey progress from Geoscience Australia and the Geological Surveys of Western Australia, South Australia, Northern Territory, Queensland, New South Wales, Victoria and Tasmania (information current on 30 June 2020).

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

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Line spacing Terrain clearance Line direction	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Tasmanian Tiers	MRT	GA	MAGSPEC	Oct 2020	Up to an estimated 66 000	200 m 60 m N–S or E–W	11 000	End of 2021	Before end of 2021	See Figure 1 in previous section (GA News)	TBA
Cobar	GSNSW	GA	GA	TBA	46 000	200 m	9 200		Before end of 2021	See Figure 1 in previous section (GA News)	TBA
Gawler Craton	GSSA	GA	Various	2017	1 670 000	200 m, various orientations depending on structure	294 000	26 Jun 2019	Aug 2019	http://www.energymining.sa.gov.au/minerals/geoscience/pace_copper/gawler_craton_airborne_survey	Released
Tanami	NTGS	GA	Thomson Aviation	14 Jul 2018	275 216	100/200 m 60 m N–S/E–W	48 267	2 Dec 2018	Jun 2019	195: Aug 2018 p. 16	Released
Mt Peake	NTGS	GA	MAGSPEC	10 Jul 2019	136 576	200 m N-S	24 748	Oct 2019	Feb 2020	Aug 2019	Released

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
Kidson Sub-basin	GSWA	GA	CGG Aviation	14 Jul 2017	72 933	2500 m	155 000	3 May 2018	15 Oct 2018	The survey area covers the Anketell, Joanna Spring, Dummer, Paterson Range, Sahara, Percival, Helena, Rudall, Tabletop, Ural, Wilson, Runton, Morris and Ryan 1:250 k standard map sheet areas	Expected release before the end of Dec 2020
Little Sandy Desert W and E Blocks	GSWA	GA	Sander Geophysics	W Block: 27 Apr 2018 E Block: 18 Jul 2018	52 090	2500 m	129 400	W Block: 3 Jun 2018 E Block: 2 Sep 2018	Received by Jul 2019	195: Aug 2018 p. 17	Expected release before the end of Dec 2020
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	Expected release before the end of Dec 2020
Warburton-Great Victoria Desert	GSWA	GA	Sander Geophysics	Warb: 14 Jul 2018 GVD: 27 Jul 2018	62 500	2500 m	153 300	Warb: 31 Jul 2018 GVD: 3 Oct 2018	Received by Jul 2019	195: Aug 2018 p. 17	Expected release before the end of Dec 2020

(*Continued*)

Table 2. Ground and airborne gravity surveys (*Continued*)

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
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)	Expected release before the end of Dec 2020
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)	Released
TISA	NTGS	GA	Atlas Geophysics	2 Jul 2019	5719	2 km × 2 km grid	31 285	Sep 2019	Nov 2019	See Figure 1 in previous section (GA News)	Released

TBA, to be advised

Table 3. Airborne electromagnetic surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Mundi	GSNSW	GA	TBA	2020/2021	1900	2.5	~ 5000	Dec 2020	TBA	See Figure 1 in previous section (GA News)	TBA
Surat-Galilee Basins QLD	GA	GA	SkyTEM Australia	2 Jul 2017	4627	Variable	Traverses	23 Jul 2017	Nov 2017	188: Jun 2017 p. 21	Pending, to be released at: http://pid.geoscience.gov.au/dataset/ga/121991
Stuart Corridor, NT	GA	GA	SkyTEM Australia	6 Jul 2017	9832	Variable	Traverses	12 Aug 2017	Nov 2017	188: Jun 2017 p. 22	eCAT release http://pid.geoscience.gov.au/dataset/ga/131098
Ord-Bonaparte, WA	GA	GA	SkyTEM Australia	18 Oct 2015	2784	Variable to 500 m		4 Nov 2015	May 2016	See Figure 1 in previous section (GA News)	Pending, to be released at http://pid.geoscience.gov.au/dataset/ga/135452
Daly River, NT	GA	GA	SkyTEM Australia	9 Jul 2017	3378	Variable 1-2 km	Traverses	24 Aug 2017	Feb 2018	See Figure 1 in previous section (GA News)	eCAT release http://pid.geoscience.gov.au/dataset/ga/122012
AusAEM2, NT-WA	GA	GA	CGG Tempest	May 2019	73 005 with areas of industry infill	20 km	1 074 500	Oct 2019	Mar 2020	201: Aug 2019 p. 16	72% complete. Acquisition suspended. Release of acquired portion pending
AusAEM20	GSWA	GA	CGG & SkyTEM	2020/ 2021	24 000 km as Phase 1	20 km	480 000	Dec 21	TBA	See Figure 1 in previous section (GA News)	TBA
Cobar	GSNSW	GA	NRG Xcite	30 Sep 2019	6701 with areas of industry infill	2.5 and 5 km	19 145	19 Oct 2019	Jan 2020	201: Aug 2019 p. 17	Released
Howard East	GA	GA	SkyTEM Australia	23 Jul 2017	2073.6	Variable to 100 m	Traverses	8 Aug 2017	Feb 2018	See Figure 1 in previous section (GA News)	eCAT release http://pid.geoscience.gov.au/dataset/ga/132400

TBA, to be advised

Table 4. Magnetotelluric (MT) surveys

Location	Client	State	Survey name	Total number of MT stations deployed	Spacing	Technique	Comments
Northern Australia	GA	Qld/NT	Exploring for the Future – AusLAMP	366 stations deployed in 2016 - 2019	50 km	Long period MT	The survey covers areas of NT and Qld. Data to be released early 2021.
AusLAMP NSW	GSNSW/ GA	NSW	AusLAMP NSW	224 stations deployed in 2016-19	50 km	Long period MT	Covering the state of NSW. https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/132148 *Ongoing*
Southeast Lachlan	GSV/GSNSW/ GA	Vic/ NSW	SE Lachlan	Deployment planned to commence in late 2020	~4 km	AMT and BBMT	~160 sites in the Southeast Lachlan
AusLAMP TAS	GA	TAS	King Island MT	4 sites completed	<20 km	Long period MT	Covering King Island. Acquisition completed.
East Tennant	GSQ/GA	NT	East Tennant MT	131 sites completed	1.5 – 10 km	AMT and BBMT	Released https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/132016
Cloncurry	GA/GSSA/ UoA/AuScope	QLD	Cloncurry Extension	200 stations have been acquired	2 km	AMT and BBMT	Approximately 500 sites planned in the northern Cloncurry. Data acquisition is in progress
Spencer Gulf	GA/GSSA/ UofA/ AuScope	SA	Offshore marine MT	12 stations completed	10 km	BBMT	This is a pilot project for marine MT survey https://www.auscope.org.au/news-features/auslamp-marine-01

TBA, to be advised

Table 5. Seismic reflection surveys

Location	Client	State	Survey name	Line km	Geophone interval	VP/SP interval	Record length	Technique	Comments
South East Lachlan	GSV/ GSNSW/ GA/ AuScope	Vic/NSW	SE Lachlan	629	10 m	40 m	20 s	2D - Deep crustal seismic reflection	This survey covers the Southeast Lachlan Orogen crossing the Victorian-NSW border. Data acquisition was completed in Apr 2018. Raw data and processed seismic data has been released and are available from GA, GSV and GSNSW eCat 122684
Kidson	GA/ GSWA	WA	Kidson Sub-basin	872	20 m	40 m	20 s	2D - Deep crustal seismic reflection	Within the Kidson Sub-basin of the Canning Basin extending across the Paterson Orogen and onto the eastern margin of the Pilbara Craton. Data acquisition was completed in Aug 2018. Raw and processed seismic data have been released and are available from GA and GSWA eCat 128284
Barkly/ Camooweal	GA/NTGS	NT	Barkly sub-basin	813	10 m	30 m	20 s	2D - Deep crustal seismic reflection	Acquisition of 2D land reflection seismic data to image basin and basement structure in the Barkly region of the Northern Territory. Data acquisition was completed in Nov 2019. eCat 132890

Table 6. Passive seismic surveys

Location	Client	State	Survey name	Total number of stations deployed	Spacing	Technique	Comments
Northern Australia	GA	Qld/NT	AusArray Phase 2	About 135 broad-band seismic stations	50 km	Broad-band 1 year observations	The survey covers the area between Tanami - Tennant Creek –Uluru and West Australian border. The first public release of transportable array data is expected by end 2020. See: http://www.ga.gov.au/eftf/minerals/nawa/ausarray https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/135130 https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/135179 https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/135284 https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/134501
Northern Australia	GA	Various	AusArray, semi-permanent	3 high-sensitivity broad-band seismic stations installed in Oct 2019	~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 operated by GA, ensuring continuity of seismic data for lithospheric imaging and quality control. Associated data can be accessed through http://www.iris.edu https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/135130 https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/135179 https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/135284 https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/134501

Geological Survey of New South Wales: New state-wide geophysical images for New South Wales

During 2019 the Geological Survey of New South Wales (GSNSW) undertook a refresh of publicly available geophysics by collating, cataloguing and quality-assuring all the company data acquired across New South Wales. All company and government airborne geophysical surveys from the past 60 years can now be discovered and searched through the GSNSW MinView web-based mapping application, and can usually be immediately downloaded.

After completion of the refresh, over 150 high-quality company airborne magnetic datasets were flagged as providing significantly higher resolution data than the existing state-wide magnetic image, which mainly comprises regional-scale government surveys. A new merge has now been created which includes open-file company, GSNSW and Geoscience Australia surveys, and surveys flown by the NSW Government for the coal industry (Figure 1). Magnetic grids from individual surveys were merged together using the Intrepid software package. This allowed grids to be levelled to the AWAGS (https://www.ga.gov.au/about/projects/resources/awags) Australia-wide magnetic traverses, which accurately sample the long spatial wavelengths. Wherever possible, smaller surveys were inserted into larger surveys so regional magnetic variations are retained. The inclusion of high-resolution data has enabled the new state-wide images to be gridded with a 25 m cell size rather than the previous 50 m. This provides excellent resolution of complex anomaly patterns, especially when zooming into camp and prospect scales.

The new images are delivered through the MinView portal, where they can be displayed and integrated with other GSNSW datasets. Images of the total magnetic intensity (reduced to the pole), first vertical derivative and tilt-angle filter can be viewed online. Images and grids of an extended set of enhancements can be directly downloaded from MinView, either for the whole of New South Wales or for a selected area, and in a variety of projections most appropriate to different areas of the state. Grids are available with either 25 m or 50 m cell sizes, depending on the resolution needed and allowing for the large file size of the higher resolution grids.

As part of the refresh, the state-wide gravity grid was also updated following the removal of 50 000 older, poor quality data points from the original grid. No company data has been incorporated into the gravity grid, however a new MatLab-based imaging algorithm has greatly improved the presentation of the data. A new image of the state-wide isostatically corrected gravity based on the new grid is available on MinView. The GSNSW will commence work on an update of the state-wide radiometrics image in early 2021.

The new total magnetic intensity image of state-wide magnetics is shown in Figure 2. We invite all geologists and geophysicists to inspect the new images on MinView (https://minview.geoscience.nsw.gov.au/#/?lon=148.9143&lat=-32.65607&z=6&bm=bm1&l=) and download the data for incorporation into their New South Wales GIS and modelling projects.

Under the *NSW Mining Regulation* (2016), a large amount of currently confidential company geophysical data collected before June 2016 will become open file on 1 June 2021. This will initiate another major update of the state-wide magnetic grids by adding over 100 high-quality company surveys. GSNSW will continue to update the merge in future years as more recent data becomes available.

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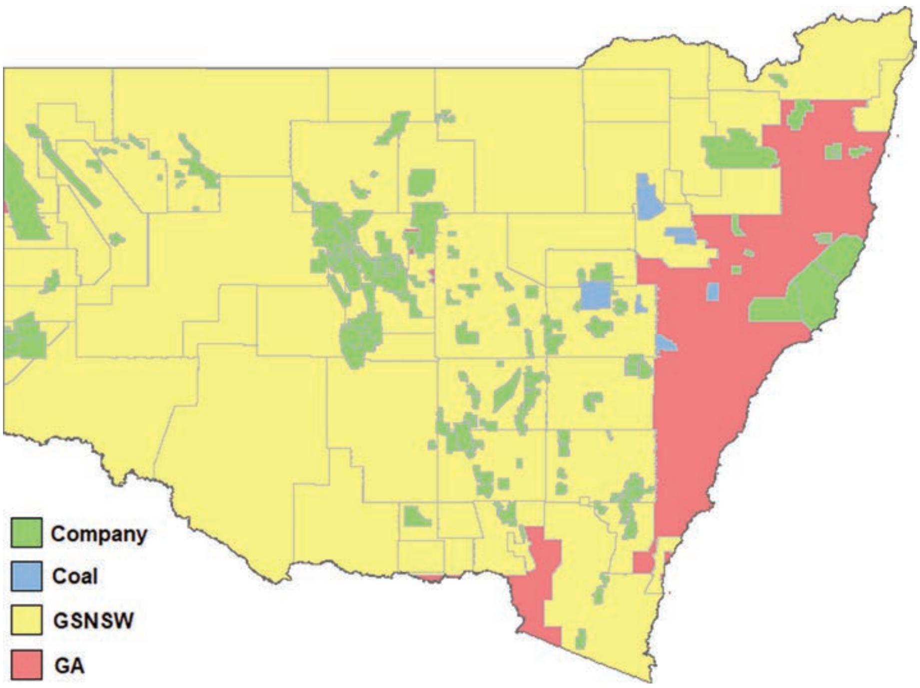

Figure 1. *Composition of the updated magnetic merge of NSW, coloured by survey type.*

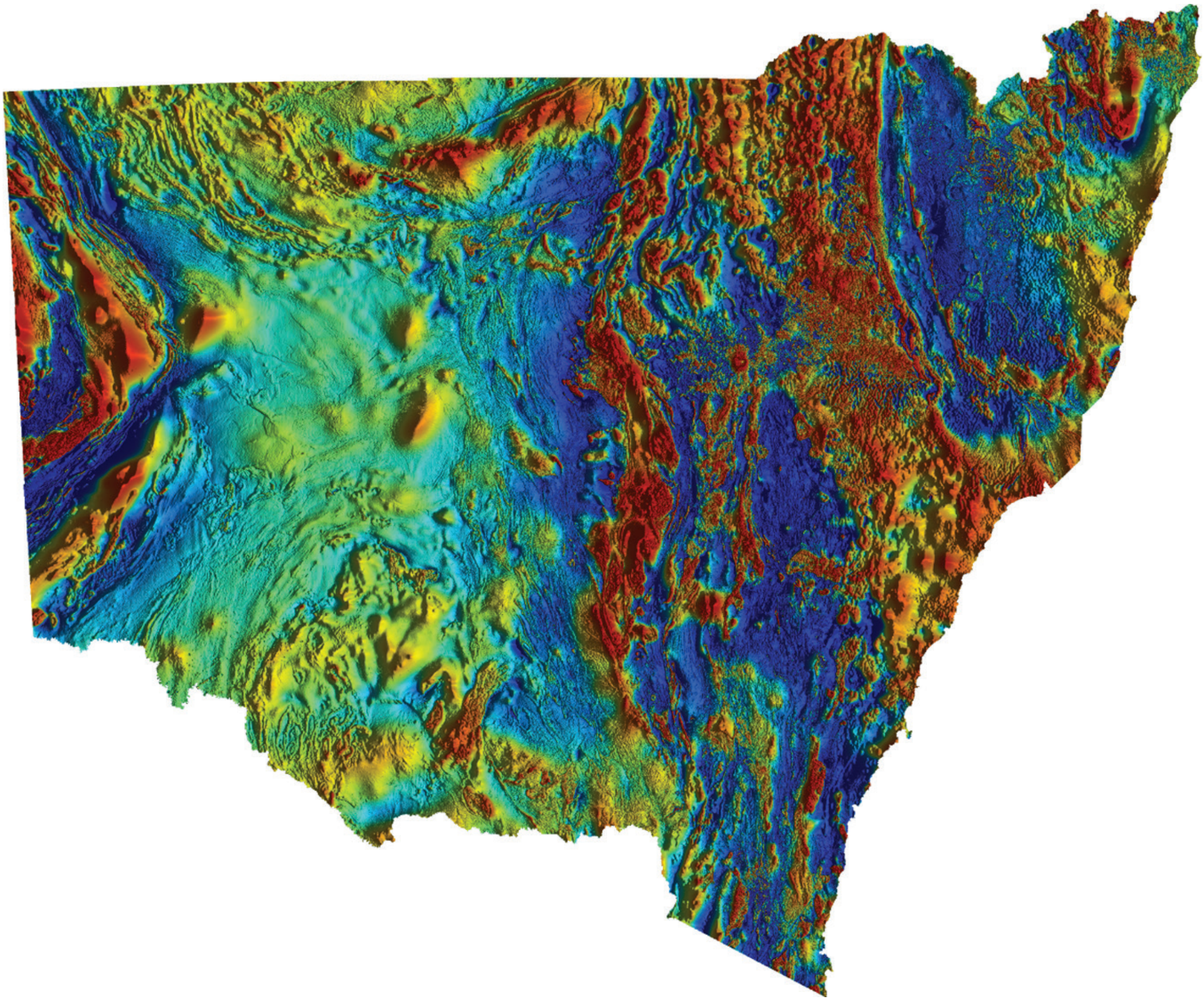

Figure 2. *Pseudo-colour image of the NSW total magnetic intensity (reduced to the pole), gridded with 25 m cells.*

The ASEG in social media

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

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

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

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

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

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

Geological Survey of South Australia: News

An open access paper by Dr Stephan Thiel, Dr Bruce Goleby, Dr Mark Pawley and Prof Graham Heinson entitled "AusLAMP 3D MT imaging of an intracontinental deformation zone, Musgrave Province, Central Australia" has just been published in the "Studies on Electromagnetic Induction in the Earth: Recent advances" special issue of *Earth, Planets and Space.* The paper describes the outcomes of an AusLAMP experiment of 96 long-period MT stations across the Musgrave Province in South Australia and Western Australia. Joint funding from AuScope and the GSSA enabled a 3D resistivity model of the crust and mantle beneath the Musgrave Province, highlighting the imprints of intraplate deformation events as well as Proterozoic mafic magmatism associated with the 1090 -1040 Ma Giles Event. The data and model can be downloaded through the SARIG portal (https://map.sarig.sa.gov.au/).

Seven new AusLAMP MT stations have been uploaded to SARIG. These sites were acquired in the second half of 2020, as 'repeat' sites for some that did not record correctly, and help to supplement the AusLAMP grid in western South Australia that had a few small gaps previously.

In late July, the Department for Energy and Mining participated in a webinar series, "Mining South Australia". The recordings of these presentations can be found at https://dti.sa.gov.au/investment/opportunities-for-industry/energy-mining and include a description of the Department's approach to exploration undercover, the value of innovation and partnerships, data science and the Explore Gawler competition. Dr Anthony Reid, Adrian Fabris and Dr Kate Robertson from the Geological Survey of South Australia discussed the geoscience of minerals targeting in buried terrains using magnetotellurics, geochemistry and mineralogy.

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Geological Survey of Western Australia: AusAEM20–WA Stage 1 underway

Data acquisition in Stage 1 of the AusAEM20-WA project is underway. This project (see *Preview* **205** April 2020, https://doi.org/10.1080/14432471.2020.1751781) is funded by the Western Australian Government's Exploration Incentive Scheme, and is being managed by Geoscience Australia as part of a National Collaborative Framework agreement with the Western Australia Department of Mines, Industry Regulation and Safety's (DMIRS) Geological Survey division (GSWA).

Contracts have been let to CGG Aviation Australia Pty Ltd and SkyTEM Australia Pty Ltd for the combined acquisition of approximately 24 000 line-km of AEM data in two survey blocks respectively in the East Yilgarn–Fraser Range and the Southwest–Albany areas of southern Western Australia (Figure 1). It is anticipated that acquisition should be complete and data released by the end of the 2020–21 financial year.

Additional stages are planned to follow for complete AEM coverage of Western Australia at a line spacing of 20 km.

For more information, please contact geophysics@dmirs.wa.gov.au.

