Australian Society of Exploration Geophysicists

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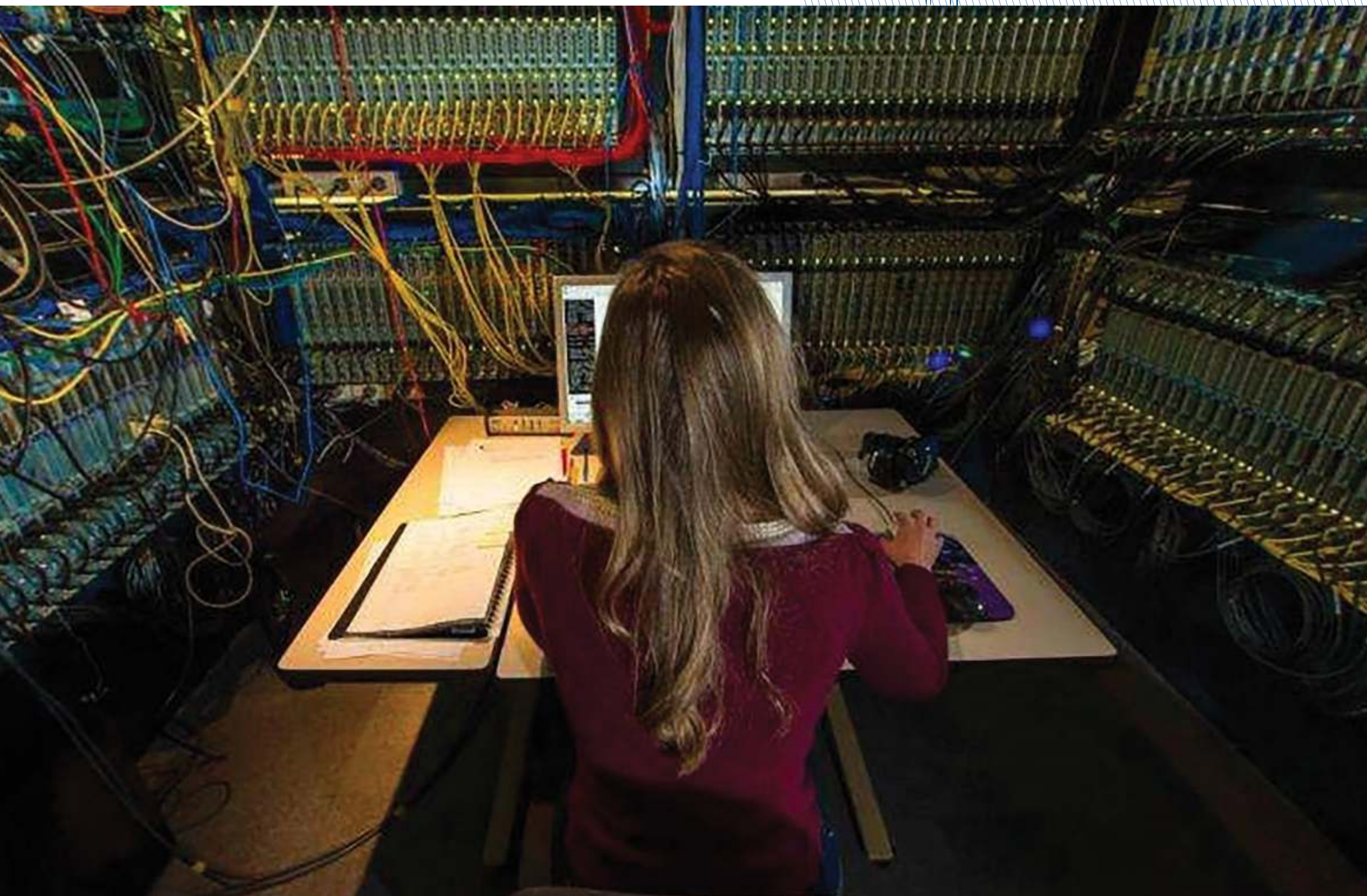
PREVIEW



NEWS AND COMMENTARY

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FRONT COVER

Joanne Stephenson, who recently completed her PhD in geophysics at the Australian National University, at work in the ANU's Terrawulf room (photo credit: ANU), See *Education matters* in the December 2021 issue of *Preview* for more details.

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

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SEE YOU IN
Brisbane

Editor's desk

This issue of *Preview* features work by one of our student members, Cyrille Njiteu, on the Bangui magnetic anomaly – the largest magnetic anomaly in Africa, and one of the largest in the world. Cyrille's work highlights the paucity of geophysical data in central Africa and in that regard caused me to reflect, once again, on how lucky we are in Australia. The sheer volume of data that is available to us can be overwhelming. Hence the call by Marina Costelloe, in her interview with Marina Pervukhina (*Education matters*), for more physicists, mathematicians and coders in the earth sciences. Co-incidentally, in *Data trends*, Shouv Sarker, a software engineer working in the Minerals Resources team at CSIRO, addresses the issue of handling large datasets in an article on cloud-based solutions for the management of AEM data. Mind blowing!

We are also blessed with the first part of Niels Christensen's memoirs. Niels will be known to many of us by virtue of his work on EM, especially during his tenure at Aarhus University. He is an Australian resident and frequent visitor - collaborating with both CSIRO and Geoscience Australia. Subsequent parts of his memoirs will be published in upcoming issues of *Preview* and although I struggle with serials in general (yes, I am a binge watcher), I am looking forward to this one!

In addition to these treats, David Denham (*Canberra observed*) reviews 2021, the year that was. Terry Harvey (*Mineral geophysics*) considers hard rock seismics – responding in part to Mick Micenko's enthusiastic write-up a couple of months ago. Mick (*Seismic window*) reflects on the outcomes of some recent networking. Tim Keeping (*Data trends*) takes a look at what is happening in date visualisation space, and Ian James (*Webwaves*) assesses the performance of the ASEG website.

Enjoy!

Lisa Worrall
Preview Editor
previeweditor@aseg.org.au

The Editor up the proverbial creek in western NSW – no paddle required!

Letter to the Editor

Dear Lisa

I noticed with interest John Milsom's comment in his *Letter to the Editor* (*Preview* Dec 2021) regarding the pioneering gravity observations in Sydney. He mentions the inadequacy ('barely usable') of the 1793 Malaspina observation and that seems most likely, but then adds 'The same objection almost certainly would have applied to the results obtained on the *La Perouse* expedition …'. I have issues with this comment despite the fact the gravity measurement known to have been made on the north shore of Botany Bay in February-March 1788 has not survived. The expedition's astronomer/ geodesist/ physicist Joseph Lepaute Dagelet was an important and an extremely competent French scientist. He may very well have, with his assistant Roux d'Abourd, actually used his gravity measurement to recompute the dimensions and density of the earth at the time – he certainly had all the gear, including one of Condamine's historic pendulums, he had Lalande's gravity writings on-board and he had the where-with-all to recalculate. This may be speculative on my part BUT he was that competent. He had previously travelled on Kerguelen's 1773-74 expedition and had assisted Lalande in the compilation of his 1779 longitude tables. He had been brought up in a prestigious clock making family and he was responsible for the expedition's clock resets, which he carried out at Botany Bay. His credentials were impeccable, he had been appointed Professor of Mathematics at the École Royale Militaire of Paris in 1777 (d'Abourd, like Napoleon Bonaparte, were students of his) and he was at the time the youngest member of the Académie Royale des Sciences (elected 1785). *Preview* readers should not be left with a suggestion he would have carried out an inadequate observation when it is extremely likely that the opposite was the case. He knew what he was doing. Sadly his death, with all the others on the expedition, was a great loss to French 18th century science.

Doug Morrison
sth.lands101@optusnet.com.au

ASEG news

President's piece

Kate Brand (née *Robertson)*

Hello Members and welcome to the first issue of *Preview* for 2022!

I hope you all had at least a few days off and are feeling well rested. Best wishes to you and your families for the year ahead - may you all stay healthy and safe.

Please save the date for our AGM on the evening of Thursday 7 April 2022, which will be in hybrid or virtual format. At this AGM we will be asking you to vote on some proposed amendments to the ASEG Constitution. These proposed amendments relate to the inclusion of a Code of Conduct (a draft of this code was circulated to Members via email and *Preview* Issue 212), as well as clarification of the roles of the Directors versus the broader Federal Executive, and would see the Immediate Past President included as a Director, thereby increasing the number of Directors from four to five. More information about these proposed amendments can be found in the Secretary's *Executive Brief* in this issue and *Preview* Issue 212.

We will also be relaunching our webinar series early in the year – please reach out if you would like to present - or if there is a particular topic you would like to hear about.

Finally, I'm delighted to share with you two new sponsorship opportunities that we have taken up. Firstly, you'll soon be hearing some new ASEG advertisements on the fantastic Exploration Radio podcast. For anyone who has not yet had a listen to this podcast, I strongly encourage you check it out (www.explorationradio.com). The podcast is a combination of fascinating stories, lessons learnt, advice shared and knowledge gained by explorers. The second is the Earth Future Festival (www.earthfuturesfestival.com), which aims to raise international awareness of the role of geoscience in our sustainable future. The global festival will take place in Sydney, Paris, New York and online in September 2022. Professionals and students in the realms of Earth Science, the Arts and Science Communication, along with community associations, school students and First Nations peoples are encouraged to submit works in video format to the festival. The work of short-listed finalists will be presented during the festival. Works can range from feature length documentaries, to short video pieces and spoken stories, through to visual and musical performances. This year's themes are Dynamic Earth, Future Earth and Human Connections. I strongly encourage ASEG Members to submit video entries to this competition.

All the best to you for 2022, we have a lot of exciting things planned for this year.

Please do not hesitate to email me at any time.

Kate Brand (née Robertson)
ASEG President
president@aseg.org.au

Executive brief

The Federal Executive of the ASEG is the governing body of the ASEG. It meets once a month via teleconference, to deal with the administration of the Society. This brief reports on the monthly meetings that were held in December 2021 and January 2022. If there is anything you wish to know more about, please contact Leslie at fedsec@aseg.org.au.

Finances

The Society's financial position at the end of December 2021 was:

Year to date income: $262 596

Year to date expenditure: $366 095

Net assets: $994 918

Membership

The Society finished the 2021 year with 863 financial Members, compared to 895 financial Members in 2020, and with eight Corporate Members, including three Corporate Plus Members. As of mid-January 2022 we have 619 financial Members, and one Corporate Member has renewed their support for the coming year. Our state branches also have local sponsors. These sponsors are acknowledged at all branch meetings and at the beginning of all webinars.

Constitution update

The Federal Executive is proposing a number of changes to the Society's Constitution, firstly to include the Code of Conduct, which was forwarded to Members for review during the 2021, and secondly to address the increasing scrutiny around the role of Directors in the non-profit and not-for profit sector. These proposed changes better define the role of the constitutionally identified Directors of the ASEG (those directors that are formally empowered to make financial decisions and hold the fiduciary accountability of the company) and clarify the roles of the Directors versus members of the ASEG Federal Executive - who act as advisors and endorse decisions. It is proposed that the number of constitutionally identified Directors increase from four to five, and that the holder of the position of Immediate Past-President be identified as a Director. It is important to note the general activities of the Federal Executive will remain unchanged, but these constitutional changes, if accepted as proposed, will protect members of the broader Federal Executive from accountability under the Act.

The draft of the revised Constitution, including the proposed changes, can be viewed at https://www.aseg.org.au/news/updated-2022-aseg-constitution-review. Any feedback or comments can be sent to Leslie at fedsec@aseg.org.au by Friday 1 April 2022, prior to a membership vote at the AGM on 7 April 2022.

Call for nominations

The next ASEG AGM will be held on Thursday 7 April 2022. Positions will be declared vacant at the AGM and we are putting out a call for nominations for all those interested in joining the Federal Executive. We have a number of long-standing committee members who will be stepping down in 2022, so we are still on the lookout for new faces to join the committee from the AGM. If you have any suggestions or would like to nominate for any position on the FedEx, please contact Leslie at fedsec@aseg.org.au or send your nomination to secretary@aseg.org.au. Please see the nomination form for more details.

The FedEx also has some vacancies on our standing committees and is also looking for volunteers to fill these roles.

Social media

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

Leslie Atkinson
ASEG Secretary
fedsec@aseg.org.au

Welcome to new Members

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

First name	Last name	Organisation	State	Country	Membership type
Brian	Barrett	Zetica Ltd	SA	Australia	Active
Martin	Bawden	Subjunctive Geo Pty Ltd	WA	Australia	Active
Alain	Delorme	Mineral Resources	WA	Australia	Active
Patrick	Fletcher	Southern Geoscience	WA	Australia	Active
Gail	Iles	RMIT University	Vic	Australia	Active
Oliver	Mowbray	University of Adelaide	SA	Australia	Student

Invitation for candidates for the Federal Executive

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

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

(i) a President
(ii) a President-Elect
(iii) a Secretary
(iv) a Treasurer

These officers will be elected by a ballot of Members.