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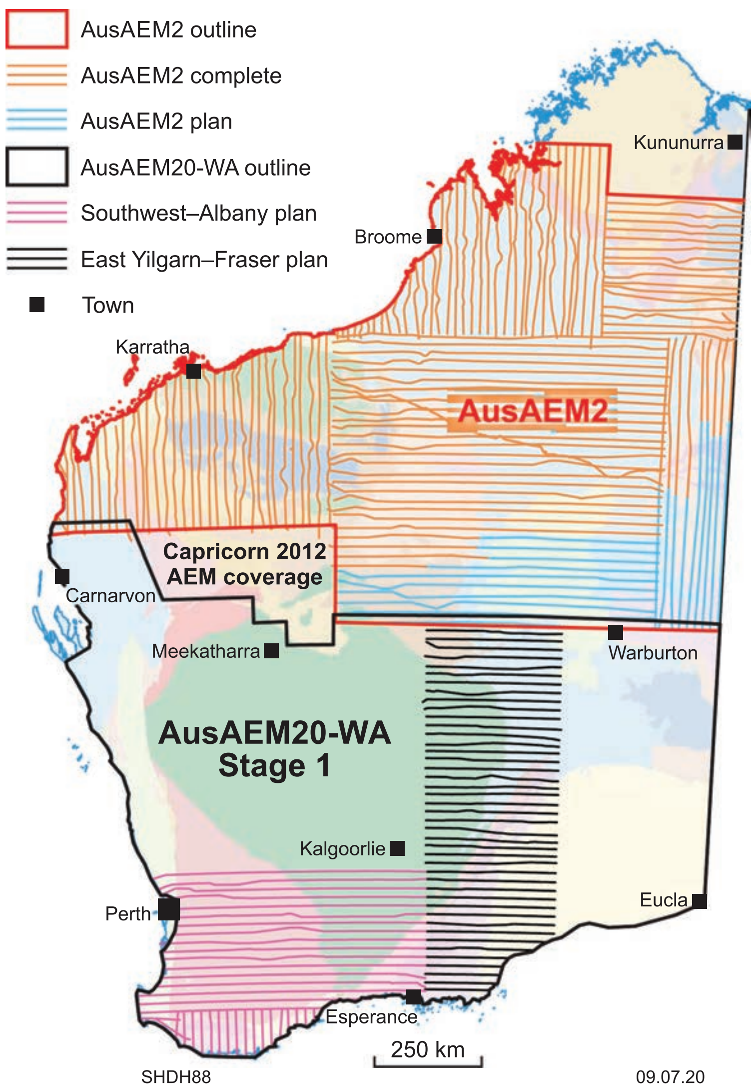

Figure 1. *Location of AusAEM20–WA Stage 1 survey areas over regional geology background.*

Canberra observed

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The good, the not-so good, the bad and the very bad

For this issue I have selected items that are good, not so good, bad and very bad. You may not agree with my views, but it shows the range of issues that make the news. And I am not going to include COVID-19!

The good: Government strengthens resources exploration

On 23 June 2020 Keith Pitt the Minister for Resources, Water and Northern Australia Minister announced that the Government will invest a further $125 million over four years on Geoscience Australia's Exploring for the Future (EFTF) programme. EFTF is an Australian Government programme, led by Geoscience Australia, dedicated to encouraging exploration for mineral and petroleum resources and to improving the management of ground water and our rural resources. This investment comes on the back of the $100 million committed in 2016 to provide new (mainly geophysical) data sets over northern Australia.

The data sets from the first four years were collected over three million km^2 of northern Australia. They are available through a portal that can be found at *ga.gov.au/eftf*. Thirteen companies have already taken up new exploration tenements in areas on which the programme focused.

The newly allocated funds are likely to be invested outside the northern Australia. Discussions are taking place with states and territories to finalise the first steps of the continuing programme. Australia will continue for many years to generate wealth from its mineral and petroleum resources, and this investment will be money well spent.

According to the Minister's media release, ACIL Allen Consulting conducted a return on investment analysis of three key EFTF activities. It concluded that the total potential benefits flowing from these activities could be between $446 million and $2.5 billion. The analysis, *Exploring for the Future Program – Return on Investment (24 December 2019)*, is available in full at: *https://www.acilallen.com.au/projects/program-evaluation/exploring-for-the-future-program-return-on-investment-analysis*. Should be worth a read if anyone needs to argue for the benefits of publicly funded strategic research.

The not-so good: Job-ready graduates

On 19 June 2020, Dan Tehan, the Minister for Education, announced the Job-ready Graduates Package. According to the Minister:

"The package focuses the public investment in higher education on national priorities and ensures the system delivers for students, industry and the community. The economy is changing and there is a need to increase the level of support going to fields of study that will contribute to national priorities and future prosperity.

The changes aim to deliver more job-ready graduates in the disciplines and regions where they are needed most and help drive the nation's economic recovery from the COVID-19 pandemic."

Are universities seen as just training places for industry? And is that why they did not qualify for the Job-Keeper programme?

The bottom line is that for science and engineering, the Commonwealth contribution will change from $19 260 to $16 500 per annum, and the student contribution will change from $9698 to $7700. The numbers for maths are $11 015 to $13 500 for the Commonwealth contributions and $9698 to $3700 for the students. For law and economics, the Commonwealth contribution will fall from $2237 to $1100 and the student contribution will increase from $11 355 to $14 500. See https://www.dese.gov.au/system/files/doc/other/job_ready_graduates_discussion_paper_0.pdf for more details.

These changes are good for the STEM subjects, but how the proposed changes will reduce complexity and produce job-ready graduates is uncertain. The government is trying to pick winners, and also trying to turn universities into training grounds for specific jobs, rather than providing students with a broad education and opportunities to follow their interests, carry out research and be adaptable in a rapidly changing world. As we know, many graduates change careers, and very few continue to practise the skills they learnt from their university courses. Better to broaden the education base rather than focus on narrow skills.

Anyway, student fees for humanities will effectively be doubled (from $6804 to $14 500) and the total Commonwealth allocation for universities will be cut. Ian Jacobs, the Vice Chancellor of the University of New South Wales, did not mince his words when he said, that "the proposed 113% increase in student fees" for communications and humanities was "astonishing" and he worried that these increases "will deter talented students" and create "extra stress for current year 12 students".

Two other consequences worth mentioning. The first is that the legal profession will continue to be the realm of the wealthy, and the second is that it appears to discriminate against women. According to an analysis of education department data from 2018 (Daniel Hurst, *The Guardian* 27 June 2020), while women make up about 58% of domestic bachelor students across the board, they represent about 67% students in these heavily affected fields of humanities, social sciences, media and communications.

As the world becomes more complex, I would have thought that the humanities and those areas that deal with human and cross-cultural issues will become more important. These areas should not be downgraded, and in any case those with arts/humanities degrees are more successful at getting jobs after graduating.

The next step will be for these changes to be approved by the Parliament. It will be interesting to see what the Senate makes of these new proposals.

The bad: Government R&D investment at lowest level as percentage of GDP

Over the last 10 years the government investment in R&D has relentlessly declined as a percentage of GDP.

According to a report released on 19 June 2020 by the Australian Bureau of Statistics, the total government investment in R&D during the financial year 2018-19 was $3330 million. This is a marginal increase over the last result, of $3279 million, for the 2016-17 financial year. However, in terms of R&D as a percentage of GDP the result is very disappointing - falling to 0.17%, the lowest it has ever been. (*http://www.abs.gov.au/ausstats/abs@.nsf/mf/8109.0?OpenDocument* and *https://www.abs.gov.au/ausstats/abs@.nsf/mf/5204.0.)*. Figure 1 shows the data for the period 1992-2019.

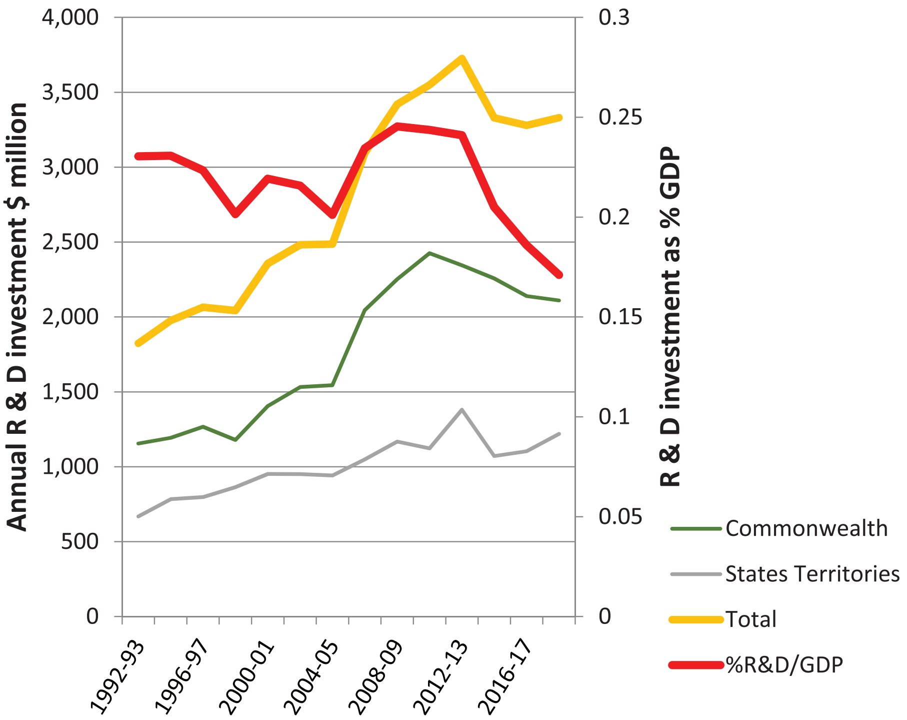

Figure 1. *Government investment in R&D from 1992-2019. The red curve shows the total investment as a percentage of GDP. See the text for the data sources.*

Australian Government organisations contributed $2110 million (63%), and state and territory government organisations contributed $1219 million (37%), to total government expenditure on R&D (GOVERD). Fortunately, investment by state and territory government organisations increased by $80 million (7%) compared to 2016-17, otherwise the outcome would have been much worse, because the Australian Government's contribution declined by $29 million.

The three most populous states Victoria ($803 million), New South Wales ($658 million) and Queensland ($616 million) accounted for over half (62%) of total GOVERD. Queensland recorded the largest increase in dollar terms, up $78 million (14%). The Australian Capital Territory recorded the largest dollar decrease, down $42 million (11%). However, it still recorded the highest ratio of GOVERD to GDP of 0.81%; ahead of Tasmania, which came in second at 0.45%.

Applied research totalled $1835 million (55% of GOVERD) followed by Strategic basic research at $840 million (25%), Experimental development at $520 million (16%) and Pure basic research at $135 million (4%). Between 2016-17 and 2018-19 Experimental development recorded the largest dollar increase of $60 million (13%).

The top three Fields of Research, in terms of expenditure, remained unchanged from 2016-17. Medical and Health Sciences ($640 million), Agricultural and Veterinary Sciences ($558 million) and Engineering ($521 million) accounted for over half (52%) of total GOVERD.

Medical and Health Sciences recorded the largest dollar increase of $138 million (28%), between 2016-17 and 2018-19.

After COVID-19 the health sector will be even more dominant. However, Research and Development does not appear to be high on the Australian Government's agenda. The ABS only produces these data every two years (most OECD countries publish annual results) and the efficiency dividend (death by a thousand cuts) is still applied annually to Commonwealth science-based agencies, such as CSIRO.

The very bad

1. Rio Tinto blowing up the Jinmium rock art site in WA

After all the good work that has been done by the resource sector to interact with and employ local indigenous people, Rio Tinto blew up a 46 000-year-old Aboriginal heritage site at Juukan Gorge with the press of a button.

And to make matters worse, Rio did not apologise for blowing up the cave, only for the distress the event caused.

Not good enough for a leading resource company.

2. The Government needlessly antagonising our main trading partner

a) I could never understand what outcome the Government thought it would get by spearheading a push for an independent investigation into the origins of the COVID-19 pandemic. It achieved nothing except needlessly upsetting China, and penalising those who used to export barley to China.

b) The second act was to consider a special status for refugees from Hong Kong. The treaty China had over the Hong Kong issue was with the UK not Australia. All we had to say was that we have a policy for providing refugee status to anyone, and people from Hong Kong would be dealt with under this policy. We could still have taken refugees from Hong Kong, but without being so blatant about it.

We really need better diplomacy that protects our trade with China without compromising our independence.

Environmental geophysics

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Henge-ing your bets

Welcome readers to this issue's column on geophysics applied to the environment. I am hoping that all of you are doing well enough in this time of COVID; I am certainly staying busy and so far feel healthy, and hope the same for you.

This month's column is not so much about the "environment" as about an archaeological study that involves some of the tools that we shallow geophysicists are known to use. I am referring specifically to the discovery of the "Giant Shafts" near the Durrington Walls Henge in England. This, then, is a brief summary of the scholarly article (Gaffney *et al.* 2020) written to describe this work (https://intarch.ac.uk/journal/issue55/4/). The Guardian also provides a very good summary of the work: https://www.theguardian.com/science/2020/jun/22/vast-neolithic-circle-of-deep-shafts-found-near-stonehenge.

First things first, I know very little about Druid archaeology, besides that Stonehenge exists, it has to do with understanding the position of the sun at the solstices, and is amazing not only for the fact that those Druids figured out where the sun was at certain times of the year, but also that they moved some big rocks over 100 km to get them to the site. My thanks to Wikipedia for helping me out here, and for some of the following background information (I contribute to Wikipedia every year or so – it is such a great resource).

We have all heard of the Neolithic, but when was it? Well that seems to vary depending on where you are around the world and the state of your local civilisation. The Neolithic is in the "Late Stone Age" i.e. before metal (seems that the Bronze Age was next). It is usually defined as the time when a group of people are able to start domesticating animals and grow crops and are therefore not surviving solely as "hunters and gatherers". It started about 12 000 years ago, and in Northern Europe finished roughly around 3700 years ago, earlier than that in, for example, the Middle East, and the same or later in other parts of the world.

Next clarification – what is a henge (honestly I didn't know that it was a thing)? A henge is a Neolithic earthwork, typically a circular bank with an internal ditch surrounding a central flat area about 20 m in diameter. They weren't lived in, and are thought to have been used for rituals (Figure 1 shows one that is in such good condition it could still be in use today). Third, bit of background (ok, not background, but I found this in my "research") – did you know that over there (Europe mostly) there are archaeological contractors (that alone is somewhat amazing to me, but wait there's more) who specialise in geophysics? Seriously, sometimes I wonder where my career would have gone in another setting.

Enough background, let's get to the study. I like the opening line of the article: "A series of *massive geophysical anomalies*, located south of Durrington Walls Henge monument, were identified during (a) fluxgate gradiometer survey undertaken by the Stonehenge Hidden Landscapes Project (SHLP)" (Gaffney *et al.* 2020). The italics are mine. I found it fascinating that the tool of choice for these surveys is the fluxgate magnetometer collecting

Figure 1. *The three aligned henges of the Thornborough Complex. Source: Wikipedia.*

vertical gradiometry data, but then I got looking at the scale of the anomalies (±2 nT only, see Figure 2) and realised that that was probably the reason. These surveys were run in 2012 and 2013 (although they appear to tie into other surveys run earlier) and the anomalies were at first attributed to human-created (Neolithic?) dewponds (or "turkey's nests" in Australian English) or, to a series of solution features that followed the contours of the dry valley. Many were found to have Bronze Age and older tools and other artefacts in them.

Ultimately, it was a combination of factors that convinced the authors that these features were likely to be man-made, and that their locations were not random. Images from the GPR showed that many of the features were deeper than your average dew pond, and had steeper walls (Figure 3). Additionally, it appears to be more than coincidence that all of these pits form a rough circle ~750 to 950 m from walls of the Durrington Walls Henge (not a complete circle, but some of the area is yet to be surveyed). Figure 4 shows the extent of

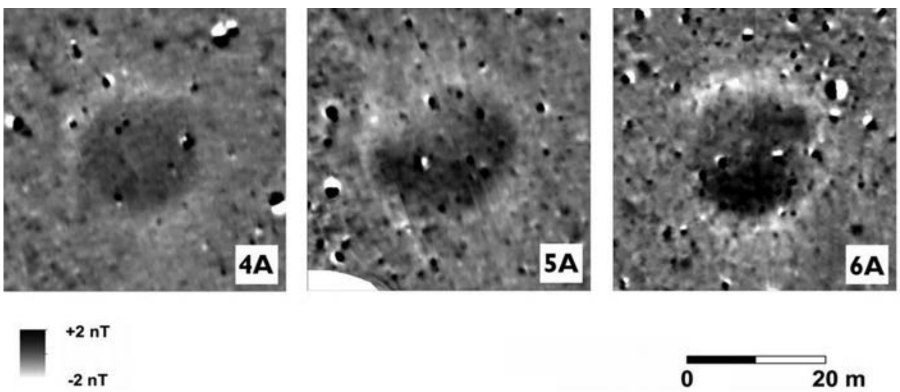


Figure 2. *Fluxgate gradiometry images of three of the circular features south of Durrington Walls Henge. Source: Gaffney* et al. *2020. The article does not specify how these data sets were processed.*

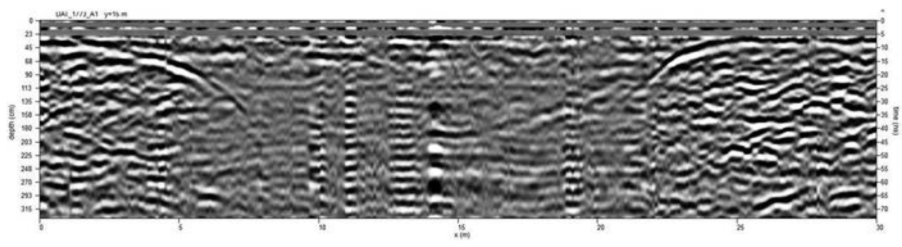


Figure 3. *GPR cross-section across Feature 8A (one of the interpreted pits). Data were collected using a 250 MHz antenna. Depth is to ~3.2 m. Source: Gaffney* et al. *2020*

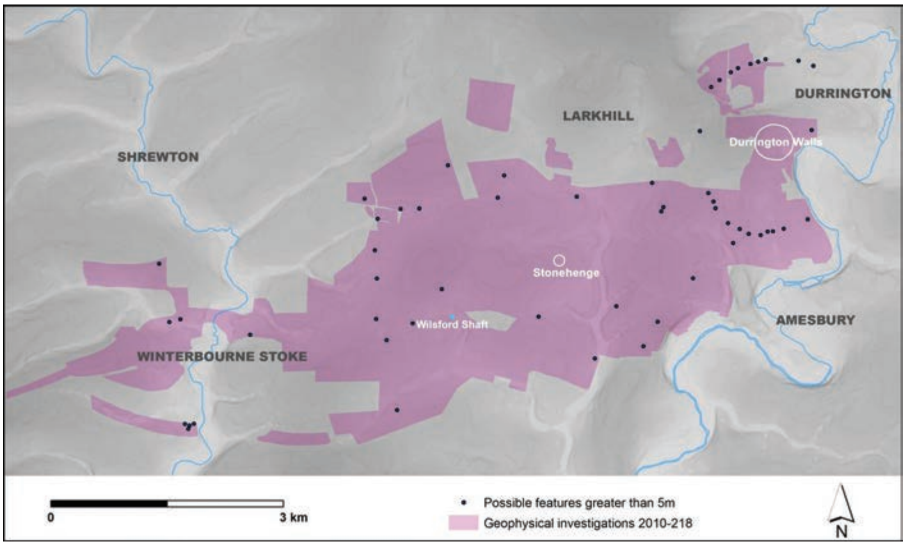


Figure 4. *The extent of large area geophysical surveys around Stonehenge and Durrington Walls and the location of probable and potential features over 5 m in diameter displayed over a digital elevation model. Source: Gaffney* et al. *2020*

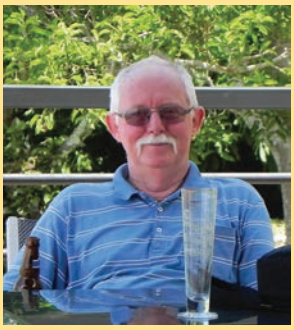
geophysical surveying that has been done recently (well after the Neolithic) in the area around Stonehenge, including the Durrington Walls Henge, a total of ~18.4 km^2. There obviously is more to do around Durrington Walls.

So far the best theory for why the pits were dug is that they marked a boundary. One theory is that only certain people were allowed to venture into the area demarcated by the boundary, and it most likely had something to do with the Durrington Walls Henge. Like all good geophysicists (archaeologists?), the authors recommend that more field work is required to really get to the bottom of this (so to speak).

Reference

Gaffney V., *et al.*, 2020 A massive, late Neolithic pit structure associated with Durrington Walls Henge, *Internet Archaeology*, 55, 47.

Minerals geophysics



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Going that extra mile

With the modern processing and presentation tools now at our disposal, any geophysical assessment, whether it involves evaluating newly acquired third party data or re-visiting existing data, will offer opportunities to advance knowledge. The key enablers for this advancement are the generation of appropriate geophysical products and the presentations of those products for optimal use by geophysicists and other team members.

Where third party geophysics are involved, such as information supplied as part of a package for property evaluation, or the results of historic surveys recovered from literature searches, the information format will largely determine the extent of possible further processing and presentation work. Images alone are of limited use; you will be effectively restricted to looking at what everyone else has already looked at. You may be better informed than they were, but why not give yourself the best chance? To carry out further geophysical processing, you need data. If digital data are not already supplied, you may have to specifically request data files, or you may have to derive the data from hard copy. Located data are best, but gridded data may well suffice. As well as offering more flexibility in further processing, having located data will allow you to review the geophysics for quality control. My past reviews of data have occasionally highlighted calculation errors (e.g. using the 2D apparent resistivity formula for 3D electrode dispositions), errors in units (gravity units processed as milligals), and the inclusion of obviously invalid data.

If the data are only available in hard-copy form, extra effort will be involved. Where the hardcopy comprises data sheets (e.g. gravity, ground magnetics, etc.) then digitisation can be achieved using optical character recognition (OCR) technology (with some careful checking of the results if the original documents are of poor quality). Where IP-resistivity survey results are only available as pseudosections, digitisation is more efficient if you have a spreadsheet set up to assign electrode dispositions on the fly; even better if the spreadsheet also formats the data for input into your inversion routine. With hard copy data in profile form (e.g. magnetics, gravity, gradient array IP-resistivity, etc.), manual digitisation can be more tedious, particularly if the vertical scale is logarithmic. But it is doable. However, digitising multichannel EM data plotted at logarithmic scales from hard copy stacked sections may be a step too far. If anyone out there has an automated process for this, I'd be much obliged for any information on how it's done.

Once you have the data in digital form, processing and presentation are at your fingertips. Where in-house geophysics are involved, the data should already be available and may well have been processed and presented. The aim here is to value-add. A typical request for a re-assessment may come from a geologist wanting to view the geophysics available for a particular work area. There will probably be regional or semi-regional geophysical surveys (e.g. magnetics, radiometrics, gravity, etc.) covering the area, but whole-of-survey images will be general in nature. One size does not fit all.

A good first step will be to window out the data for the work area and generate products and bespoke images tailored to the geologist's particular needs. This is particularly pertinent if geological mapping and structural assessment are part of the program. Pattern recognition will be enhanced on vertical derivative images, and by the use of Automatic Gain Control to suppress anomaly magnitude differences. Local anomalies can be enhanced by subtraction of an appropriate background created by say, upward continuation. Alternatively, local anomalies may be better delineated via a high pass filter such as the Butterworth. These are just some of the wide range of processing options available.

Different products can also be combined in the one presentation, using colour for one parameter and shading for another; ternary presentations aren't just for radiometric channels either. There are not necessarily hard and fast rules for this – sometimes it's just a matter of trying various combinations (hopefully the choices are intelligently informed) until you generate products that do the job. One thing though – clearly document and label what you've done. It will help inform sensible interpretations and will serve to remind you what worked this time. One of my hobby horses is proper labelling of products and, for images, inclusion of the relevant colour bar. It can be quite frustrating interpreting an image that is unlabelled, or even worse, incorrectly labelled. I nag my co-workers on this one, particularly where we have image captions like "structure over magnetics". What sort of magnetics? There are a lot of different products out there. You may be able to tell from the pattern style, then again you may not. Even if the image is properly labelled, without a colour bar you have no information on the amplitude range and, if it's not specified in the label, the colour stretch.

The ability to properly view geophysical information against available data from other geoscience disciplines is a very important factor in enhancing the interpretation process. The multi-disciplinary interpretation/presentation packages presently available, such as Leapfrog, GeoScience Analyst, GOCAD, MapInfo, etc., all have facilities enabling the import of geophysical products when presented in the appropriate format.

So give yourself and your team the best possible chance and invest effort in presenting those new products that you've just generated in the most appropriate formats.

Seismic window

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Artificial intelligence finds faults

In recent years it has taken some effort for me to get my head around Machine Learning (ML). I even bought a book ("The Master Algorithm" by Pedro Domingos) that was recommended to me by a Canadian mate. He said it made understanding ML simple. I found it a great cure for insomnia, and after a few weeks reading I came to the conclusion that nothing will make ML simple and it was a book for long cold Canadian winters. But then, a few months ago, I was fortunate enough to try out some ML software that supposedly could highlight fault planes in a seismic volume. It was quick, worked a treat, and perhaps the best thing about it was that I didn't have to know anything about the maths. Suddenly I had become a Nintendo geo and I could produce fault maps at the click of a mouse button (Figure 1).

Over the last decade there has been a great deal of movement in designing methods to highlight faults and fractures. Originally a coherence volume was calculated, but I believe Amoco held the copyright for the method and so other companies had to find alternatives such as similarity. At the time the similarity volume was providing some excellent results, especially when viewing time slices or horizon slices. But the usefulness of similarity, semblance and coherency cubes was often compromised by noisy data that resulted in variable quality of a fault trace vertically and laterally. Some innovative techniques were sometimes used to sharpen up the fault image, but this led to artefacts that obscured the major trends (e.g. thinned fault likelihood).

The ML implementation creates a seismic volume of the probability of a fault at a certain location. It produces a clear fault/no fault definition with very few artefacts (Figure 2). How it does this I wouldn't know; I'll just take the results for granted.

Actually, I do know a bit. The machine learning solution is a convolutional neural network algorithm that I believe has been trained on a database of faults worldwide. Regardless of how it works, I'm impressed that it worked straight out of the box with no input required from me. I really am being replaced by a machine.

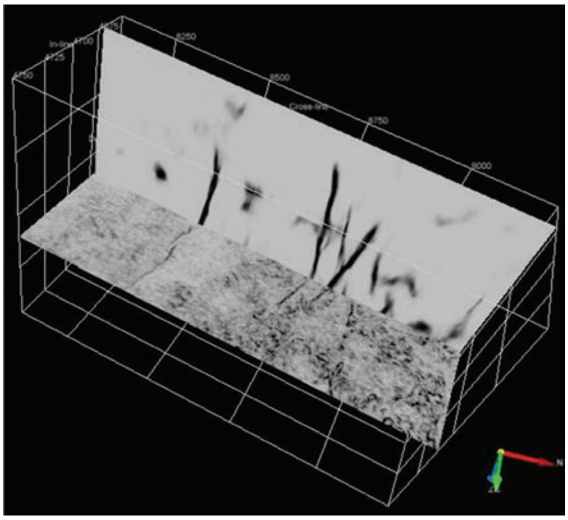

Figure 1. *Display of ML produced faults in vertical plane and similarity data in horizontal plane. The similarity derived faults are visible but fuzzy and obscured by noise.*

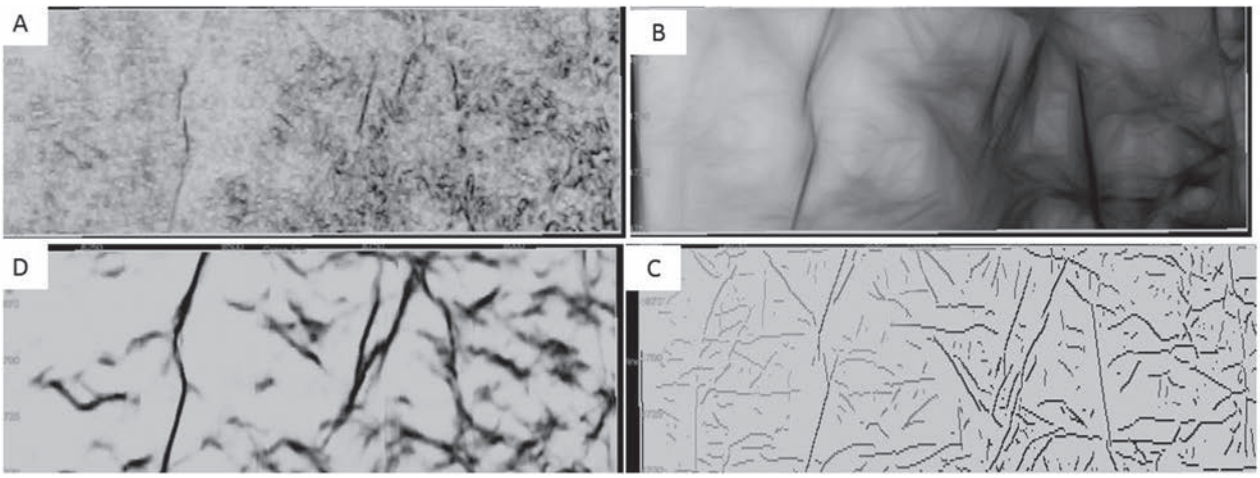

Figure 2. *Comparison of various methods of detecting faults. Clockwise from top left a) Similarity, b) fault likelihood, c) thinned fault likelihood and d) Deep learning artificial intelligence solution.*

Data trends

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Planning for a new petrophysical sampling guide, and calling for input to the formulation of a universal passive seismic data format

In response to earlier columns, and thanks to the interest of Regis Neroni and Mark Duffet. Regis, Mark and I have decided to produce a best practice guide to collecting minerals petrophysical data in the field. The guide will offer a general overview, and practical "how to" explanations for on-site geologists. There will be additional one or two pages of operational guides for field assistants to ensure consistent and repeatable sampling. A one sheet limit per technique will allow lamination for protection from the elements and heavy handling. The guide will be publicly available through on the ASEG Technical Standards page on the ASEG website.

Passive seismic data continues to steadily roll into government archives. However, a universal format has not yet been established, and questions remain about what information needs to be included. Different users are likely to have different answers. And, despite their limitations, it seems clear that the established seismology formats are not going away as many users find them to be quick and convenient.

The ASEG Technical Standards Committee is keen to resolve this problem, and to paint a fuller picture of industry use we are asking for the petroleum industry's views. The petroleum industry does seem to be taking an interest in passive seismic and one 3D seismic company has told us that they have used overnight passive data to supplement their day time active work. One sticking point maybe that while SEG Y r2 is technically suitable for passive seismic, it appears that using SEG Y r2 is proving difficult - even for those with expensive petroleum software. Explorers living on the proverbial oily rag may find located images in their 3D programs to be their best option.

If you are a petroleum explorer and you use passive seismics, we would like to hear from you, in particular we would like to hear what storage and imaging formats you use. Please email me at technical-stadards@aseg.org.au.

Webwaves

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The ASEG YouTube channel

The disruption to in-person meetings means that ASEG technical nights are now being hosted on Zoom. The ASEG has also transitioned to offering digital talks. These technical talks are, with the presenters' permission, being published on YouTube. By hosting the videos on YouTube, the ASEG can reach a wider audience, and those who live and work remotely or internationally can get benefit from the material. The posting of videos to YouTube furthers the aims of the Society by promoting the science of geophysics in the wider community.

For corporate partners and state branch advertisers, this format also represents an increase in value: their logos are included at the start of each video, with corporate partners mentioned by name. The webinars have been watched by people in six continents, with a large weighting to Australian viewers. These audiences have been, on average, higher than those at traditional technical events. The additional viewership on YouTube after the event has also increased audiences.

The ASEG YouTube channel had one video posted in April and four posted in both May and June 2020, with similar numbers of talks planned to be held in the coming months. This growing library of videos can be accessed through the ASEG Videos webpage https://aseg.org.au/aseg-videos or through YouTube, where the ASEG channel is available. Please subscribe on YouTube to catch the content as it is uploaded. The ASEG Videos channel can be reached on this link: https://bit.ly/2Ob0CCu.

In the last 90 days, the YouTube channel has had over 3000 impressions, this represents the number of times someone on YouTube has seen a thumbnail of an ASEG video. The current click through rate is 7.7% (the percentage of users who clicked to view having seen the thumbnail). There were a total of 612 views representing an average of 6.8 views per day (see Figure 1). Of the nine videos posted in this period, viewership ranges from 78 views through to 21 views. This 90 day period has also seen the channel gain 50 new subscribers. Large percentage increases shown in Figure 1 illustrate the increased activity on the channel with the transition to digital tech talks.

As shown in Figure 2, the majority of viewers (71.9%) access the videos on desktop, with 26.8% viewing on a mobile or tablet device. Smart TVs account for 1.3% of views. The highest source of viewers come from YouTube channel pages, with 33.8% of traffic. External links such as the embedded videos on the ASEG website generate 25% and search 11.6% of views (see Figure 3). Some of the remainder comes from people sharing links directly to videos. Analytics show that Facebook, LinkedIn and WhatsApp have all been used to drive viewers to the videos.

Videos posted since Covid-19 lockdown include:

- Characterizing extensive hydrogeologic systems beneath ice sheets and oceans using EM methods. (https://bit.ly/3iNgkBN) presented by Chloe Gustafson
- Working in isolation – Antarctica and on 'Mars' (https://bit.ly/3fg8Zso) presented by Steph McLennan and Jon Clarke

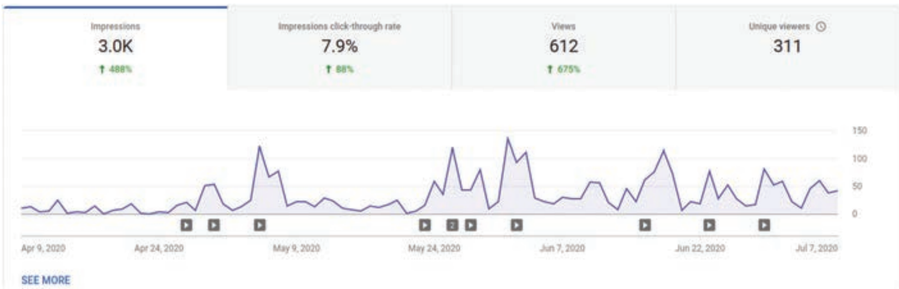

Figure 1. *YouTube channel reach in the past 90 days.*

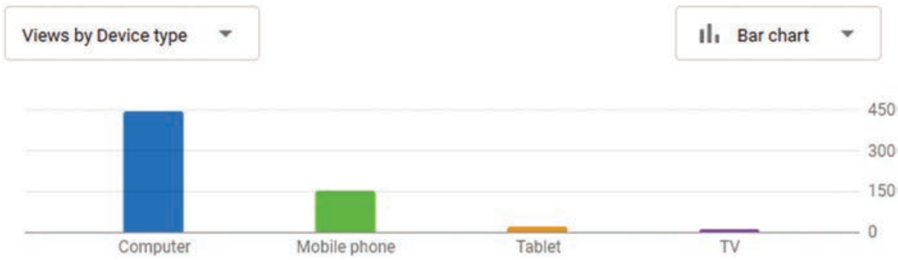

Figure 2. *Viewing device on the YouTube channel.*

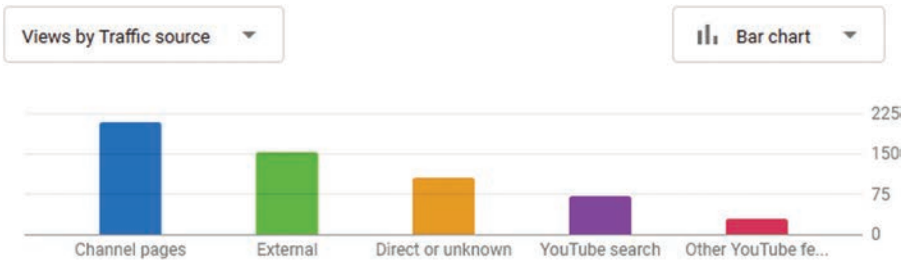

Figure 3. *Traffic source on the YouTube channel.*

- Constraining the resistivity of pore fluids in the crust with Bayesian joint inversion of MT & CSEM (https://bit.ly/2W6axO9) presented by Daniel Blatter
- Geophysical characterisation for the dredging of the Marine Industry Park, Darwin (https://bit.ly/3ec6q9j) presented by Simon Williams
- How regional geophysical data has reshaped tectonic analysis of the Australian continent (https://bit.ly/38Js0kv) presented by Peter Betts
- How remote is remote sensing from geophysics? (https://bit.ly/2W2UYqp) presented by Rob Hewson
- Adventures in unmarked grave detection (https://bit.ly/3iPOOU6) presented by Ian Moffat
- Probabilistic seismic Full Waveform Inversion (FWI) (https://bit.ly/2ZRqQ2 g) presented by Anandaroop Ray
- Coupling surface evolution and mantle dynZamics (https://bit.ly/3fg9keE) presented by Claire Mallard
- Seismic attribute illumination of a complex fault network North Slope, Alaska (https://bit.ly/38JwFDa) presented by Sumit Verma

The talks cover a broad range of topics across various geophysical themes. Upcoming webinars are advertised to ASEG Members through email and the ASEG newsletter. They can also be viewed on the events page of the ASEG website https://aseg.org.au/events.

For those of you who prefer the in-person technical talks - they will return when current restrictions relax, with the aim of continuing to post digital offerings on YouTube.

Feature

2.5D Airborne Electromagnetic inversion: A review of the benefits of moving to a higher dimension

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Introduction

Intrepid Geophysics began operating a 2.5D Airborne Electromagnetic (AEM) inversion service in early 2016, following two years of software development by Intrepid Geophysics and Jovan Silic, the primary EM software modelling and inversion algorithms developer. The software was developed to facilitate targeting of ore bodies, mapping of geology and geological structures, and the location of water aquifers for exploration and development purposes.

The 2.5D AEM inversion software makes use of Intrepid's 3D GeoModeller as a user interface, a visualisation tool and for creating forward models, but runs as a separate MPI application using control and batch files. The inversion results are loaded into GeoModeller for visualisation and QC. In addition, the results add value to 3D GeoModeller's implicit geological modelling package, which already contains a stochastic plugin for magnetic and gravity inversion. As such, resistivity/conductivity and chargeability join magnetic susceptibility and density as physical rock properties that can be modelled, conforming with Intrepid's overall philosophy of deriving rational geology from geophysics.

The 2.5D software is a substantial rewrite and parallelisation of the original CSIRO/AMIRA project P223, ArjunAir code, and is now named Moksha. The rewrite implemented a new adaptive solver and forward model (Silic *et al*. 2015). For reference, AMIRA P223 ran with strong industry support from 1981 until 2008, a period of 27 years. The partially finished software was released into the public domain in 2010.

Advantages of the 2.5D application compared to the 1D are that it can model topography and irregular subsurface structures where the structure along strike is assumed to be constant for a geo-electric distance greater than the AEM 3D source footprint. The computation is based on the response of a 2D model to a 3D source (hence the 2.5D descriptor) and can be applied to 3D structures whose conductivity precludes the spread of the source wave beyond the 2D region during the time range of the data (Raiche *et al*. 2008).

While the 2.5D module has been fully operational since 2016, the software is being continually refined to deliver improvements in resolution, performance and to add new features. For example, the recent introduction of a variable finite element mesh resolution in the X direction has allowed better definition of narrow conductors and improved productivity for surveys requiring higher mesh resolution.

Forward modelling and joint inversion of induced polarisation (IP) has also been added in an effort to manage commonly encountered IP effects in surveys flown with the more powerful suspended loop systems such as VTEM, SkyTEM and Xcite.

The software's advantages over industry standard Conductivity Depth Imaging (CDI) and 1D inversions are:

1. The ability to handle topography and thereby remove topographic artefacts e.g. resistive anomalies on hills.
2. The ability to model resistivity contrasts up to 1 million to 1.
3. The elimination of non-geological "pant-leg" conductors by being able to handle strong vertical/lateral discontinuities. Pant-legs are typical of 2D effects in a 1D inversion. For example, a resistor is imaged beneath a conductive "pant-leg" centred above a vertical conductor. The 1D assumption is inadequate for imaging the 3D structure as the horizontal-dipole behaviour cannot be explained by a 1D conductivity structure (Oldenburg *et al*. 2019).
4. Prediction of geologically reasonable fold structures that are accurate for dips greater than 20°. 1D is only reasonably accurate for dips up to about 20° over extensive (large conductors) without significant lateral conductivity variations. 1D inversions over an approximate 1D horizontal layer with significant lateral conductivity variations will not only produce artefacts, but can place conductive features at depth where there are none.
5. Joint inversion of X and Z components linked by a full vector treatment of Maxwell's equations.
6. Joint inductive and IP (chargeability, time constant and frequency effect) inversion.
7. The ability to constrain inversions using a resistivity reference model based on known or hypothesised geology.

In a non 1D geological scenario, it would be preferable to invert the data in 3D and remove the assumption of geological strike with respect to flight direction. However, this is not always a practical option for the following reasons:

1. 3D at a survey scale will not be valid at wider line spacing when lateral continuity is not assured.
2. 3D is invariably an under-determined inversion problem with more unknowns than data points. Thus, it requires the imposition of extra conditions or assumptions on the inverted model.
3. 3D solves for millions of unknowns requiring large compute resources so that inverting at high spatial resolutions becomes very expensive in both time and cost.

2.5D is a good compromise as it uses a numerical implementation of Maxwell's equation in an over-determined system. This is in contrast to the 3D system of equations being under-determined as described in the second point above. The 1D class of solvers largely ignores the horizontal variations.

Over the past five years, 2.5D inversion service work was completed by Intrepid on surveys using all major AEM systems (TEM and FDEM), see Figure 1, and spread across most mineral exploration regions, see Figure 2. The bulk of these inversion projects was undertaken for conductive targeting and geological/ structural mapping purposes, with the split roughly equal. Approximately 10% of projects were related to groundwater mapping.