In addition, the following offices are recognised:

- Vice President
- the Immediate Past President (unless otherwise a member of the Federal Executive)
- the Chairperson of the Publications Committee
- the Chairperson of the Membership Committee
- the Chairperson of the State Branch Committees (unless otherwise a member of the Federal Executive)
- the Chairperson of the Communications Committee
- the Chairperson of the Education committee
- the Chairperson of the Diversity Committee
- Up to three others to be determined by the Federal Executive.

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

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

Leslie Atkinson

c/- ASEG Secretariat

PO Box 576, Crows Nest NSW 1585

Tel: +61 2 9431 8622

Fax: +61 2 9431 8677

Email: secretary@aseg.org.au

Nominations should be received via post, fax, or email **no later than COB Monday 7 March 2022**. Positions for which there are multiple nominations will then be determined by an online ballot of Members, and results declared at the Annual General Meeting.

ASEG Annual General Meeting

The 2022 Annual General Meeting of the Australian Society of Exploration Geophysicists will take place at:

5:30 pm AEST, on Thursday, 7 April 2022, via Zoom and face-to-face at a venue to be advised.

Be there to make a difference!

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

Free subscription to *Preview* online

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

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

ASEG branch news

New South Wales

The NSW Branch finished 2021 strongly with two great events. We braved it for another in person event at Club York on 20 November. **James Daniell**, ex- Geoscience Australia, JCU lecturer and now senior geophysicist with Fender gave us a talk on using re-processed historical seismic data to understand the sedimentary processes on the Great Barrier Reef. Despite the enormity of the Great Barrier Reef, little is known about its geological evolution, primarily because there is very little seismic data available. James' talk provided an overview of historical seismic data, outlined steps taken to reprocess that data and provided an interpretation at three locations along the length of the GBR. The study highlighted the interaction between sediment influx via prograding deltas, incision via sub-marine canyons, and the stabilizing effects of carbonate reefs, all of which have led to contrasting depositional environments along the reef margin.

After two failed attempts (third time lucky), the NSW ASEG Branch successfully executed their annual member dinner at the Australian Heritage Hotel (Wine Room) at The Rocks, Sydney on 1 December. All attendees sampled tasty food, probably a bit too much wine, and thoroughly enjoyed the psychedelic ASEG 50th year celebration cake, cut by two of our ASEG foundation members, **Mike Smith** and **Phil Cooney**.

Stay tuned for a jam-packed technical meeting schedule for 2022.

An invitation to attend NSW Branch meetings is extended to interstate and international visitors who happen to be in town at the time. Most talks are livestreamed on Zoom and uploaded to ASEG's YouTube page later, so you also have the option to join us online. Meetings are generally held on the third Wednesday of each month from 5:30 pm at Club York. News, meetings notices, addresses and relevant contact details can be found at the NSW Branch website. All are welcome.

Stephanie Kovach and Jim Austin
nswsecretary@aseg.org.au
nswpresident@aseg.org.au

The NSW Branch gathering to celebrate the ASEG's 50th year.

Mike Smith and Phil Cooney, ASEG foundation members, cut the ASEG's 50th birthday cake.

Queensland

Happy New Year to all! Following a last-minute cancellation from our venue, we finished off 2021 with the second part of **Peter Fullagar**'s talk, "Beyond plates – fast TEM inversion using conductive ellipsoids". Many thanks to Peter for his patience and thanks to everyone who called in to this interesting talk. If you missed it, it's now available on the ASEG YouTube channel.

ASEG Qld had a committee meeting late last year and we have agreed to host more social events in 2022. The first will be an Axe-throwing and Beers welcome back event, details to be confirmed. We would love to hear from members on what they would like organised in

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what is likely be another tough year for many in the industry. Due to ongoing COVID concerns we'll hold off on both technical talks and social events until cases plateau, so look out for further announcements.

Speaking of isolation, hybrid events were successful last year and we will continue to offer them for technical meetings this year; keep an eye out for our email links showing how to join. We're still on the lookout for 2022 speakers, so please get in touch if you would like to present. Presenters from outside the Brisbane region are welcome and can always present virtually.

Finally, keep an ear out for student geophysics field trips; **Nick Josephs** is looking for ideas/companies/venues to introduce students to our industry. This is particularly useful if your business is on the lookout for budding young geophysicists qldsecretary@aseg.org.au

James Alderman
qldpresident@aseg.org.au

South Australia & Northern Territory

The SA&NT Branch has adopted a holding pattern until the current COVID wave of infections has passed. We expect to resume normal service once things settle down, so keep an eye on the SA&NT events page on the ASEG website for information about upcoming events as it becomes available.

As usual, we couldn't host any of our fantastic events without the valued support of our sponsors and we hope they all renew their support in 2022. The SA/NT Branch is sponsored by **Beach Energy**, **Borehole Wireline**, **Oz Minerals**, **Vintage Energy**, **Minotaur Exploration**, the **SA Department for Energy and Mining**, **Zonge**, **Santos** and **Heathgate**.

Ben Kay
sa-ntpresident@aseg.org.au

Tasmania

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

Mark Duffett
taspresident@aseg.org.au

Victoria

Victoria Branch ended a priceless 2021 on a swanky high. I was informed by our Treasurer that the branch would no longer qualify to receive further funding from the Federal Executive if it did not spend the allotted funds that

Ian Neilson presents to the Victorian Branch.

Diamond drill core illustrating high grade gold intersected in eastern Victoria had banked up over the past two years. It took me less than a nanosecond to oblige as I broke all manner of records to secure a guest speaker for our first in-person technical meeting night in over five months. Enter **Ian Neilson**, chief geologist of First AU and director of PGN Geosciences, whose talk "The Land that Time Forgot: The Victorian Eastern Goldfields", drew a mighty audience to the Kelvin Club on the night of 25 November 2021. I pulled out all the stops for a grand re-opening, hired a string quartet and even booked Tom Gleeson for the half-time entertainment. I was advised to spend money like it was going out of fashion!

Ian is a prospector/explorer/great buddy/entrepreneur who presented to members that night his vision for renewed gold exploration in eastern Victoria. Ian even brought in a sample tray of diamond core from his latest drilling campaign to show the audience what a bonanza gold grade intersection looked like. Frankly, under the poor lighting and my unwillingness to touch the core samples (who knows how many other geos have spat on that core for a more thorough look?), I honestly saw mostly pyrite ☺. Ian has a number of projects he is working on at the moment that aim to demonstrate the upside potential of eastern Victoria. Dare I say, he might actually already have an elephant by the tail.

Despite splurging away half the branch coffers in one night, I did not stop there. Victoria Branch joined PESA and SPE to throw a titanic Christmas luncheon with **Michael Asten**, perennial ASEG ringleader, past President and my old university professor in a previous life, as guest speaker with his key address "Synchronous natural climate cycles of the past millennium in central Europe, the Arctic and east Asia; what do they tell us about global temperature change?", presented to hungry, loud-munching geoscientists and engineers on 15 December 2021 at the Kelvin Club. It was a sensational turnout, albeit rather sombre without a string quartet.

Michael presented proxy temperature cycles in datasets from European glaciations and agricultural records from China. The correlation of synchronous spectral peaks in these regional temperature datasets with the detection of global cosmic ray flux gives support to the idea that natural climate cycles are partially under astronomical control – which is absolutely mind blowing… and casts doubt on human-caused global warming. Michael alluded to the temporal coincidence of the fall of the Roman Empire, mass famine, the Black Death and even witch persecutions with phases of cooling or ice ages, and further observed that social phenomena such as the Renaissance, Scholasticism and the Age of Enlightenment occurred during warmer periods. See? Global warming isn't such a terrible thing, is it? According to Michael's models, the next ice age should occur by 2100. I'm 100% confident I won't be around to witness it, but I'm sure aliens would have invaded the Earth by then (fingers crossed).

I certainly hope members took advantage of the eased restrictions at interstate borders to avail themselves of travel during the festive holidays to visit family and friends. I managed to

The ASEG/PESA/SPE Christmas luncheon at the Kelvin Club.

Professor Michael Asten addressing the Victorian Branch's Christmas luncheon at the Kelvin Club.

ASEG news

bypass Queensland biosecurity for a debaucherously wicked sojourn on the Gold Coast. It was a smashing week of unbridled emancipation…and slightly over-priced beer, but it was well worth the lockdowns. To our incarcerated comrades in fortress Western Australia - inbreeding is real, it is a big deal and there is no treatment - but your government has decided that protecting its iron ore royalties is more of a priority at the moment than allowing families to reunite during the most important time of the year. Happy New Year, by the way.

The current omicron variant is ripping through Australia like wildfire. Probably better to contract COVID- 19 during summer than winter, I presume (not medical advice). There are many more letters left in the Greek alphabet. They'll probably skip 'pi' and go straight to 'theta' next. Wouldn't want to give mathematics a bad name now, would we? I'd hazard a guess and say the next variant of concern will come from us antipodeans.

I don't know what 2022 will hold for branch members. I don't even know if **Jarrod Dunne**, **Nathan Gardiner** or I will even be around to run this ship aground on an annual basis. We certainly tried our best. Steered this ship right into a reef. There's currently $449 left in the branch account. It's barely enough to buy a round of drinks for every Victorian member. As your President, I think I did a fine job of spending your membership fees. Ooh, that reminds me – don't forget to renew your membership for 2022. I'm in a hurry to restock the liquor cabinet at home so please, don't delay. Hope you've all had some leisurely R&R. It's now back to the coal mines for all the chumps that are still working. Bring on the Great Resignation. And don't forget your booster shot!

Thong Huynh
vicpresident@aseg.org.au

Western Australia

After an uncertain start to the year amid COVID lockdowns, the WA Branch managed to build up some steam and end the year with some big events. Our Modern Applications of Geophysics (MAG21) symposium was a great opportunity to get together and hear some classic mineral exploration case studies. While we had so many geophysicists assembled together, we took the opportunity to recognise **Greg Street** who was recently awarded Honorary ASEG Membership. While the award wasn't brand new (it was awarded at AEGC 2021), it was special to be able to present the plaque in-person to Greg in front of friends and colleagues in the industry. Of course Greg was afforded a right-of-reply and he took the chance to give a speech of encouragement to our young geoscientists in the audience. Congratulations Greg!

On November 25, the GESSSWA (GSA Earth Science Students Symposium) was held at Curtin University. This event is organised by a student group and is aimed at all tertiary

Greg Street receives his Honorary ASEG Membership from Darren Hunt.

Michel Nzikou representing the ASEG at GESSSWA.

earth science students as a platform to showcase their research and to engage with industry representatives (future employers). The WA Branch was a gold sponsor of the event and was represented on the day by our Education Officer **Michel Nzikou**. Michel was able to display our ASEG banners and talk to groups of students about geophysics and the benefits of ASEG membership (free for them!). ASEG WA is proud to support this student initiative and we look forward to a continuing relationship with this group.

The year concluded with a short AGM and extended Christmas drinks at the Stables Bar in downtown Perth, thanks to our event sponsors **Xcalibur**, **Explore Geo**, **Wireline Services**, **Searcher Seismic** and **Resource Potentials**. A good time was had by all, and we even saw the numbers swell around 8pm, when the PESA Christmas lunch finished up and members found their way to the ASEG function.

It was also chance to farewell our departing WA president **Todd Mojesky** in his last official function in the role. Todd has been at the helm of the WA committee over the last few years and has safely steered us through some challenging times during the pandemic. During his time as president, Todd has been a champion for education in geophysics, at universities and for the next generation of geophysicists at the high school level. As incoming President, I would like to thank Todd on behalf of our state community for his service to the Society. We will miss your brilliant laid-back intros to the Tech Nights, always with a touch of humour added. We are looking forward to seeing you at future events, in a much more relaxed non-official capacity.

Darren Hunt
wapresident@aseg.org.au

Australian Capital Territory

Open source geophysical exploration tools created by ASEG ACT members at Geoscience Australia (GA) were showcased at the Geological Survey of Queensland – University of Queensland Sustainable Minerals Institute webinar late last year. The YouTube link for the presentation can be found here: https://youtu.be/0pOh9V7EFoI?list=PLdX2u2s9AjXd0jfMtzx-ITTx7MvDdhFZx. This open source toolset for geophysical modelling, inference and inversion, together with GA's magnetotelluric advancements, and geological characterisation outcomes of the Great Artesian Basin are among topics announced for GA's eagerly awaited 2022 Distinguished Lecture Series.

Is the pandemic burning itself out into a manageable endemic? Well let's hope so - I have got my booster shot. Here's wishing all the best to all of us in 2022.

Anandaroop Ray
actpresident@aseg.org.au

ASEG national calendar

Date	Branch	Event	Presenter	Time	Venue
ASEG Branch face-to-face meetings have been disrupted in many states due to COVID outbreaks. Some branches are hosting webinars. Registration is open to Members and non-members alike, and corporate partners and sponsors of state branches are acknowledged before each session. Recorded webinars are uploaded to the ASEG's website (https://www.aseg.org.au/aseg-videos), as well as to the ASEG's YouTube channel (https://bit.ly/2ZNglaZ). Please monitor the Events page on the ASEG website for the latest information about upcoming webinars and other on-line events					
07 Apr	National	ASEG AGM	TBA	1730	Virtual

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/

Twitter: https://twitter.com/ASEG_news

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

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

Geoscience Australia: News

Welcome to Geoscience Australia's (GA) first geophysical update for 2022. Working with our State and Territory partners we have a very big year for acquisition and product delivery ahead, starting off with up to four aircraft acquiring 90 000 line km + of regional to semi-detailed airborne electromagnetics across regional Australia (Figure 1 and article below).