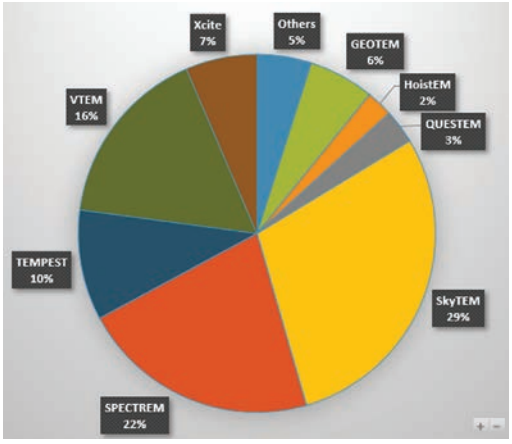

Figure 1. *2.5D inversion service by AEM system*

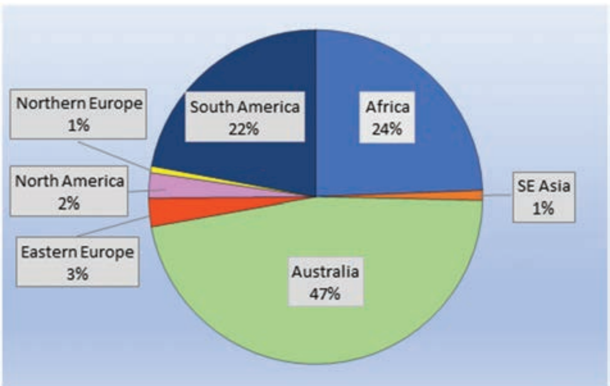

Figure 2. *2.5D Inversion service by region.*

Examples of 2.5D inversion and forward modelling

Data from Quamby/Dugald River (Queensland, Australia) and Kevitsa (Finland) are used to illustrate the advantages of 2.5D inversions over the more commonly provided and utilised CDIs and 1D inversions when the geology and targets sought do not fit the 1D assumption.

Data from Elura (New South Wales, Australia) are used to illustrate the application of the Moksha software in tandem with a full 3D geology modelling package to forward model the performance of different AEM systems over a realistic exploration target. The detectability of deposit styles in different weathering regimes using different systems can be predetermined, resulting in a more cost-effective survey design.

Quamby/Dugald River, Queensland, Australia

The data used in this example came from the East Isa VTEM^{TM}Plus AEM survey. The survey was flown in 2016, and was funded under the Queensland Government's Future Resources (Mount Isa Geophysics) Initiative and managed by Geoscience Australia on behalf of the Geological Survey of Queensland. The Initiative aims to attract explorers into 'greenfield' terrains and to contribute to the discovery of the next generation of major mineral and energy deposits under shallow sedimentary cover.

This example demonstrates the ability of 2.5D inversion technology to reliably image steeply-dipping and folded geology, and to present exploration targets ready for testing.

Z component-only inversions were performed on eight lines of VTEM^{TM}Plus that were 2 km apart over an 8 x 15 km block in the Quamby/Dugald River mineral district, east of Mt. Isa. A number of discrete exploration targets were defined, and some of these have a close spatial relationship to the shale hosted Pb/Zn mineralisation at Dugald River.

Figure 3 shows the survey area and the location of the Dugald River mine relative to the VTEM^{TM}Plus flight lines on a Google

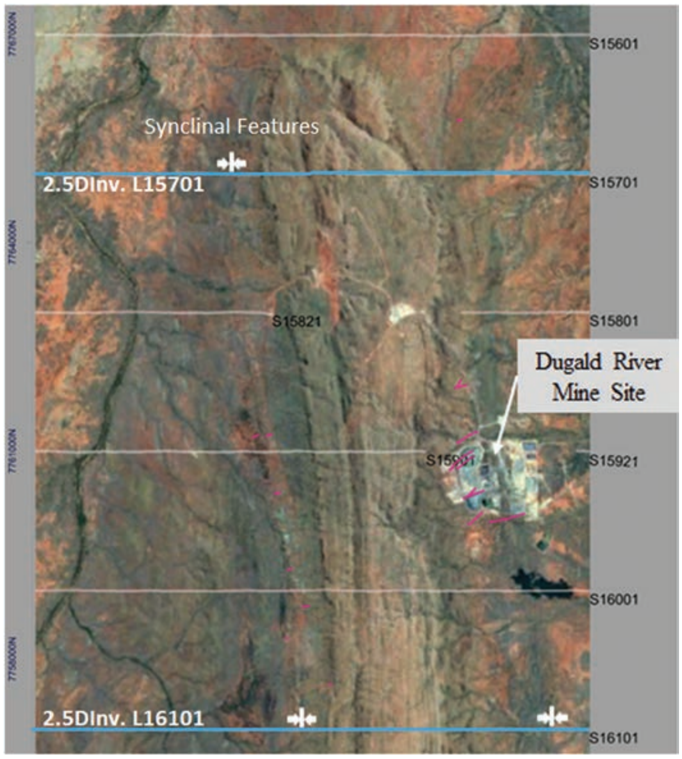

Figure 3. *Dugald River area showing the inverted VTEM^{TM}Plus flight lines relative to the mine site. Mapped synclinal features are highlighted by white symbols and inclined drill holes are in magenta.*

Earth backdrop. The mapped synclinal features are highlighted with white symbols, and inclined drill holes are in magenta. Inversion results are presented for lines 15701 and 16101, which are denoted in blue. Figure 4 shows the geology of the survey area with the mapped synclinal features highlighted by red symbols.

The 2.5D Z component-only inversion results in Figures 5 and 6 highlight the synclinally folded shale package (grey/

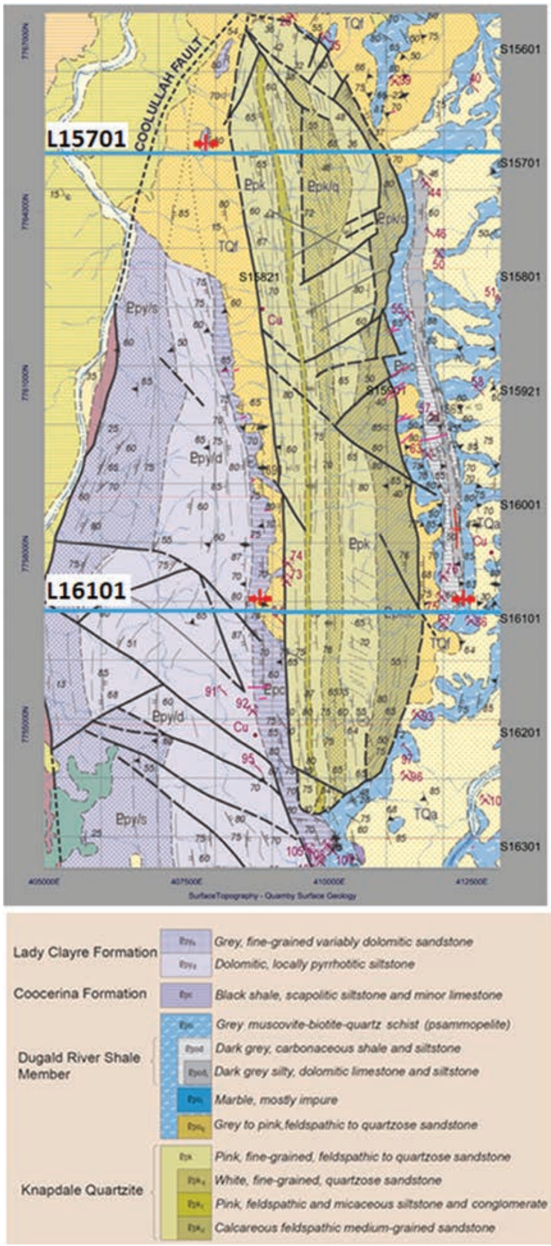

Figure 4. *Quamby 1:100 K geology (Wyborn 1997) showing the conductive shale horizons. Mapped synclinal features are highlighted by red symbols and inverted VTEM™Plus lines are in blue.*

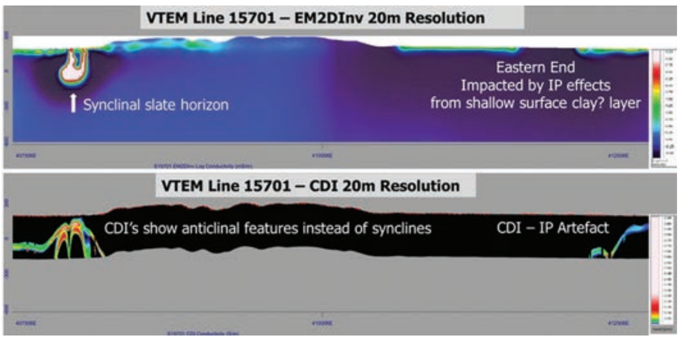

Figure 5. *Line 15701 2.5D inversion, Z component-only, (top) and CDI (bottom). The colour stretches are roughly equivalent; the CDI units are conductivity in Siemens/m and the 2.5D inversion units are log conductivity in milli-Siemens/m.*

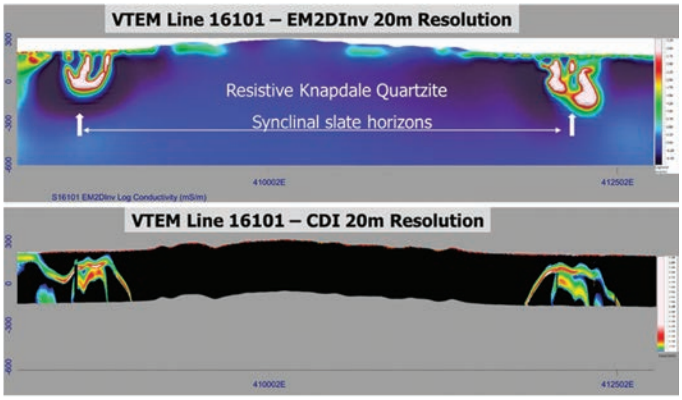

Figure 6. *Line 16101 2.5D inversion, Z component-only, (top) and CDI (bottom) showing the location and geometry of conductive anomalies. The colour stretches are roughly equivalent; the CDI units are conductivity in Siemens/m and the 2.5D inversion units are log conductivity in milli-Siemens/m.*

grey-pink striped colours in Figure 4), which is host to the Dugald River deposit. These shales wrap around the Knapdale Quartzite core.

Comparison of AEM inversion results

The log conductivity results for 2.5D, Z component-only, and CDI inversions for Lines 15701 and 16101 across the Quamby/Dugald River subset are shown Figures 5 and 6.

The 2.5D inversion results show synclinal features with dips that closely match the known geology from drilling and surface mapping. Conversely, the CDIs show anticlinal patterns caused by difficulties handling strong lateral resistivity contrasts and a breakdown of the 1D assumption in the presence of steeply dipping complex geology.

Interactive views of channel data misfits, the noise model and conductivity section for line 16101 (Figure 7) enable the user to validate the inversion results in this folded synclinal slate horizon example. Observed profiles are in colours and the predicted profiles are in black. The noise model panel (bright green and blue) shown below the three profile panels in Figure 7 is a by-channel (Y axis) map of the noise estimates used in the inversion. Channel values in blue are below the chosen noise threshold and channel values in red are negative transients assigned as IP effects. The former are down-weighted and the latter are ignored during the inversion.

Managing IP effects in 2.5D inversions

The eastern end of line 15701 displays a CDI artefact, which is interpreted as being caused by near surface IP effects in this area (Figure 5). These IP effects manifest as negative late time transients as seen in the profile displays and highlighted in red in the noise panel in Figure 8. The source of the IP effects has not been investigated in the field, but these effects are often associated with near surface clays.

A joint Z component-only inductive and IP inversion was run over this line, and the results are presented in Figure 8, where it is compared with a Z component-only inductive inversion. The red zones in the accompanying noise map highlight the time gates and areas with negative transients.

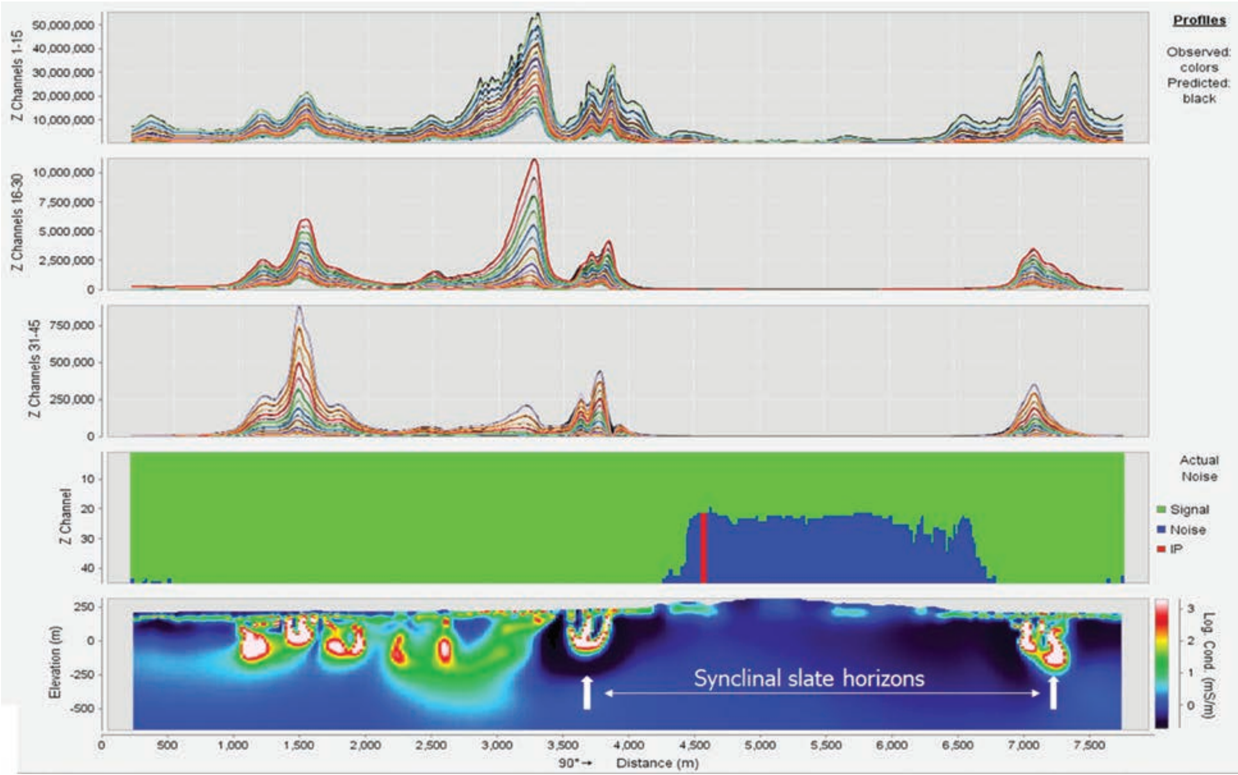

Figure 7. *Line 16101 2.5D inversion profile misfits (top three panels), noise map and conductivity section (bottom panels). Note the colour inverted profiles match the observed data closely such that the observed profiles (black) are not visible at print resolution.*

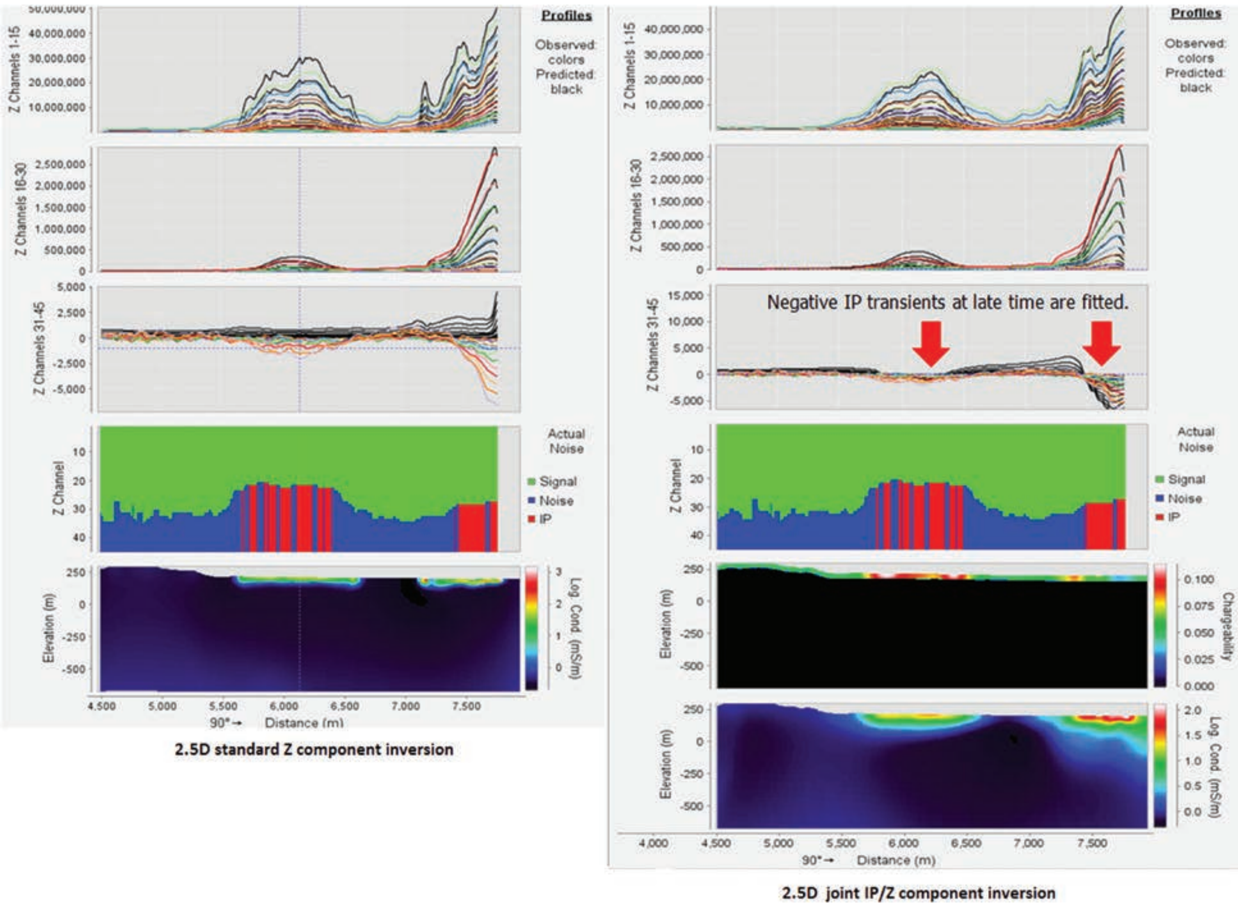

Figure 8. *Line 157101 2.5D standard Z component inversion (left) and joint IP/Z component inversion (right).*

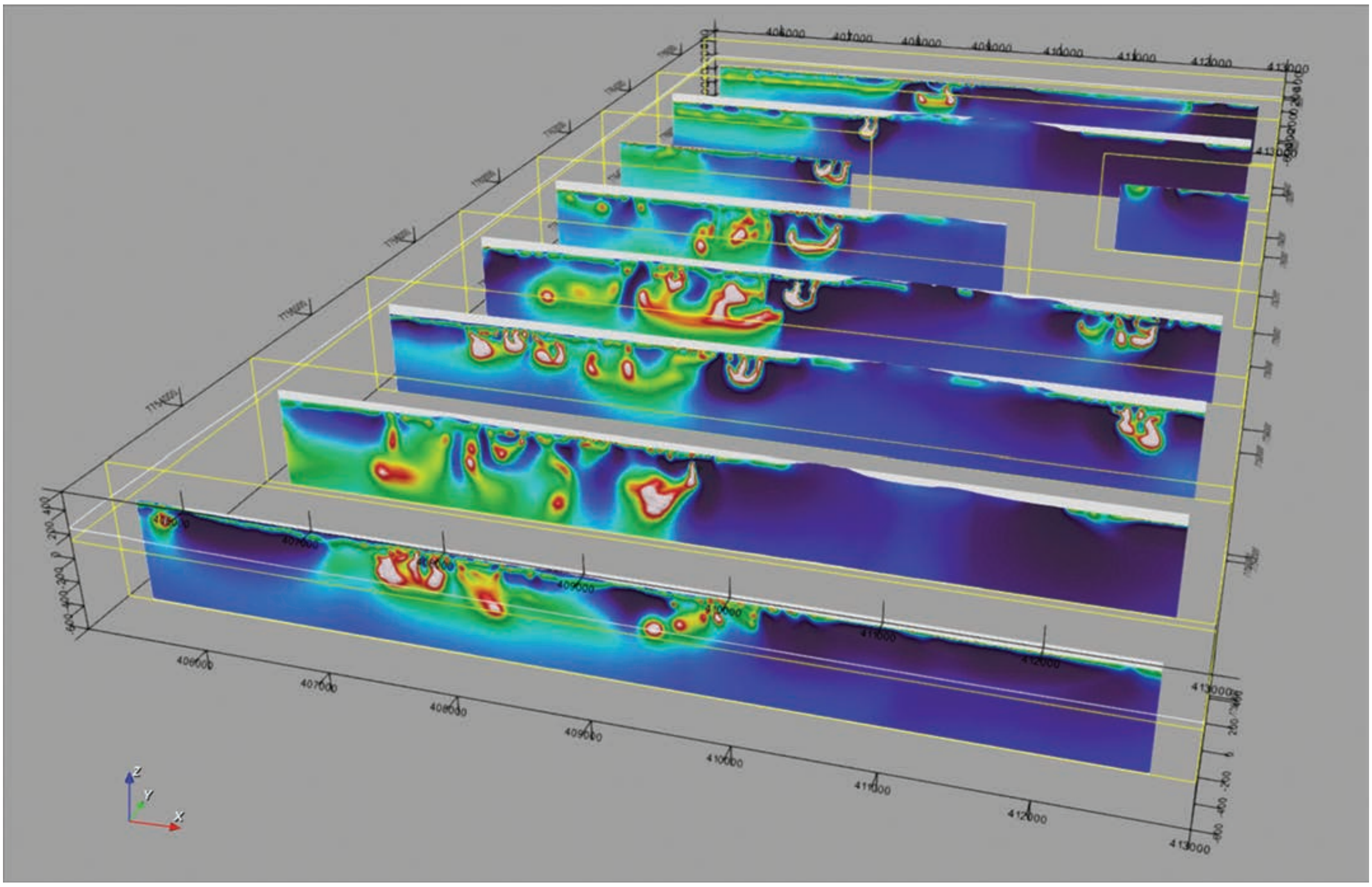

Figure 9. *Quamby/Dugald River 3D perspective view of AEM 2.5D inversion results.*

The inductive-only inversion in the left side panel does not fit the negative late time IP pull down, (evident in Channels 31-45 in Figure 8), but does in the joint inversion on the right (as denoted by the red arrows). A chargeability section is also generated from the joint inversion as shown in the panel below the noise map.