Upcoming data releases in the next four months include the Geological Survey of Queensland's Canobie airborne gravity gradiometry survey, the Northern Territory Geological Survey's 55 000 km^2 ground gravity survey near Tennant Creek and the Geological Survey of Western Australia's Murchison airborne EM (AEM) survey of 2021. We are also currently working on updated versions of GA's geophysical archive and data delivery systems (GADDS), Australian Fundamental Gravity Network (AFGN) portal, and formalisation of the AEM calibration range north of Perth. The latter is being undertaken in collaboration and consultation with CSIRO and the Traditional Owners of the land – the Yued Noongar, for appropriate naming, additional ground surveying, operations-protocol and data availability for the range. Figure 1 and the tables following this section show GA-managed survey status as of January 2022.

National AEM coverage and focus-area programmes

Geoscience Australia has contracted SkyTEM Australia Pty Ltd and Xcalibur Multiphysics to acquire approximately 40 000 and 60 000 line km of regional

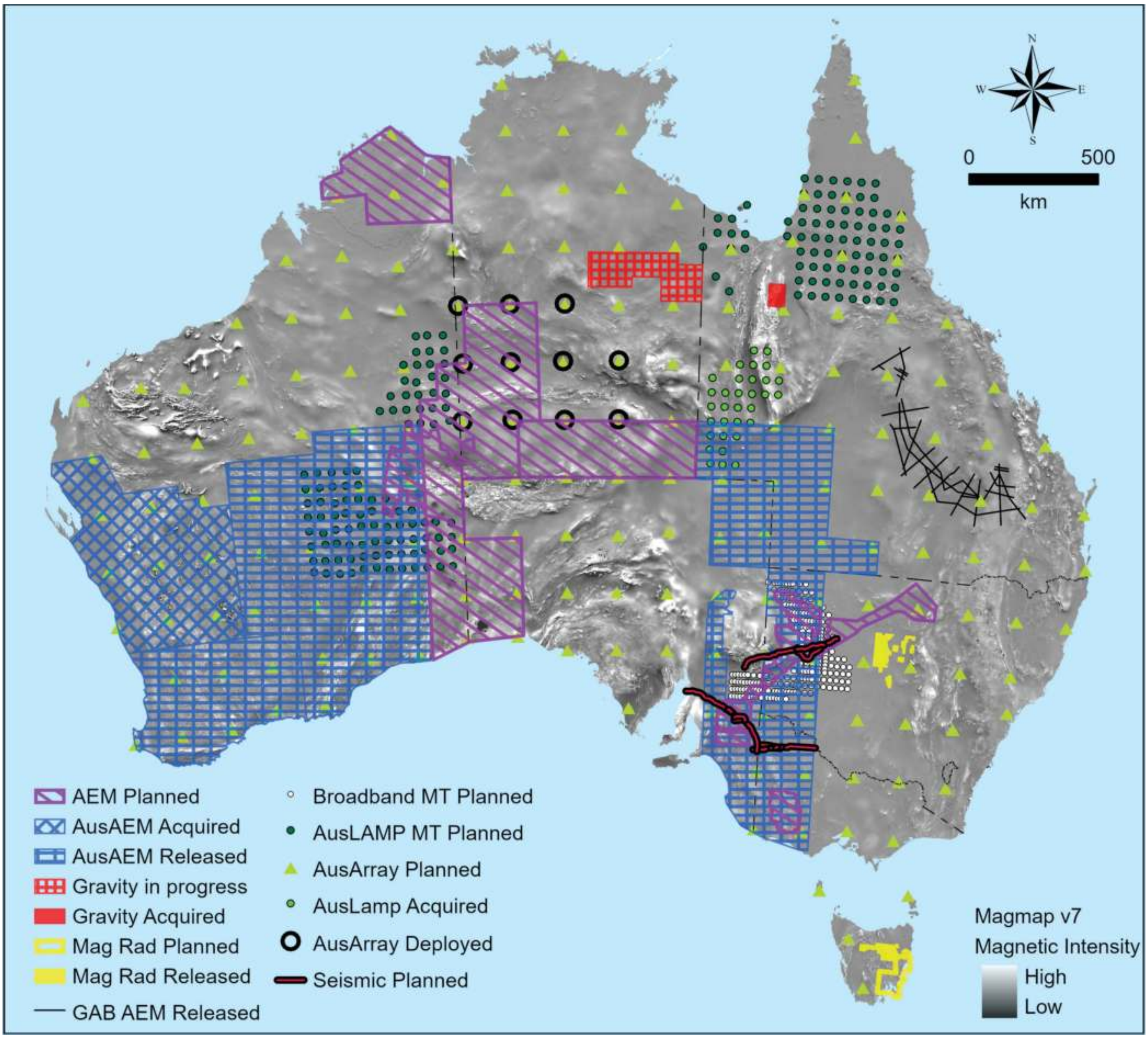

Figure 1. *2021 -2022 geophysical surveys – in progress, planned or for release by Geoscience Australia as part of the Exploring for the Future (EFTF) programme and in collaboration with State and Territory agencies. Background image of national TMI compilation, Geoscience Australia, 2019 (see http://pid.geoscience.gov.au/dataset/ga/144725).*

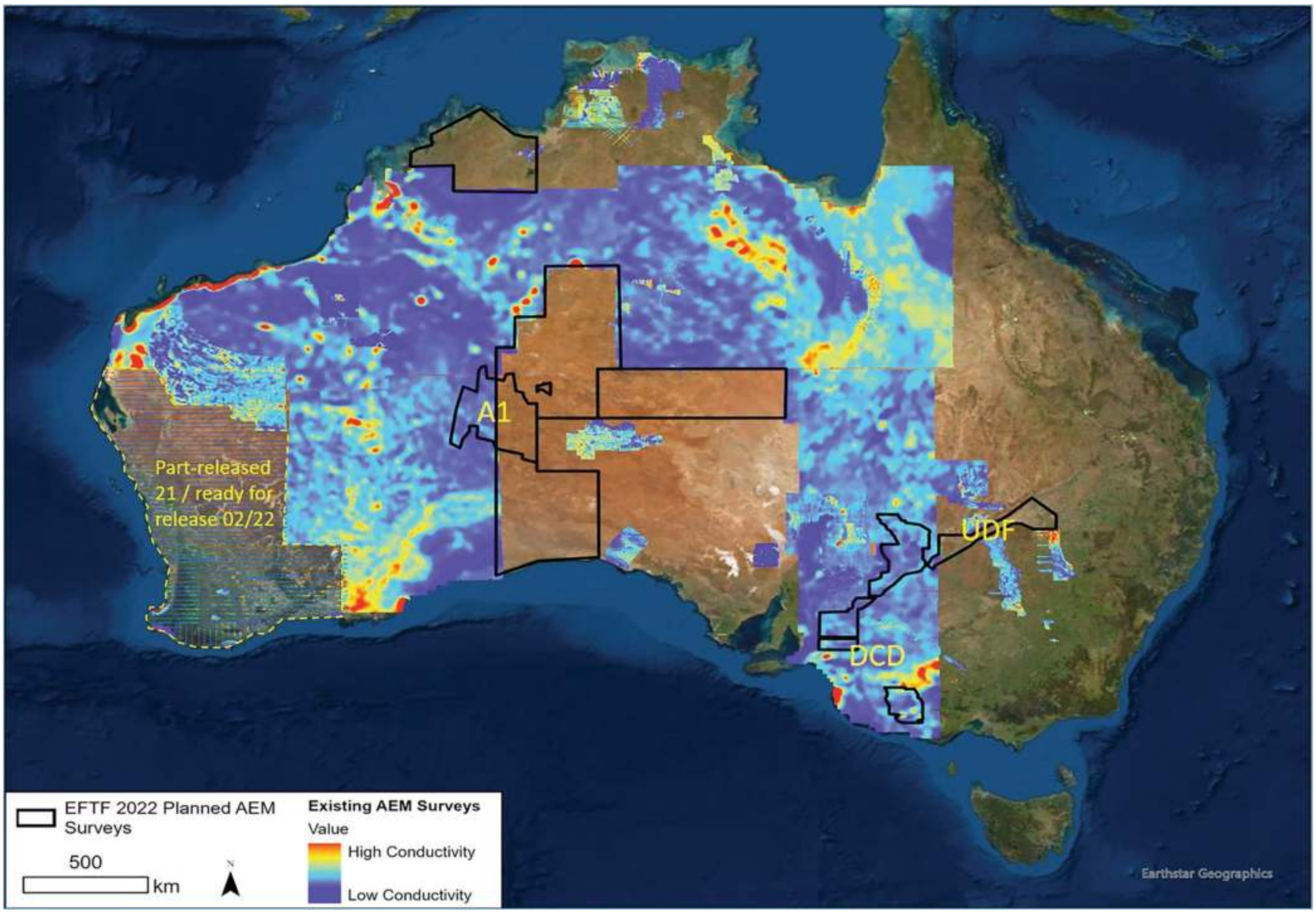

Figure 2. *Status of national AEM (AusAEM) coverage, January 2022. Focus areas Musgraves (A1), Darling Curnamona Delamarian (DCD) and Upper Darling Floodplain (UDF) referred to in text. Existing coverage across southern half of Western Australia and planned surveying along eastern and northeastern margins of the state is 100% funded by the Geological Survey of Western Australia. Along with funding from the Federal Government's Exploring for the Future (EFTF) programme, the AusAEM programme has been expanded with funding from the Geological Surveys of Western Australia and Queensland, combined with valuable in-kind support from all Australian state and territory geological surveys.*

to semi-detailed AEM respectively over the next six months. Together with focus areas, the surveys will see national regional AEM coverage increasing to two thirds of the continent, including 100% coverage across all of Western Australia (an initiative and programme fully funded by the Geological Survey of Western Australia). The status of coverage is shown in Figure 2.

As with previous national AEM programmes, survey objectives include regional to reconnaissance scale mapping for:

(a) trends in regolith thickness, character, and variability including;
(b) variations in bedrock conductivity;
(c) the continuity of key conductive bedrock (lithology-related) units under cover;
(d) groundwater resource potential of specific regions."

Focus areas include:

Musgraves (Block A1). Covering an area of significant mineral exploration interest, employing AEM on a semi-regional basis to map palaeo-valleys and other near-surface structures that may hold potable water resources to build and sustain economic development throughout the region.

Upper Darling Floodplain (Block UDF). This survey aims to provide AEM data at various line spacings along the Darling River, from south of Wilcannia to around Weilmoringle in the north and east of Gongolgon on the Bogan river. Tied to surface and downhole measurements (including ground magnetic resonance), detailed basin electrical resistivity mapping will provide critical information on the impacts and suitability of river sections for irrigation.

Darling - Curnamona - Delamarian (DCD Blocks 1 – 6). As follow-up to the 2021 Eastern Resources Corridor programme, semi-detailed AEM to better define and map basin architecture, undercover geology and assess minerals and groundwater potential in six key areas through the Curnamona/Delamerian geological provinces.

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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 31 January 2022).

Further information about these surveys is available from Mike Barlow Mike.Barlow@ga.gov.au (02) 6249 9275 or Ron Hackney Ron.Hackney@ga.gov.au (02) 6249 5861).

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Line spacing Terrain clearance Line direction	Area (km^2)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Tasmanian Tiers	MRT	GA	MAGSPEC	Mar 2021	Up to an estimated 25 000	200 m 60 m N–S or E–W	4300	Apr 2021	May 2021	See Figure 1 in previous section (GA News)	https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/145547
Cobar	GSNSW	GA	GPX	Jun 2021	53 000	200 m	11 600	Aug 2021	Sep 2021	See Figure 1 in previous section (GA News)	https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/146166

TBA, to be advised.