To summarise, a 3D perspective view of the 2.5D inversion results for the full set of eight lines from this area is shown in Figure 9.

Quamby/Dugald River takeaway

The distinct anomalies apparent in the 2.5D sections provide clear drilling targets for rapid strategic decision making. Whilst the VTEM[TM]Plus survey was conducted at a 2 km line spacing, conductivity imaging by the 2.5D inversion software demonstrates an ability to correctly identify the geometry (dips) of structurally complex exploration targets.

Kevitsa, Finland

The Kevitsa VTEM survey data was provided to Intrepid by First Quantum Minerals Ltd. (FQML) prior to the Kevitsa mine being sold to Boliden in June 2016.

This example illustrates the ability of the 2.5D inversion process to generate 2D depth slices or 2D level plans at constant elevation to highlight geological structure. These products enable direct comparison of conductivity with 2D maps of other geophysical data such as magnetics and gravity, as well as maps of the surface geology. The inversion resolves resistivity and conductivity contrasts very well, and can produce these enhancements accurately when flight lines are spaced close enough to adequately map across line continuity.

The geology of the Kevitsa mine area, as it was known in 2009 (FQML 2009), is shown in Figure 10. The extent of the VTEM survey is shown over a 2020 Google Earth image in Figure 11. The survey was flown in 2009 prior to mine construction.

A 50 m conductivity depth slice generated from 2.5D inversion of the VTEM survey lines flown from East to West is shown in Figure 12. The correlation of the depth slice with the geological map is very good, and the inversion clearly maps the phyllitic rocks within the mafic intrusive complex. The correlation is emphasised by overlaying the geological structure boundaries on the inversion depth slice, see Figure 13. There is also a significant correlation between the airborne magnetics reduced to pole (RTP) Total Magnetic Intensity (TMI) and the geological structure, see Figures 14 and 15. The 2.5D inversion depth slice more clearly defines the geological structure in this instance, with the TMI adding some detail in the more magnetics units as might be expected. The correlation with the geological map is not surprising since there is little surface exposure in this area, and the map had been interpreted from the existing geophysics and some drilling.

This type of enhancement is not achievable for a 1D inversion when there are strong lateral discontinuities in the geo-electrical section. For example, pant-leg artefacts, expected in geological scenarios such as Kevitsa, could create false structural features which would mar the interpretability of the depth slice. 2.5D and CDI 300 m depth slices are shown in Figures 16. Cross sections

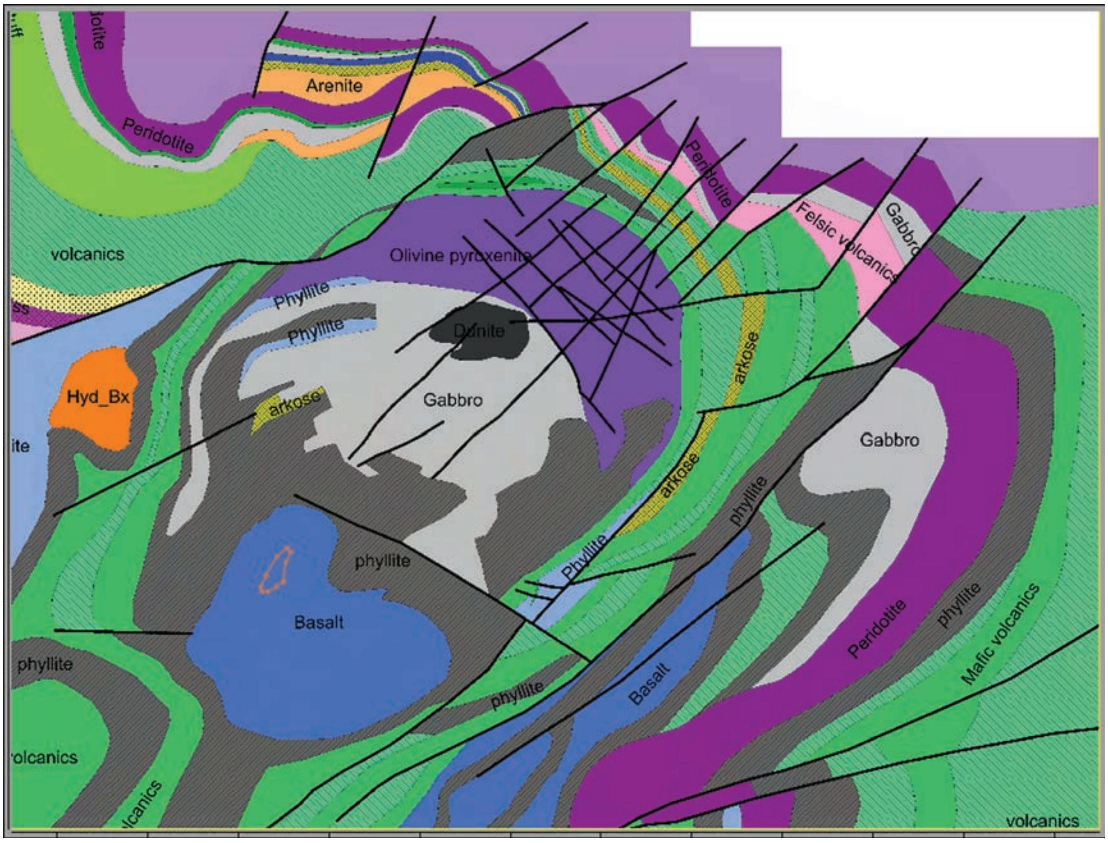

Figure 10. *Solid geology map of the Kevitsa mine area (FQML 2009).*

Figure 11. *Extent of the Kevitsa 2009 VTEM survey shown over a 2020 Google Earth image. The survey was flown before mining commenced.*

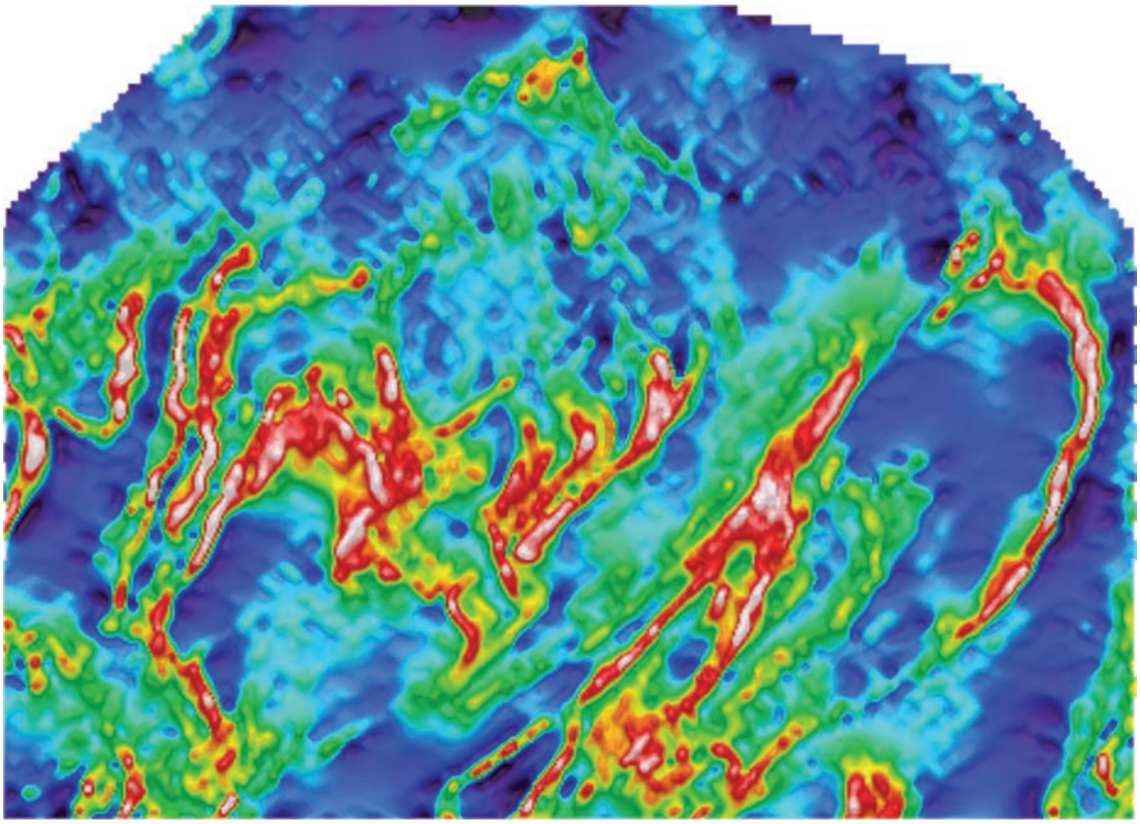

Figure 12. *Kevitsa VTEM 2.5D inversion 50 m depth slice.*

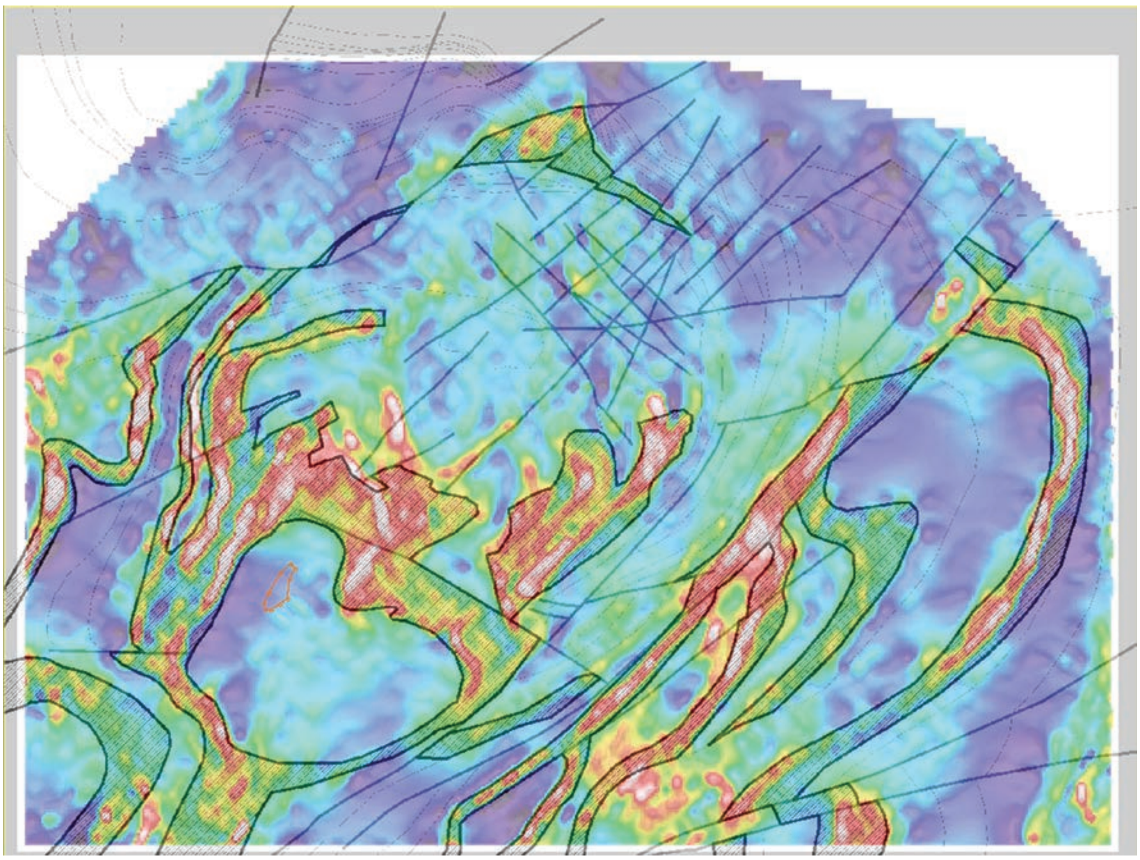

Figure 13. *Kevitsa VTEM 2.5D inversion 50 m depth slice with geological structure overlay.*

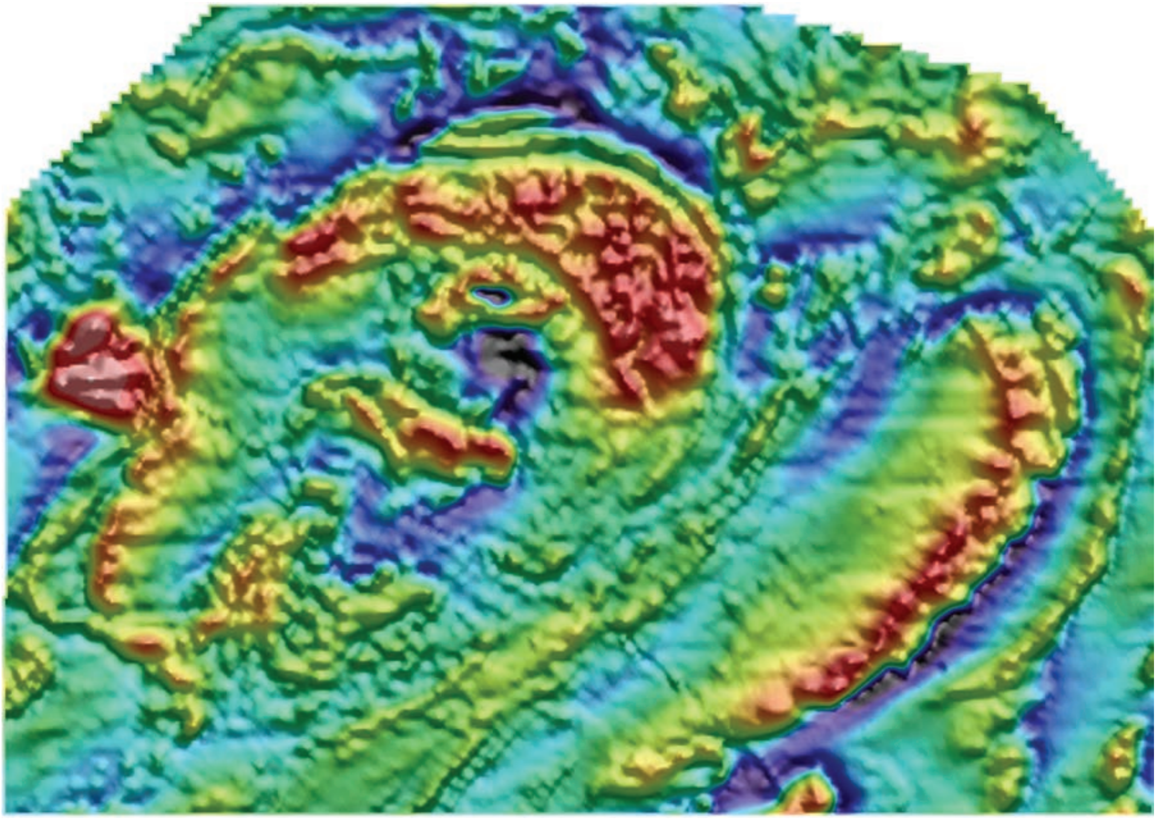

Figure 14. *Kevitsa VTEM TMI RTP (colour) and 1VD drape (grey scale).*

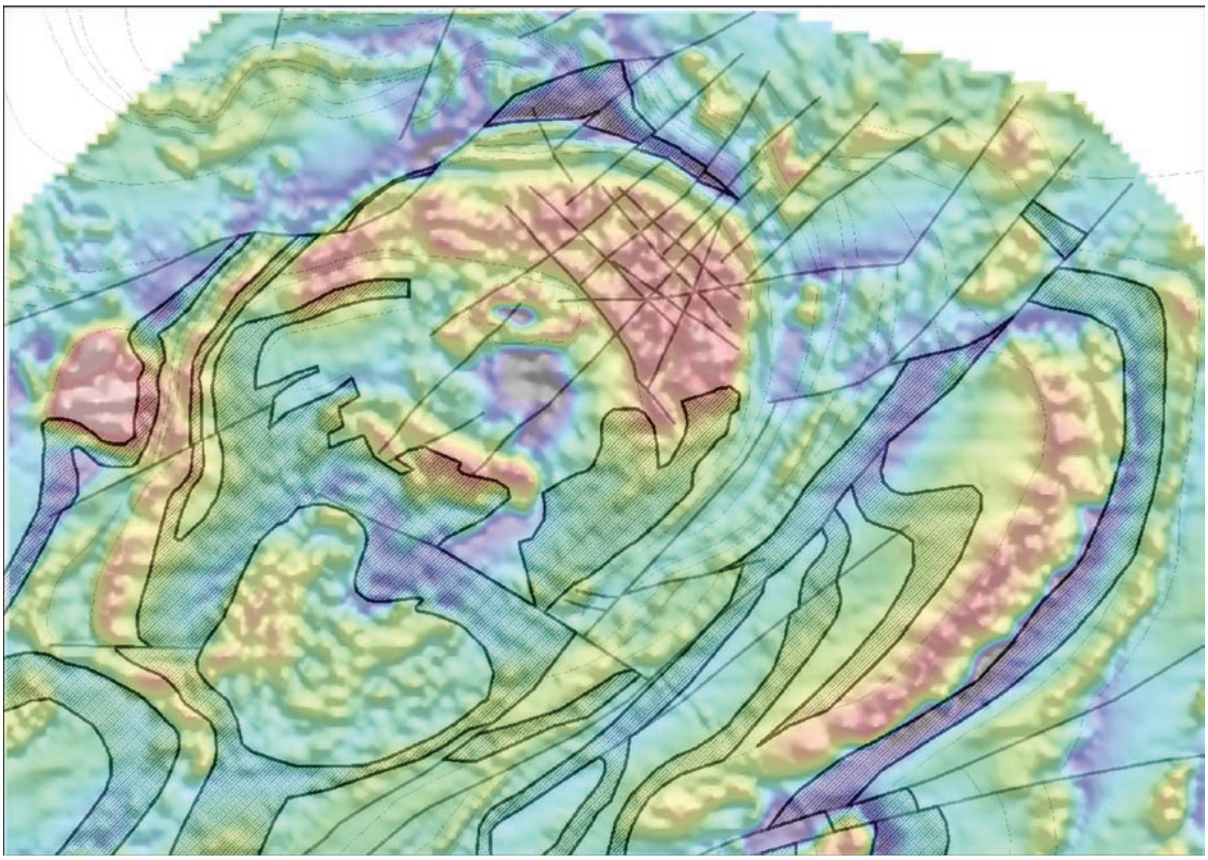

Figure 15. *Kevitsa VTEM TMI RTP and 1VD drape with geological structure overlay.*