Table 2. Ground and airborne gravity surveys

Survey name	Client	Project management	Contractor	Start survey	Line km/ no. of stations	Line spacing/ station spacing	Area (km^2)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Canobie	GSQ	GA	Xcalibur Multiphysics	Nov 2021	~5000	1–2 km	5300	Dec 2021	Jan 2022	See Figure 1 in previous section (GA news)	Expected Apr 2022
Brunette Downs Ground Gravity	NTGS	GA	Atlas Geophysics	Oct 2021	~ 12 000	2 x 2 km grid	55 000	TBA	TBA	TBA	TBA
Melbourne, Eastern Victoria, South Australia	AusScope GSV DEL WP	GA	Sander Geophysics	TBA	137 000	0.5–5 km	146 000	TBA	TBA	See Figure 1 in previous section (GA news)	TBA
Kidson Sub-basin	GSWA	GA	Xcalibur Multiphysics	14 Jul 2017	72 933	2500 m	155 000	3 May 2018	15 Oct 2018	See Figure 1 in previous section (GA news)	Set for release Feb 2022
Little Sandy Desert W and E Blocks	GSWA	GA	Sander Geophysics	W Block: 27 Apr 2018 E Block: 18 Jul 2018	52 090	2500 m	129 400	W Block: 3 Jun 2018 E Block: 2 Sep 2018	Received by Jul 2019	195: Aug 2018 p. 17	Set for release Feb 2022
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	Set for release Feb 2022
Warburton-Great Victoria Desert	GSWA	GA	Sander Geophysics	Warb: 14 Jul 2018 GVD: 22 Jul 2018	62 500	2500 m	153 300	Warb: 31 Jul 2018 GVD: 3 Oct 2018	Received by Jul 2019	195: Aug 2018 p. 17	Set for release Feb 2022
Pilbara	GSWA	GA	Sander Geophysics	23 Apr 2019	69 019	2500 m	170 041	18 Jun 2019	Final data received Aug 2019	See Figure 1 in previous section (GA News)	Set for release Feb 2022
SE Lachlan	GSNSW/ GSV	GA	Atlas Geophysics	May 2019	303.5 km with 762 stations	3 regional traverses	Traverses	Jun 2019	Jul 2019		Set for incorporation into the national database in 2022

TBA, to be advised

Table 3. Airborne electromagnetic surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Spacing AGL Dir	Area (km^2)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Western Resources Corridor	GA/ GSWA	GA	Xcalibur Multiphysics	Mar 2022	~ 38 000	20 km	760 000	TBA	TBA	TBA	
Musgraves	GA	GA	Xcalibur Multiphysics	Mar 2022	~ 22 000	1 – 5 km	~ 100 000	TBA	TBA	TBA	
Upper Darling River	GA	GA	SkyTEM	Mar 2022	25 000	.25 – 5 km	TBA	TBA	TBA		
DCD	GA	GA	SkyTEM	Jun 2022	14 500	1 – 10 km	TBA	TBA	TBA		
Eastern Resources Corridor	GA	GA	Xcalibur Multiphysics	Apr 2021	32 000	20 km	640 000	Jul 2021	Oct 2021	See Figure 1 in previous section	http://pid.geoscience.gov.au/dataset/ga/145744
Mundi	GSNSW	GA	NRG	Mar 2021	1900	2.5	~ 5000	Apr 2021	Dec 2021	See Figure 1 in previous section (GA News)	https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/145897 or https://www.regional.nsw.gov.au/meg/geoscience/minexcrc/mundi
AusAEM20	GSWA	GA	Xcalibur Multiphysics & SkyTEM	Aug 2020	62 000	20 km	1 240 000	Nov 21	Dec 2021	See Figure 1 in previous section (GA News)	Feb 2022 (final release – Murchison block)

TBA, to be advised

Table 4. Magnetotelluric (MT) surveys

Location	Client	State	Survey name	Total number of MT stations deployed	Spacing	Technique	Comments
Northern Australia	GA	Qld/NT	Exploring for the Future – AusLAMP	366 stations deployed in 2016–19 32 stations deployed in 2021	50 km	Long period MT	The survey covers areas of NT and Qld. Data package: http://pid.geoscience.gov.au/dataset/ga/134997 Model: http://pid.geoscience.gov.au/dataset/ga/145233 News article: http://www.ga.gov.au/news-events/news/latest-news/exploring-for-the-future-takes-a-deeper-look-at-northern-australia Acquisition of 32 new sites in SW Qld completed mid-2021, data to be released late 2022 together with additional data planned to be acquired under Exploring for the Future during 2022.
AusLAMP NSW	GSNSW/ GA	NSW	AusLAMP NSW	~300 stations deployed 2016-21	50 km	Long period MT	Covering the state of NSW. Acquisition is essentially complete with fewer than 10 sites remaining to be acquired or reacquired. Phase 1 data release: http://pid.geoscience.gov.au/dataset/ga/132148.
Southeast Lachlan	GSV/ GSNSW/ GA	Vic/ NSW	SE Lachlan	Deployment planned to commence early/ mid-2021	~4 km	AMT and BBMT	~160 stations in the Southeast Lachlan. Acquisition delayed due to COVID-19 travel restrictions.
Spencer Gulf	GA/GSSA/ UofA/ AuScope	SA	Offshore marine MT	12 stations completed	10 km	BBMT	This is a pilot project for marine MT acquisition. https://www.auscope.org.au/news-features/auslamp-marine-01 Preliminary results were presented at the Australasian Exploration Geoscience Conference in Sep 2021.

TBA, to be advised

News

Table 5. Seismic reflection surveys

Location	Client	State	Survey name	Line km	Geophone interval	VP/SP interval	Record length	Technique	Comments
Officer Basin	GA	SA	Shallow legacy data	~2000	Varies	Varies	3-6 sec	2D shallow legacy data, explosive, vibroseis	GA commissioned reprocessing of selected legacy 2D seismic data in the Officer Basin, South Australia, as part of the Exploring for the Future programme. The objective is to produce a modern, industry-standard 2D land seismic reflection dataset to assist industry to better target areas likely to contain the next major oil, gas and mineral deposits. Reprocessing by Velseis is complete and data have been QC'ed. Release of the Velseis direct processed data package is planned for Nov 2021. A Velseis direct processed data package is available on request to clientservices@ga.gov.au.
Officer Basin	GA	SA	L137 Officer Basin	550	40 m	240 m	20 sec	2D deep crustal seismic explosive reflection seismic	GA commissioned reprocessing of 2D legacy deep crustal seismic data in the Officer Basin, South Australia, as part of the Exploring for the Future programme. The objective is to produce a modern, industry-standard 2D land seismic reflection dataset to assist industry to better target areas likely to contain the next major oil, gas and mineral deposits. Reprocessing by Velseis is complete and data have been QCed. A GA website data package (images, segy and metadata) is available from http://pid.geoscience.gov.au/dataset/ga/74944 A Velseis direct processed data package is available on request to clientservices@ga.gov.au
Pedirka Basin	GA	SA	Shallow legacy data	~2000	Varies	Varies	3-6 sec	2D shallow legacy data, explosive, vibroseis	GA commissioned reprocessing of selected legacy 2D seismic data in the Pedirka Basin, South Australia, as part of the Exploring for the Future programme. The objective is to produce a modern industry standard 2D land seismic reflection dataset to assist industry to better target areas likely to contain the next major oil, gas and mineral deposits. Reprocessing of these data by Geofizika started in May 2021 and is planned to be complete by the end of Nov 2021. Final deliverables in QC/QA stage and due for completion by the end of Jan 2022.
Central Darling Basin	Coal Innovation NSW (CINSW)	NSW	Central Darling seismic survey	~208	10 m	10 m	6-16 sec	2D high resolution and deep crustal seismic	GA and CINSW signed an MoU to acquire and process 2D high resolution and deep crustal seismic data in the Central Darling Basin. New seismic data will be acquired, processed and interpreted to assist in proving up a geological resource in NSW for the safe and permanent storage of CO_2. The new seismic data obtained will provide greater certainty in planning for future drilling. Data acquisition was completed in May 2021. CINSW contracted Velseis to process the data and the GA seismic team is QCing the processing of this dataset. Processing of these data started in Jul 2021 and is due for completion by the end of 2021.
2019 Camooweal 2D Seismic Survey Archiving Project	GSQ	Qld	Camooweal seismic survey	~300	30 m	10 m	20 s	2D deep crustal seismic	Under a MOU with GSQ, GA is preparing a Data Processing Package for the 300 line km 2019 Camooweal 2D Seismic Survey. This data package will support an interpretation project being undertaken by GSQ to produce new precompetitive geoscience information to assist industry in better targeting areas likely to contain significant gas and sedimentary-hosted mineral deposits.