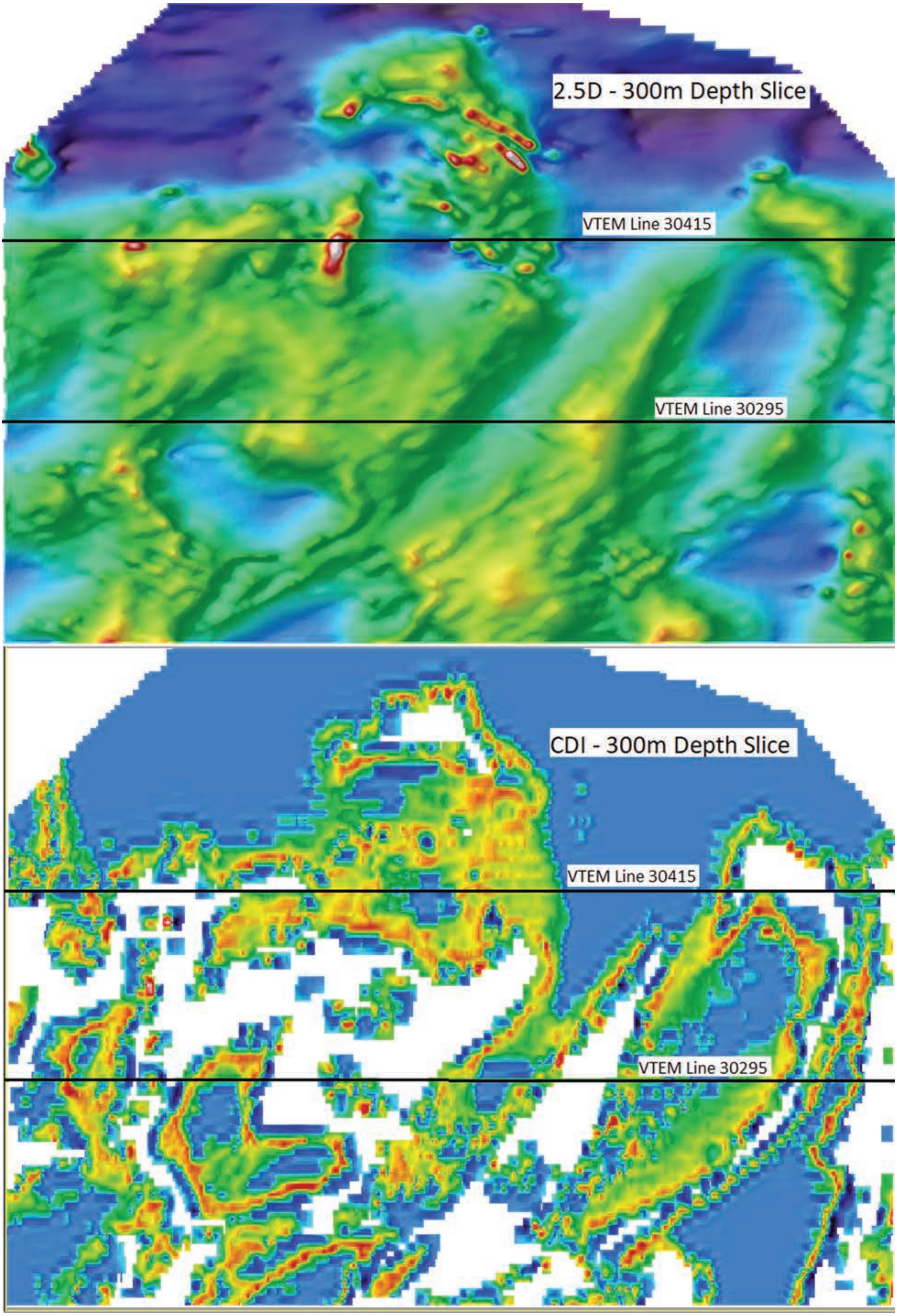

Figure 16. *Kevitsa: Comparison of the log conductivity 2.5D (top) and CDI (bottom) 300 m depth slice*

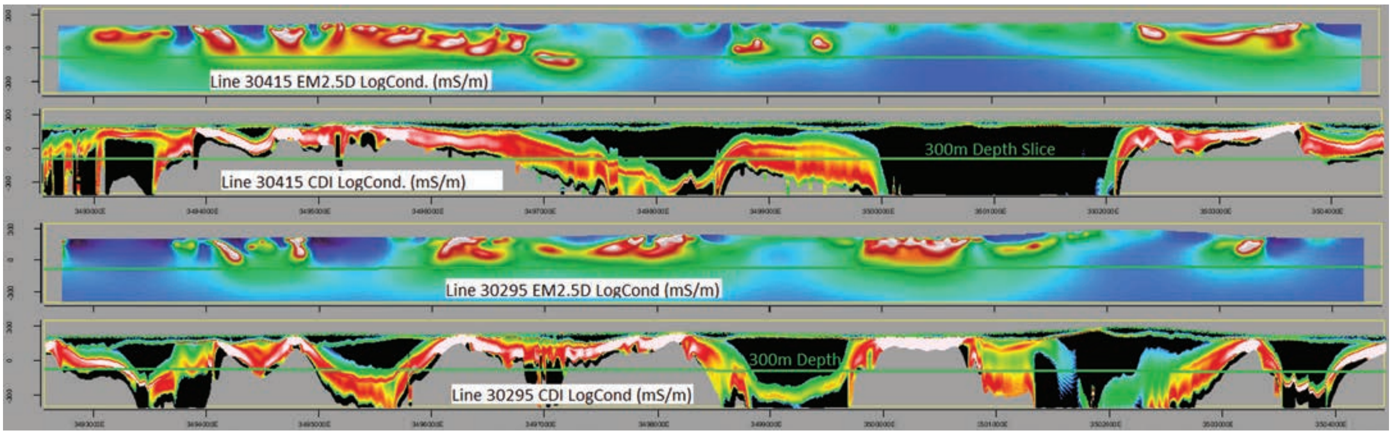

Figure 17. *Kevista: Cross sections along Line 30415 and 30295 of the log conductivity 2.5D (top) and CDI (bottom) 300 m depth slices*

along lines 30415 and 30295 of the 2.5D and CDI 300 m depth slices are shown in Figures 17. A consistent linear stretch (log conductivity, 1 to 3 mS/m) has been applied to all images. The pant-leg artefacts at the edges of conductive features on the CDI sections and some deeper conductors produce quite coherent conductivity trends in the CDI depth slice that could easily be mistaken for geological structure.

Kevitsa takeaway

Depth slices generated by 2D gridding of the 2.5D inversion log conductivity cross sections are better than vertical sections for defining geology and geological structures (formation boundaries and faults) mapped on a horizontal plane. These products also facilitate the integrated interpretation of AEM, magnetics, gravity and surface geology.

In addition, multiple depth slices can be used to build a more complete 3D picture of the geology. The 2D gridding methodology is faster and easier to control than full 3D gridding, which can be plagued by base level shifts between sections when the inversion nears the depth of investigation. The 2D depth slices are easily de-corrugated to remove this effect.

This type of enhancement is not achievable for a 1D inversion when there are strong lateral discontinuities in the geo-electrical section. For example, pant-leg artefacts, expected in geological scenarios such as Kevitsa, could create false structural features.

Elura, New South Wales, Australia

Forward modelling can be used to test the ability of AEM systems to detect ore bodies of interest beneath conductive cover and, further, to inform choices about the "best" and/or most cost-effective survey system for solving a particular exploration problem.

In this example the Moksha software was used to test whether the NRG Xcite system (or similar helicopter AEM systems) could have detected the Elura Cu-Pb-Zn-Ag massive sulphide orebody.

The Elura orebody was discovered in 1973 by the Electrolytic Zinc Company of Australasia Ltd prior to the availability of modern lower frequency AEM systems. The discovery was made by geochemical follow up of a bullseye magnetic anomaly. The first massive sulphide drill hole intersection occurred in 1974, and mining commenced in 1983, (Schmidt 1989). The Elura Mine was purchased by CBH Resources Ltd in 2003, and renamed the Endeavor Mine. The mine is currently in Care and Maintenance.

The modelling work flow was as follows:

1. Published material from the "Proceedings of the Elura Symposium, Sydney 1980" (Emerson 1980), was used to build a 3D model of the massive sulphide orebody. The papers in the proceedings provide a well described set of mineralised rock units and their resistivities on a series of cross sections and level plans that allowed an accurate model of the upper 500 m of the deposit to be generated.
2. The 3D model was built in GeoModeller, which provides part of the user interface and visualisation engine for Moksha.
3. The model units and assigned properties were exported to a 2D section mesh which was used to generate the finite element mesh used in the 2.5D AEM modelling process.
4. The mesh resolution was optimised for the size and scale of the problem to ensure that an accurate electrical model response could be calculated.
5. The mesh was of variable resolution and was adapted to accurately define the geometry of the smallest features to be resolved.

The main massive sulphide lens at Elura is in the form of a steeply dipping pipe with X, Y, Z dimensions of ~60 x 150 x 500 m. This pipe lies beneath a layer of conductive regolith ~100 m thick. This regolith is what limits AEM detection. Weathering of the orebody has resulted in the formation of a gossan, which has a small surface outcrop (Section 5730N, Figure 18).

The sections and plans in Figures 18 and 19 show the general geometry and mineral zonation of the orebody. The core of the orebody consists of massive pyrite and pyrrhotite that is highly conductive. The ore units, resistivities and forward model mesh dimensions are summarised in the forward model mesh and ore type property legend, Figure 20.

The 2.5D forward model has been calculated for both X and Z components using system noise estimated from the recent NRG Xcite Cobar regional survey flown by the Geological Survey of New South Wales in collaboration with Geoscience Australia.

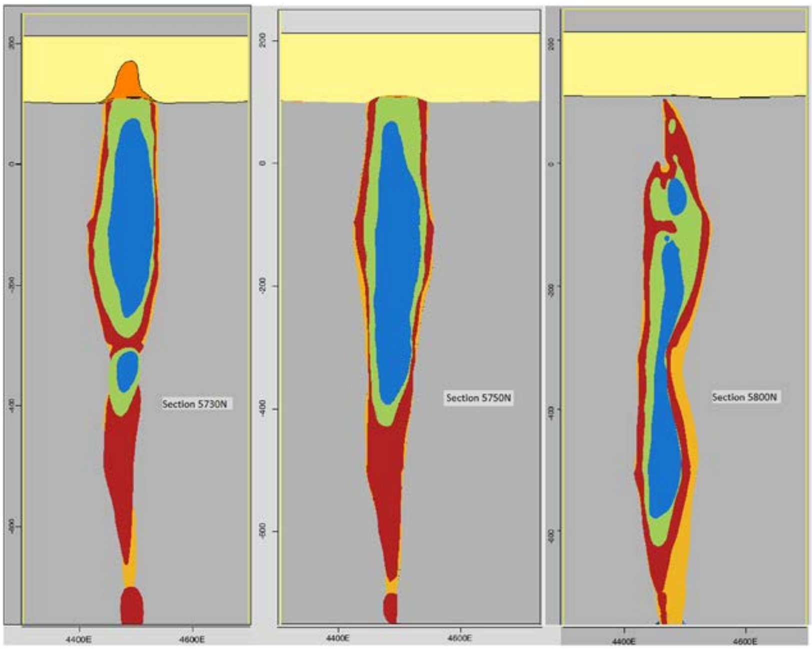

Figure 18. *Ore lens vertical geometry, sections 5730, 5750 and 5800N (see Figure 20 for legend).*

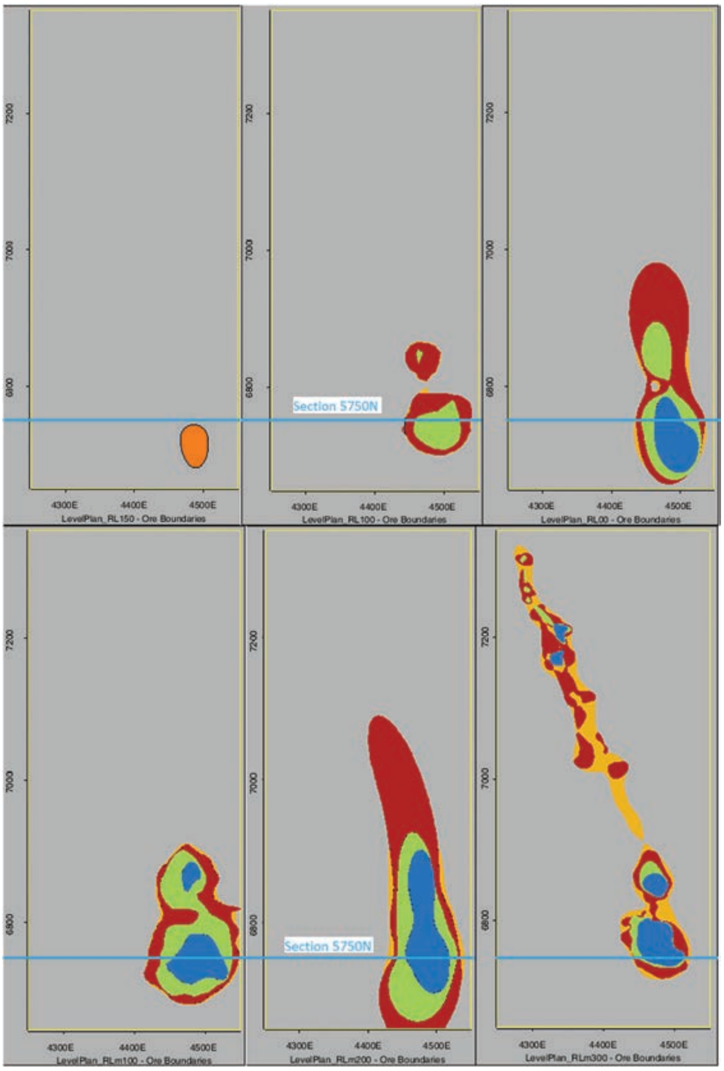

Figure 19. *Ore lenses horizontal geometry, plan sections +150 to -300 m (see Figure 20 for legend).*

Forward model resistivity and mesh geometry

Lithology	Resistivity (ohm-m)	dX Mesh (m)	dZ Mesh Depth1 (m)	dZ Mesh Depth2 (m)
Above Topo	100000.0	5.0	0.0	144.5
Saprolite	37.0	5.0	5.0	162.2
Gossan	70.0	5.0	10.4	181.5
Massive_Po	0.13	2.5	16.3	202.5
Massive_Py	0.25	2.5	22.7	225.4
Silica_PyPo	35.0	5.0	29.7	250.3
Breccia_Stringer	35.0	5.0	37.3	277.4
Siltstone	845.0	5.0	45.6	306.8
			54.6	338.8
Survey Clearance	35.0		64.4	373.7
			75.1	411.6
			86.7	452.9
			99.4	497.9
			113.2	547.0
			128.2	600.5

Ore type property legend

37 sd 29	Saprolite
70 sd 35	Gossan
0.125 sd 0.03	Massive_Po
0.25 sd 0.10	Massive_Py
35	Silica_PyPo
35	Stringer
845 sd 552	Siltstone

Resistivity ohm-m
Schneider & Emerson, 1980

Figure 20. *2.5D Forward model resistivity and mesh geometry and ore type property legend.*

The survey was designed to map geology, minerals and groundwater in the Greater Cobar area and was flown as part of the MinEx Cooperative Research Centre's (MinEx CRC) National Drilling Initiative. The NRG Xcite survey could not be flown over the known Elura deposit because the cultural disturbance at the mine is too extensive to obtain noise-free data. The nearest line is ~1 km north of the orebody extremities.

The Elura orebody is clearly visible in the last 10 channels of the Z component forward modelled data, and is well above noise levels. The X component is more heavily affected by noise, but the orebody response is visible at early to mid-time, see Figure 21. With the addition of motion noise to the X component, which is not included in these estimates, this response may be difficult to identify.

Elura takeaway

We can conclude from the forward model of section 5750N that the Elura orebody would be recognisable in the Z component of the Xcite data if a survey line had crossed over the main massive sulphide lens, which has a strike length of ~150 m. It is unlikely that a response would have been seen in a line 100 m to the south, as the mineralisation cuts out quickly in that direction.

Conversely, had a survey line been flown 200 m further to the north, where the top of mineralisation is ~320 m below surface and the massive sulphide lenses are smaller, the survey would have been unlikely to detect the conductor. Note, it was beyond the scope of the modelling exercise to forward model heliborne systems with larger dipole moments (and therefore broader footprint), although this may be attempted at a later date.

The conductive cover in the northern part of the Cobar Basin, where Elura is located, is generally thicker than further to the south. Clearly thinner regolith would enhance detectability. Nevertheless, to ensure detection of this deposit style (very steeply plunging, short strike length sulphides) a close line spacing (<200 m) is probably required.

Operational challenges

AEM data processing, including 2.5D inversions comes with a number of challenges. These challenges can be broadly grouped as relating to system complexity and geological noise.

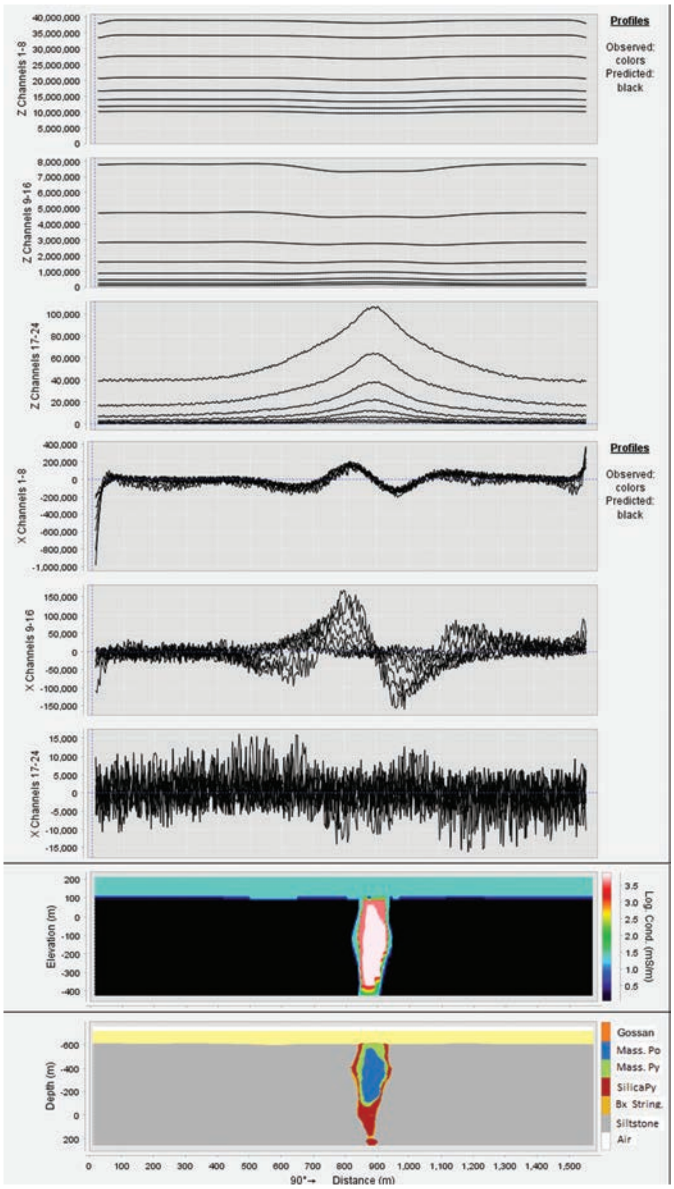

Figure 21. *2.5D Xcite forward model; section 5750N, flown from left to right.*

System complexity

A high level of AEM processing experience is often necessary to resolve the complexity of some of the problems encountered when processing data from both old and modern AEM survey systems. A lack of experience can lead to poor outcomes. In particular, considerable care is necessary when reviewing the system setup, as recorded system parameters can vary from survey to survey. The more modern helicopter suspended loop systems have the ability to vary transmitter waveforms, receiver filters and time gate positions depending on survey conditions. Errors sometimes occur in documentation, and detecting these errors requires a combination of experience and multiple test runs prior to commencing full survey inversions. Well-designed work flows that formalise a series of checks are essential for a good outcome.

Geological noise

Conductive cover

Conductive cover can pose serious limitations on an AEM system's ability to detect a buried conductor. In simple terms, a thicker and/or more conductive surficial cover (regolith) limits the detection depths of an AEM system. It is important to understand this attribute of a survey environment before planning and conducting an AEM survey, particularly in Australia. Existing AEM surveys can be informative, and forward modelling particular geological targets within known regolith and geological environments, such as demonstrated by the Elura example, can be very useful, saving time and money.

IP effects

IP effects can be serious problem in AEM surveys, and in some cases can completely mask an AEM system's ability to detect a late time conductive response. This is often caused by the response of near surface clays to the AEM system's transmitted signal. A more powerful transmitted signal can increase the IP response. The IP response is opposite in sign to the inductive response and causes pulldown (a decrease in the measured response) at mid to late decay times where the positive response of a deep conductive target is expected. Hence, it can completely overpower the inductive response and in this case, there is no reliable way to recover the target. A typical IP decay is shown in Figure 22.

It is important to try to identify whether this might be a problem in a survey area. The 2.5D inversion software is capable of inverting for the inductive and IP responses jointly, which may be helpful in separating an inductive from an IP response. The presence of IP effects commonly results in poor misfits in an inductive inversion, and is a pointer to their presence. The 2.5D software can also forward model a complex inductive and IP response, which may be helpful in understanding the geo-electric section geometry in such a situation.

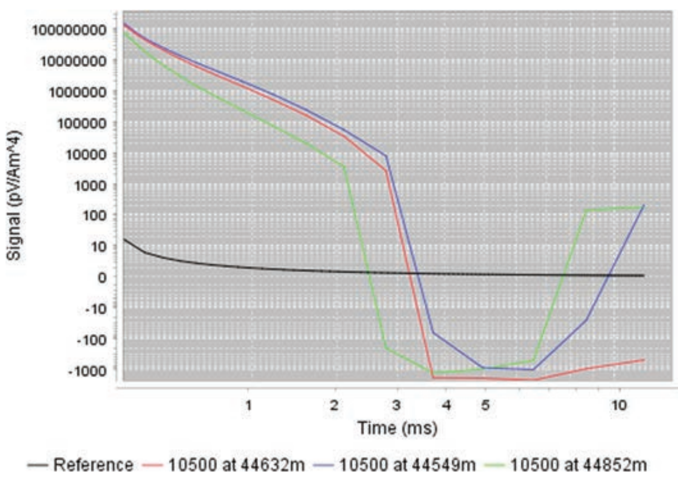

Figure 22. *A typical IP decay curve.*

SPM effects

Super paramagnetic (SPM) effects are much less common than IP effects. They manifest as late time positive anomalies with a characteristic slow decay rate (1/time). Due to their slow late-time decay, SPM responses can be confused with the responses of deep conductors and vice versa. SPM effects are best recognised by their decay rate, and also by their fast falloff with increased survey elevation. The latter attribute means they are less commonly observed in fixed wing AEM surveys. Typical SPM decays are shown in red, green and blue, and compared with more shallow inductive decays in yellow and pink, in Figure 23.

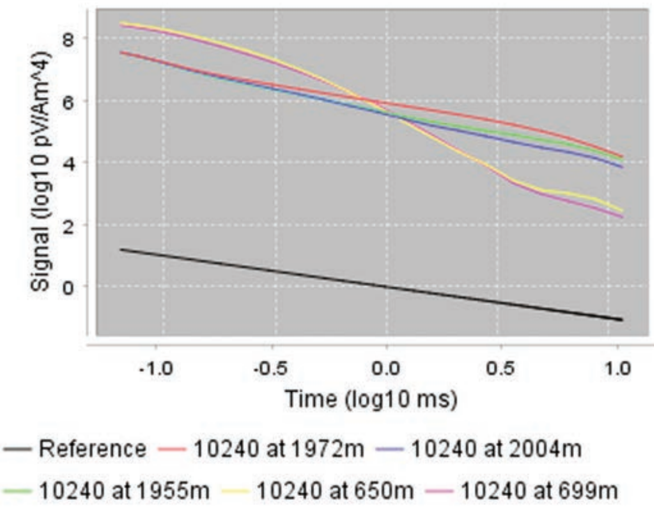

Figure 23. *Typical SPM decays in red, green and blue*

SPM effects are usually caused by very fine magnetite accumulations in surface soils or rocks (magnetite deposits). The 2.5D inversion software does not fit this type of anomaly due its slow decay rate. Care needs to be taken that the misfit failure is not caused by the inversion being run at too low a resolution.

Correlated noise

Correlated noise at late time can be a serious problem for 2.5D inversions. The 2.5D inversion sees relatively long wavelength (300 to 500 m) correlated noise at late time as signal, and fits it accordingly. This can produce a series of conductive blobs instead of either a deeper flat lying conductor or, alternatively, no conductor at all. This late time noise can have amplitudes well above noise levels, and has a negative impact on inversion quality. It can be removed by lateral smoothing, but this runs the risk of removing real late time anomalies of similar wavelength. This has been seen in some older surveys where it has been removed in 1D inversions by strong lateral smoothing. The source of the noise appears to be related to loop motion or swing. An example of this type of noise before and after lateral smoothing appears in Figure 24.

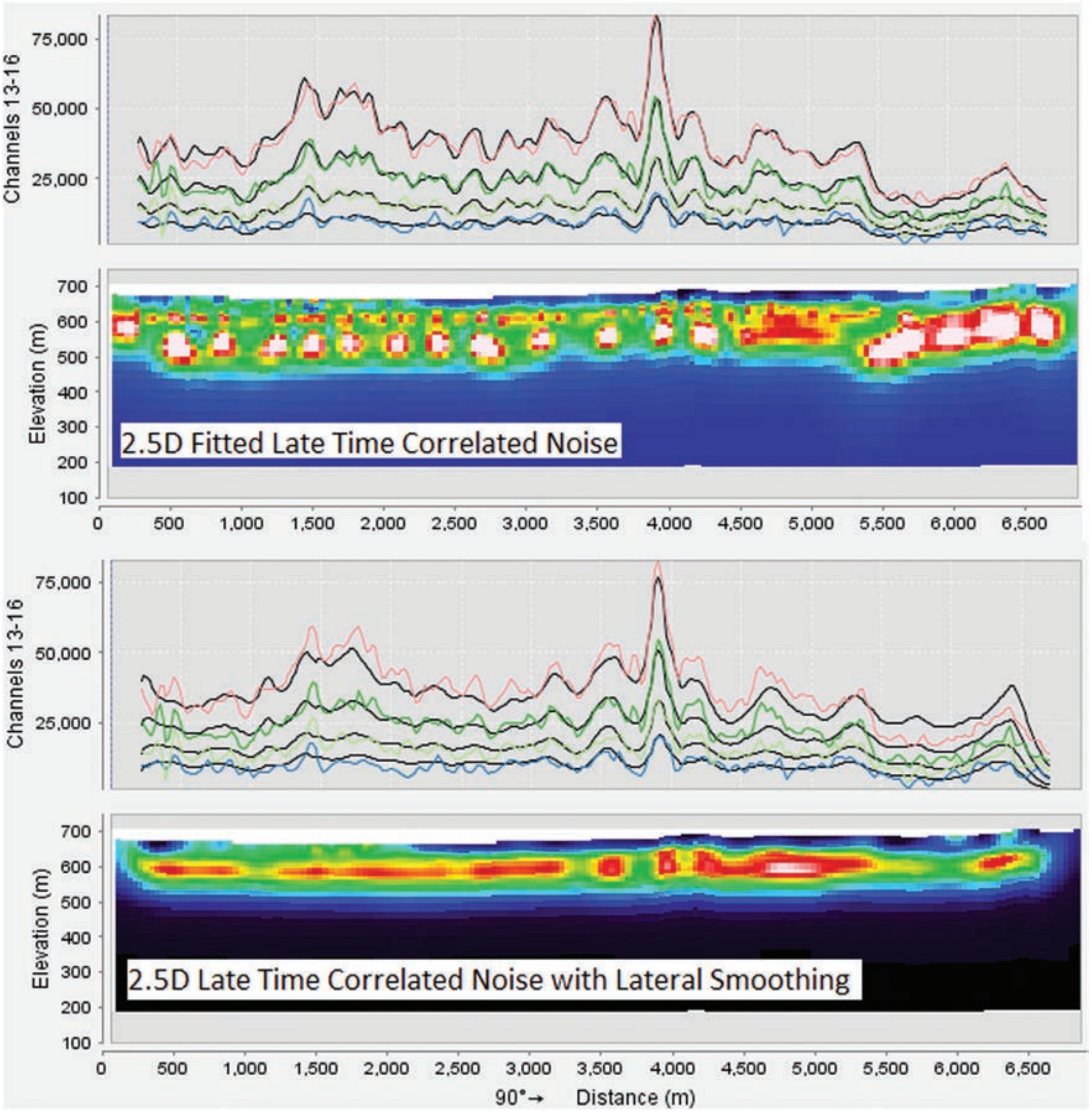

Figure 24. *Late time correlated noise before (top) and after (bottom) lateral smoothing.*

Summary

CDI or 1D inversions are well-established processing strategies for AEM data. Experienced users have learned how to recognise and manage some of the shortcomings of these inversions, and appear to be reluctant to change their practice. However, CDIs or 1D inversions can mislead geologists and/or less experienced users and, as a consequence, result in poor exploration outcomes.

The 2.5D AEM inversion technology developed by Intrepid produces very clean and spatially accurate images of subsurface conductivity in both cross section and in plan (with some post processing) that are mostly free from the problems often seen in CDI and 1D inversions – particularly where 1D assumptions are not met.

2.5D inversions are much less computationally expensive than 3D inversions, and not limited by line spacing.

2.5D inversions can be performed on data from all of the common AEM systems and at survey scale on lines of >100 km in length. Constrained inversions are also an option if there is adequate information about the geo-electrical section.

All of the 2.5D inversion products generated by the Intrepid software come with information on reliability through the delivery of survey and predicted profile misfits at survey resolution.

The Quamby/Dugald River and Kevitsa examples demonstrate that 2.5D inversion products can be used confidently by geologists and geophysicists for orebody targeting and for geological and structural mapping in plan as well as in cross section. These products also facilitate the integrated interpretation of AEM, magnetics, gravity and surface geology.

The Elura example demonstrates that 2.5D forward modelling is an effective tool that can assist with the analysis of target detectability when the explorer is in the AEM survey planning phase.

Older AEM survey data and/or data acquired in areas with conductive cover or other forms of geo-electrical noise (e.g. IP effects) can, however, present problems that require experience and appropriate analytical tools to manage.

Raising awareness of new technologies and encouraging their acceptance can be a challenge for geophysicists working in exploration. Hopefully this article has gone some way towards promoting the use of 2.5D AEM inversion technology and inversion products for orebody targeting and geological mapping.

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Michael Asten's best of *Exploration Geophysics*

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ASEG President 2009 - 2010
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Our ASEG President of the time, Ted Tyne, kicked off this series in February 2020 (Tyne 2020), noting that our journal *Exploration Geophysics* (*EG*) is now 50 years old – 50 years that cover three literal generations of geophysicists, and all the new paradigms of instrumentation and interpretation devised over that span of time. Ted asked me to contribute my perspective on the best of geophysics in the *EG* pantheon; the timing makes for a pleasant task amidst the murky greys of the COVID-19 second wave/second lockdown in my home city (Melbourne).

I am giving my vote to "The application of geophysics to the discovery of the Hellyer ore deposit, Tasmania" by Tom Eadie, Jovan Silic and Doug Jack (Eadie *et al*., 1985).

I confess to some subjectivity; having spent about half of my professional life (both academic and in industry) working with electromagnetic (EM) methods in mineral exploration, I continue to be fascinated at how time-domain EM in expert hands was successful in detecting this major orebody in the rough and tough terrane of western Tasmania. The immediate attraction was the existence of the near-by and near-surface small Que River lead-zinc mine. However, the mineral assemblage of pyrite, zinc (sphalerite) and lead (galena) ores is only moderately conductive when compared with copper or nickel targets in the Mt Isa block (Qld) or the Yilgarn (WA). And, the top of economic mineralisation for the main Hellyer orebody is at a depth of 150 to 400 m below barren host rocks and black shales, that made for a low amplitude subtle anomaly which many geophysicists of that time may have found unconvincing.

Jovan expands on some of the exploration challenges of the time (Silic, Eadie, and Jack 1985) and they offer instructive lessons for any who think geophysics is a routine process. The original Que River deposit was a vertical structure and EM interpretation followed similar thinking. However, due to the only moderately conductive nature of the Hellyer mineralisation and its particular geometry, the EM response was principally a current channelling not inductive response – a class now well understood (but not then!) to be very insensitive to dip. Tom recalls some tense sessions with company geologists when the early drilling suggested flat-lying mineralisation at a time when the geophysical interpretations (guided by the adjacent Que River deposit) were indicative of vertical mineralisation. Jovan's work on Hellyer became a core part of a subsequent PhD thesis. Students interested in the evolution of the understanding of the geometry of the orebody and its EM responses will find more details in reports on subsequent borehole EM surveys (Eadie 1987; Silic and Eadie 1989).

The Hellyer case history has especial significance in the history of EM geophysics because it ranks as perhaps the first Australian orebody *discovery* by EM methods followed by drilling. Earlier EM case histories of the copper-rich Elura orebody near Cobar (NSW) exist but the ore deposit was found primarily by magnetic and gravity methods (Davis 1980), although it later became a proving ground for a wide range of electrical and EM methods. *EG* published a special issue in 1980 bringing together about 35 papers on geophysical and geological studies on Elura – a great step in understanding various geophysical technologies, but not crediting EM geophysics with the discovery.

EM studies on nickel sulphide orebodies at Forrestania (WA) also exist prior to the Hellyer paper, but like the Elura history, Forrestania was discovered by other methods – the recognition, geochemistry and drilling of near-surface gossans (Porter and McKay 1981). Characterisation of the EM response followed discovery (Staples 1984).

Multiple discoveries of orebodies by their EM response were reported in *EG* in the decades following the Hellyer body; the Eloise copper-rich body (Brescianini et al., 1992) and the Ernest-Henry copper-gold orebody (Webb and Rowston 1995) are two examples of orebodies below blind cover in the Mt Isa block, Queensland, but the Hellyer case history remains a beacon of early EM achievement in the pages of *EG*.

So what happened to the two geophysicists who analysed the EM data over Hellyer, and stuck the proverbial pins in that geologically blind cover some four decades ago? Tom Eadie rose through the exploration ranks to be Executive General Manager Exploration of Pasminco, and now holds a number of board positions in mining companies. Jovan Silic has remained a specialist geophysicist consulting globally to a wide range of mineral exploration groups, while taking time in the northern summers to cruise the Mediterranean Sea. Jovan's take-home message from the Hellyer story, and one which was also applied to other major discoveries (Silic and Seed 2001), is "Never ignore the subtleties of the data until you have fully explained them. Today with too much reliance on automatic interpretation techniques it is quite likely that some would walk away from the Hellyer response without fully understanding why".

The last word from Tom Eadie; post-retirement he operates the Black Cat truffle farm south of Creswick in the Victorian goldfields. He comments that "the patterns of the truffles outline geological structures - perhaps a tool for finding the gold"! Should we expect a research proposal early next April for the use of truffle dogs supplementing geoscientists in future gold exploration?

Captain Jovan Silic ("Never ignore the subtleties … ") with wife Endang, sailing the Mediterranean on their boat EndanaTrin, near Jovan's birth place in Croatia.

Tom Eadie on his truffle farm. Olfactory geoscientists pawing the ground are (left) Lottie the Lagotto and (right) Winston the Australian Shepherd.

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The application of geophysics to the discovery of the Hellyer ore deposit, Tasmania

E. T. Eadie, J. Silic and D. J. Jack

Introduction

In August 1983, a drill hole aimed at a deep conductor in Northwestern Tasmania intersected 24 m of high grade base and precious metal mineralization at a depth of 120 m. This intersection proved to be the small, shallow end of the 15 Mt Hellyer deposit (Sisc & Jack 1984; Eadie & Silic 1984). The ore body is covered by greater than UK) m of volcanics, making the story of its discovery technically impressive.

History of exploration in the Hellyer-Que River area

Modern exploration in the Hellyer-Que River area for Pb/Zn dates back to the 1960s when the volcanics (Fig. 1) were recognized as being similar to those hosting the Mt Lyell and Rosebery ore bodies.

In 1970, the Aberfoyle group commenced a regional stream sediment geochemical survey followed in 1972 by coverage of a 400 km^2 block with helicopter-borne electromagnetics (EM). Ground follow-up of one of the few good discrete conductors (which was in the vicinity of anomalous stream geochemistry) resulted in the 1974 discovery of ihe Que River ore deposit (Webster & Skey 1979).

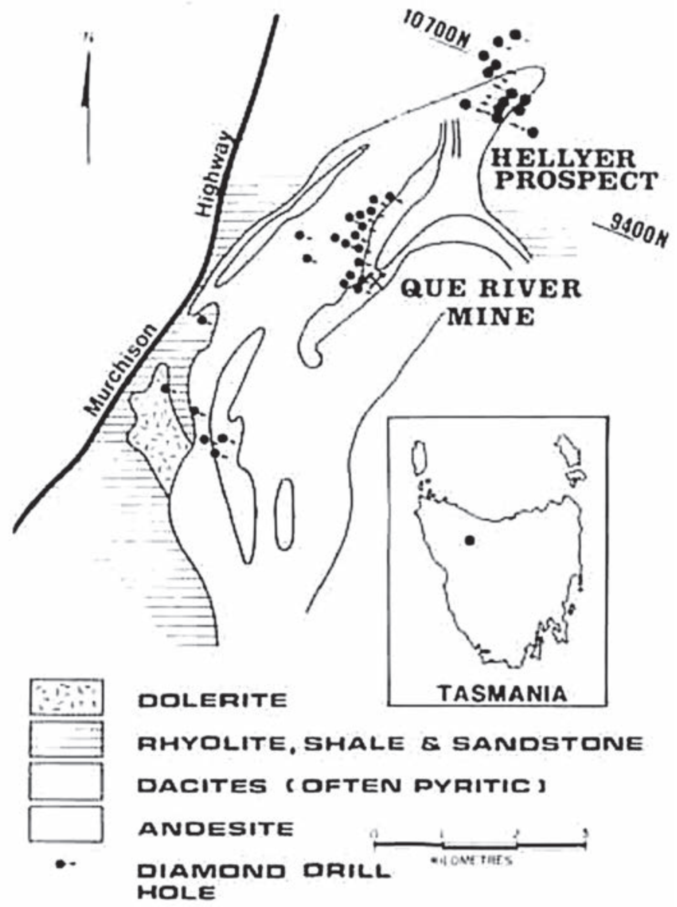

Figure 1: *Summary geological plan of Hellyer-Que River area.*

One of the conclusions drawn from test work on the deposit was that the main ore lens (PQ) was effectively nonconductive due to the large amounts of sphalerite although it responded well to induced polarization (IP). This conclusion was supported in later years by test surveys with moving loop Sirotem and Crone PEM which both responded to the shallow S lens (detected by the original helicopter EM survey) but not to the deeper, base metal rich PQ lens. Because of this, IP became the favoured geophysical tool. In the following 10 years, several IP anomalies, generally supported by high geochemistry, were drilled, showing uneconomic concentrations of sulphides.

In 1979, new light was shed on the exploration problem when UTEM, a fixed transmitter broadband EM system (Lamontagne *el at.* 1978), was tested at Que River. This experiment showed that the PQ lens was in fact more conductive than the S lens, and had been missed by the other EM systems because of its relatively large depth to top and its proximity to the shallow S lens.

When UTEM became readily available in Australia in 1983, the northern two-thirds of the andesite unit was surveyed. The grid was extended far enough north to determine the UTEM response of some disseminated sulphides encountered when drilling an IP/geochemical anomaly in 1982. The most northern line was placed at 10300N (Fig. 2), where an anomaly was detected which was recognized to be as strong as the one over Que River. This was the only moderately strong response on the whole grid of over 100 line km.

The survey was immediately extended another 400 m to the northern extent of the outcropping volcanics. Detailed UTEM work in this area defined a deep, moderately conductive body. Concurrently with the geophysical work, geological mapping of new exposure created by Hydro Electric Commission preparation for a new transmission line, revealed a pod of barite and intense alteration concentrated into the nose of an anticline overlying the conductor, which was in an area that had long been known to have anomalous Pb and Zn in soils. The combination of these factors made this a very high priority target, which management thought merited three drill holes. The first of these holes intersected 24 m of base metal mineralization, the Hellyer ore body.

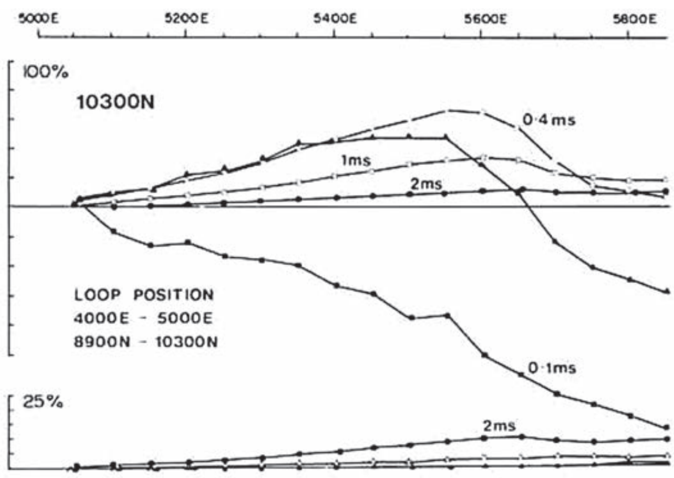

Figure 2: *Vertical component UTEM data line 10300N.*

Analysis of the geophysical data

The ability of UTEM to detect the Hellyer deposit where IP, airborne EM (McPhar H400), and Max Min had failed (Eadie & Silic 1984), shows well the power of fixed loop, time domain EM systems. The three most critical lines of UTEM vertical component data are shown in Figs 2, 3 and 4.

The feature that inspired the extension of the grid to the north is seen at station 5675E on 10300N (Fig. 2). This anomaly, which was interpreted to be from a deep, conductive body, is apparent in the data from 0.2 to 2 ms. The fact that the anomaly lasted until 2 ms made this by far the most conductive feature on the grid.

Figures 3 and 4 display the results from Lines 10400N and 10700N, respectively. The amplitude of the response is much lower on these follow up lines than on 10300N because:

(1) the second transmitter loop was located to be maximum coupled with the expected vertical body and ended up being almost totally null-coupled with the actual flat-lying body;
(2) there is less enhancement due to current channelling because the second loop is much closer to the targetconductor.

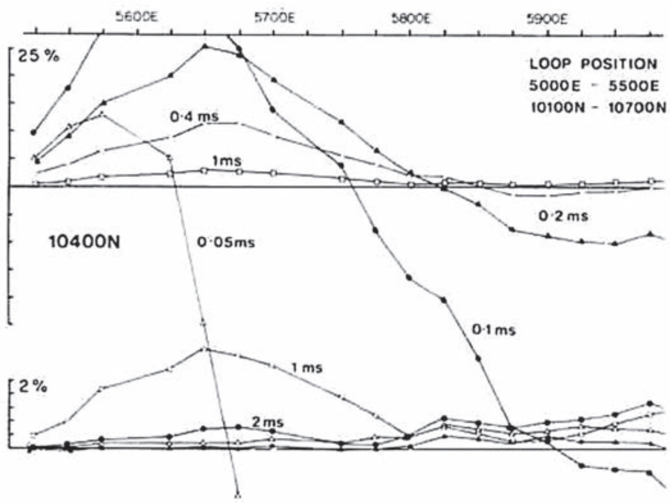

Figure 3: *Vertical component UTEM data on line 10400N, the first line drilled.*

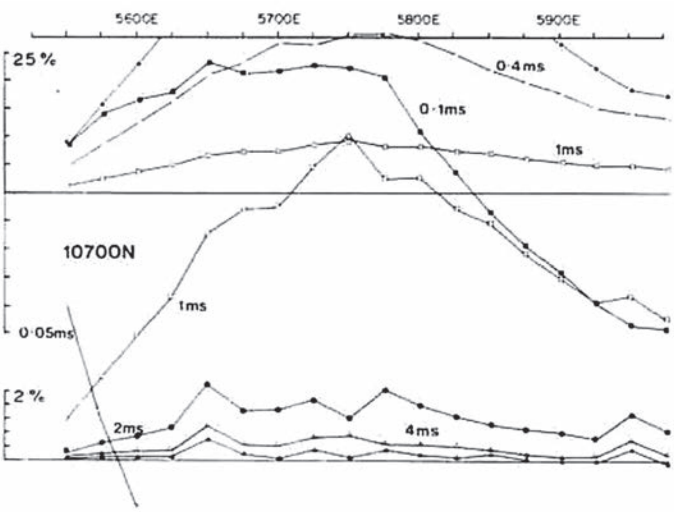

Figure 4: *Vertical component UTEM data on line 10700N.*

However, the data was good enough to interpret a continuous body from 10300N to 10700N, plunging to the north and open in this direction.

In spite of the fact that the anomaly on 10700N continued to the later time of at least 4 ms, the first drill hole was located on 10400N (Fig. 5), the reasoning being that the target was shallower on 10400N and there was no chance of the data being influenced by the encroaching shales as there was on I0700N (Fig. 6), thus enabling a more precise interpretation. The first hole of the drilling programme, HL 3, successfully intersected the target, as did the third hole, HL 5, on 10700N.

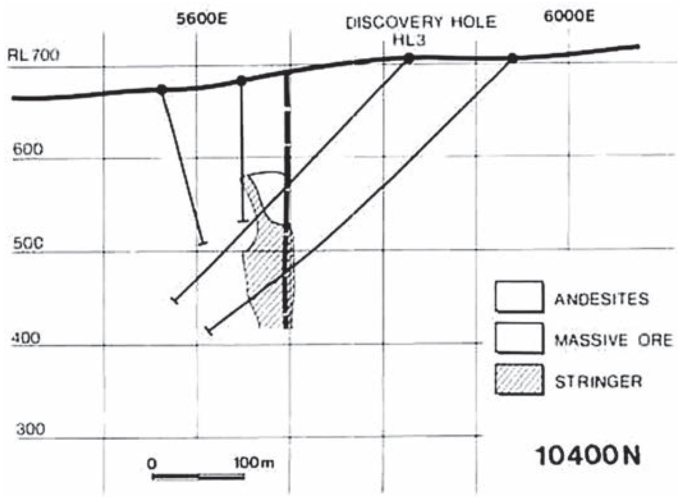

Figure 5: *Geological section 10400N.*

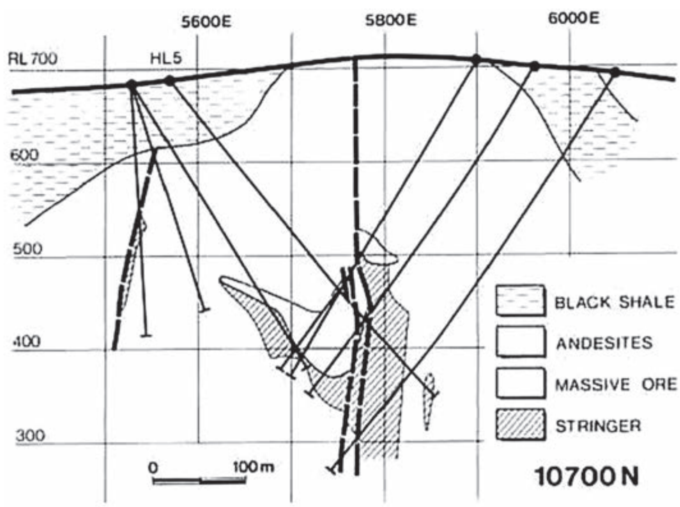

Figure 6: *Geological section 10700N.*

Acknowledgments

The authors would like to acknowledge Gary McArthur, Supervising Geologist, Hellyer, for his excellent work and for preparing the geological cross sections. We would also like to acknowledge Aberfoyle's management, in particular Max Richards, Hugh Skey and John Sise for the inspiration and support they supplied throughout the exploration period, Guido Staltari of GEC for continual geophysical discussions in the planning and interpretation process, and the staff of

Aberfoyle Exploration, in particular Errol Smith, for invaluable help with the field work. In addition, we would like to thank Aberfoyle Ltd and Paringa Mining and Exploration Co. PLC for permission to publish this paper.

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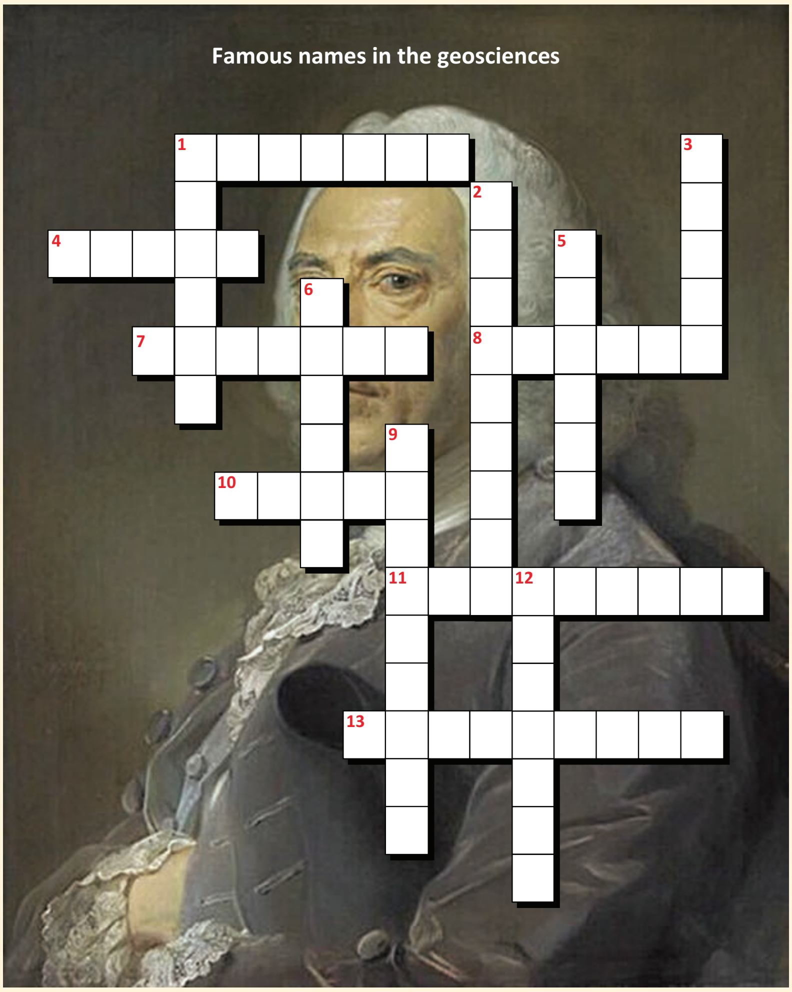
Tom Eadie graduated with a BSc(Hons) in geology and geophysics from the University of British Columbia in 1976. After a brief stint with Gulf Oil of Canada as a seismic interpreter, he worked for two years with Gcolerrex as a party chief on field crews. Returning to university, he obtained an MSc in geophysics from the University of Toronto in 1980, working on electrical methods in oil exploration. He then joined Cominco, Vancouver, in part helping to develop EM field and interpretation methods for Pb/Zn exploration. From 1983 he has been on an Aberfoyle-Cominco exchange with Jovan Silic.

Jovan Silic graduated from the University of Western Australia in 1971 with first class honours in physics. From 1971 to 1975 he worked with the BMR on Australian National Antarctic Research as a geophysicist. From 1975 to 1979, still with BMR, he worked on research into electrical prospecting methods. He was also involved in acquisition and interpretation of regional geophysical data, emphasising automated in-version techniques on potential field data. In 1979. he joined Aberfoyle Exploration where he was in charge of the geophysical programme. From August 1983, he has been on an Aberfoyle-Cominco exchange with Tom Eadie.

Doug Jack graduated in mining geology at the University of the Witwatersrand, Johannesburg. South Africa, in 1976. He then joined Union Carbide Exploration initially as a photogeologist working principally on Karoo uranium. From 1979 he ran an uranium exploration programme in Botswana where he spent 2 1/2 years. In 1981 he was transferred to Australia where he worked on uranium exploration in the Northern Territory, Archean gold in Western Australia and tungsten in New South Wales. He joined Aberfoyle in January 1983, based in Tasmania he was the field geologist immediately prior to the discovery of Hellyer.

Preview crossword #9



Across	Down
1. German geophysicist who first proposed the controversial yet radical theory of continental drift.	**1.** Canadian geologist whose contributions to the theory of plate tectonics introduced the idea of hotspots and the recognition of transform boundaries, and who later postulated a model for the formation and breakup of continents.
4. Scottish geologist largely responsible for the general acceptance of the view that all features of the Earth's surface are produced by physical, chemical, and biological processes through long periods of geological time.	**2.** American geologist and pioneer in the field of planetary science who became the first and so far, only person ever to receive a lunar burial.
7. French geophysicist and geodesist whose expedition over the Andes enabled him to become the first person to measure the horizontal gravitational pull of mountains.	**3.** Generally regarded as one of the greatest mathematicians of all time for his contributions to number theory, geometry, probability theory, geodesy, planetary astronomy, the theory of functions, and potential theory, including electromagnetism.
8. French mathematician and physicist that invented the torsion pendulum and for which the unit of gravity gradient is named after.	**5.** Scottish geologist, chemist and naturalist who established one of the fundamental principles of geology – uniformitarianism.
10. Danish geologist who proposed the revolutionary idea that fossils are the remains of ancient living organisms and that many rocks are the result of sedimentation, containing a chronological history of geologic events.	**6.** French naturalist whose works laid the foundation of vertebrate paleontology. He established extinction as a fact and later became the most influential proponent of catastrophism in geology.
11. A Swiss peasant and mountaineer whose observations started the science of glaciology.	**9.** Geophysicist whose equations relate the amplitudes of P-waves and S-waves at each side of an interface, between two arbitrary elastic media, as a function of the angle of incidence and are largely used in reflection seismology for determining structure and properties of the subsurface.
13. The German physicist whose name is synonymous with the method of seismic migration.	**12.** American seismologist and physicist who developed a scale for measuring earthquake magnitude.

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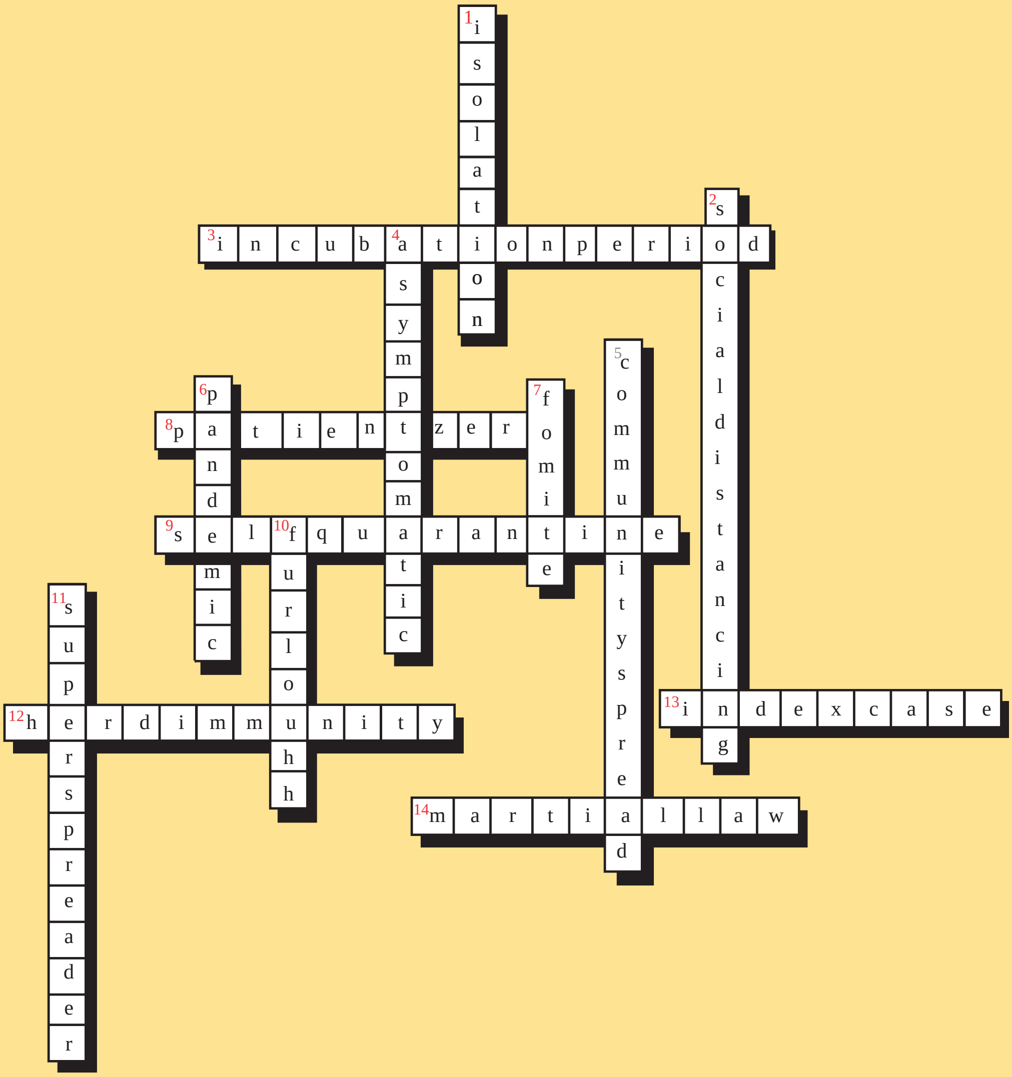

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Section 6. **Membership of Other Societies**

Australian:

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

International:

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

❑ Others ______________________________

Section 7. **ASEG Membership Directory Record**

Please complete this section for the ASEG membership database. The same information is included in the ASEG Website (www.aseg.org.au)

Employment area:

❑ Industry ❑ Contract/Service Provider ❑ Government ❑ Student

❑ Education ❑ Consulting ❑ Other ________________

Type of Business:

❑ Oil/Gas ❑ Ground Water/Environmental ❑ Coal ❑ Survey/Geotechnical/Engineering

❑ Minerals ❑ Petrophysics/Log Analysis ❑ Research/Education ❑ Data Acquisition

❑ Solid Earth Geophysics ❑ Archaeology/Marine Salvaging ❑ Computer/Data Processing ❑ Other ________________

Section 8. **Payment Details** (This document will be an Australian Tax Invoice when you have made payment)

Membership Grades and Rates

❑ Active/Associate (Australia) - $172.00	❑ Active/Associate 5 Year Membership (Australia) - $860.00
❑ Active/Associate (Group IV Countries) - $156.00	❑ Active/Associate 5 Year Membership (Group IV Countries) - $780.00
❑ Active/Associate (Group III Countries) - $68.00	❑ Active/Associate 5 Year Membership (Group III Countries) - $340.00
❑ Active/Associate (Group I & II Countries) - $13.00	❑ Active/Associate 5 Year Membership (Group I & II Countries) - $65.00
❑ Active Graduate (Australia) - $86.00	

Section 8. ***Preview & Exploration Geophysics***

The association produces a magazine called *Preview* and *Exploration Geophysics*. The ASEG has a new publisher for 2019 onwards please read and agree to the following, in order to receive ASEG publications:

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

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

3) I understand and agree that *Exploration Geophysics* articles shall not be networked to any other site, nor posted to a library or public website, nor in any way used to substitute for an existing or potential library or other subscription. 4) I understand and agree that any member who is discovered by the publisher to be in breach of these conditions shall have their subscription access immediately terminated, and the publisher shall have the right to pursue recompense at its discretion from that member.

Yes / No (please circle)

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:*____________

AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS
A.B.N. 71 000 876 040
PO BOX 576, CROWS NEST NSW 1585 AUSTRALIA
Phone: +61 2 9431 8691) Fax: +61 2 9431 8677
Email: secretary@aseg.org.au Website: www.aseg.org.au

Application for Student Membership 2020

INSTRUCTIONS FOR APPLICANTS

1. Student Membership is available to anyone who is a full-time undergraduate 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 to be a graduate or undergraduate student. However, Student Membership must be renewed annually. The duration of a Student Membership is limited to five years.
2. Fill out the application form, ensuring that your supervisor signs Section 2.
3. Submit the two pages of your application to the Secretariat at the address shown on the top of this page, retaining a copy of this page for your own records.

Section 1. Personal Details

Surname Date of Birth

Given Names

Mr / Mrs / Miss / Ms / Other (list)

Address

State Post Code

E-mail *(Personal email address not university is preferred)*

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

Mobile

Section 2. Student Declaration

Institution

Department

Major Subject Expected Graduation Date

Supervisor/Lecturer* Supervisor Signature

* Must be an active member of the ASEG

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

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*

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Yes / No (please circle)

Section 5 Declaration

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

*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.

August	**2020**		
18	Lithologically-constrained stochastic magnetotelluric inversion for imaging shallow conductors in geothermal field https://us02web.zoom.us/webinar/register/WN_qDrzV7GsQOKBtCnBApxeBQ		*Webinar*
27	The Victoria Gold Mining & Exploration Forum https://www.informa.com.au/event/conference/victoria-gold-mining-exploration-forum/		*Virtual event*
September	**2020**		
6–10	1st Asia-Pacific Geophysics Student Conference (APGSC) http://apgsc.ustc.edu.cn/index/lists/001		China
7–11	ISC (International Conference on Geotechnical and Geophysical Site Characterization) conference www.isc6.org	Budapest	Hungary
21	Biogeophysics: Exploring Earth's subsurface biosphere using geophysical approaches https://www.knowledgette.com/p/biogeophysics-exploring-earth-s-subsurface-biosphere-using-geophysical-approach		*Webinar*
October	**2020**		
11–16	SEG International Exposition and 90th annual Meeting https://seg.org/aM/2020	Houston	USA
November	**2020**		
2–4	3rd Asia Pacific Meeting on Near Surface Geoscience & Engineering https://eage.eventsair.com/3rd-apac-nsge/	Chiang Mai	Thailand
2–6	Offshore Technology Conference Asia (OTC Asia) http://2020.otcasia.org/welcome		*Virtual event*
10–11	2nd Joint SbGf-SEG Workshop on Machine Learning https://seg.org/Events/Second-Workshop-on-Machine-Learning	Rio de Janeiro	Brazil
December	**2020**		
2	Advances in Marine Seismic Data Acquisition Workshop https://seg.org/Events/Advances-in-Marine-Seismic-Data-Acquisition-Workshop	Singapore	Singapore
7–11	AGU Fall Meeting https://www.agu.org/Fall-Meeting	San Francisco	USA
8–11	82nd EAGE annual Conference and Exhibition https://eage.eventsair.com/eageannual2020/	Amsterdam	The Netherlands
February	**2020**		
9–12	Australian Earth Sciences Convention 2021 https://www.aesconvention.com.au/		*Virtual event*
April	**2021**		
25–30	European Geosciences Union https://www.egu2021.eu/	Vienna	Austria
May	**2021**		
31–3 Jun	83rd EAGE Conference & Exhibition 2021	Madrid	Spain
August	**2021**		
23–27	Advanced Earth Observation Forum 2020 https://earthobsforum.org/	Brisbane	Australia
September	**2021**		
15–20	Australasian Exploration Geoscience Conference (AEGC 2021) 2021.aegc.com.au	Brisbane	Australia
27–1 Oct	Australian and New Zealand Geomorphology Group Conference https://www.anzgg.org/conferences	Alice Springs	Australia

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

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

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

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