Table 6. Passive seismic surveys

Location	Client	State	Survey name	Total number of stations deployed	Spacing	Technique	Comments
Australia	GA	Various	AusArray	About 180 temporal seismic stations	~200 km spacing	Broad-band ~18 months of observations	The survey will cover all of Australia to establish continental-scale model of lithospheric structure and serve as a background framework for more dense (~50 km) movable seismic arrays. Deployment of this national array commenced with an initial 11 seismic stations deployed in the NT and will progress to other States and Territories depending on the pace of land clearance process and the status of COVID-19 travel restrictions.
Northern Australia	GA	Qld/NT	AusArray	About 265 broad-band seismic stations	50 km	Broad-band 1 year observations	The survey covers the area between Tanami, Tennant Creek, Uluru and the Western Australia border. The first public data release of the transportable array was in 2020, with further data and model releases expected by Dec 2022. See: http://www.ga.gov.au/eftf/minerals/nawa/ausarray Various applications of AusArray data are described in the following Exploring for the Future extended abstracts: · AusArray overview: http://pid.geoscience.gov.au/dataset/ga/135284 · Body wave tomography: http://pid.geoscience.gov.au/dataset/ga/134501 · Ambient noise tomography (including an updated, higher resolution model for the Tennant Creek to Mount Isa region): http://pid.geoscience.gov.au/dataset/ga/135130 · Northern Australia Moho: http://pid.geoscience.gov.au/dataset/ga/135179
Australia	GA	Various	AusArray, semi-permanent	12 high-sensitivity broad-band seismic stations	~1000 km	Broad-band 4 years observations	Semi-permanent seismic stations provide a back-bone for movable deployments and complement the Australian National Seismological Network (ANSN) operated by GA, ensuring continuity of seismic data for lithospheric imaging and quality control. Associated data can be accessed through http://www.iris.edu

Henderson byte: The latest on Mercury's magnetic field

On 1 October 2021, the first of many planned fly bys of Mercury by a new spacecraft was successfully completed. Its purpose, among other things, was to learn more about the nature of Mercury's magnetic field.

Before 1 October, two spacecraft had orbited Mercury. The first, *Mariner 10*, flew by three times during 1974 and 1975 and covered about half of the planet's surface. In April 1974 a magnetic field was detected, albeit a weak one, only 1.1% of the strength of Earth's magnetic field. Its detection was taken by some scientists as an indication that Mercury's outer core was still liquid, or at least partially liquid with iron and possibly other metals. In which case, a global field could be generated by the dynamo mechanism.

The second mission to Mercury, *Messenger*, was in orbit from 17 March 2011, for four years. By careful analysis of the behaviour of the orbits under gravity, it was confirmed that the planet has a liquid outer core and a solid inner core.

To date we know that the field is approximately a dipole of global extent. Like Earth's magnetic field, the field is tilted but more asymmetric being stronger at its south pole. The magnetic field is strong enough near the bow shock facing the Sun to slow the solar wind, and produce a magnetosphere.

To learn even more about the origin of the magnetic field, *BepiColombo*, a joint mission of the European Space Agency and the Japan Aerospace Exploration Agency was launched on 20 October 2018. Its arrival in orbit at Mercury is planned for 5 December 2025, after six fly bys. The mission will perform a comprehensive study of Mercury, including characterisation of its magnetic field, the solid and liquid cores in more detail and the magnetosphere. It will also conduct some gravity mapping.

BepiColombo comprises two satellites launched together: the Mercury Planetary Orbiter (MPO) and Mercury Magnetospheric Orbiter (MMO). The MPO's scientific payload has eleven instruments including a magnetometer. The MMO's five groups of instruments also include a magnetometer. On arriving in orbit on 5 December 2025, the MMO and MPO satellites will separate and observe Mercury in collaboration for one year or more. Note the date in your calendar!

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Geological Survey of South Australia: Uploads to the gravity database

In a previous *Preview* article (Heath 2020), the Geological Survey of South Australia's geophysicists outlined the updates that have been made to the gravity module on the SA Government database SA_Geodata. Since then, we have been fortunate to welcome Sara Mobasher to the organisation. Sara is assisting with the process of QC-ing and uploading a range of public domain gravity surveys to the database. Previously these surveys had not been uploaded to the database due to resourcing issues (but of course that doesn't mean they are not publicly available – see Heath 2020 for details).

Gravity survey data are usually attached ("paperclipped") to Open File Envelopes, pdfs that contain summaries of exploration licence activity over periods of time. By uploading these surveys to the database, the surveys are then harvested by SARIG (www.map.sarig.sa.gov.au) and become spatially visible online.

We are undertaking a process of compiling all gravity surveys that have been submitted to the Department of Energy and Mining through regular annual reporting, identifying those surveys that require upload, analysing, formatting and compiling the metadata, and finally uploading the surveys onto the database.

At the time of writing we have identified approximately 40 surveys that require upload, as well as numerous surveys that have already been uploaded to the database but are still marked as confidential. Over the next month or so these will all become available for public consumption via the layers on SARIG. In the next edition of *Preview* we will provide a list of all the surveys that have been uploaded as part of this project.

If you know of a public domain gravity survey (or any public domain geophysical surveys for that matter) that are not available via SARIG please do contact us with as much information as possible so that we can locate it, add it to our systems and ensure all the data is publicly available.

For more information, including assistance with accessing geophysical data in South Australia, please contact dem.customerservices@sa.gov.au.

Reference

Heath, P., 2020. Geological Survey of South Australia: SARIG updated. *Preview* **208**, Oct 2020, p 26.

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CSIRO: New Discovery Innovation in Minerals Exploration seminar

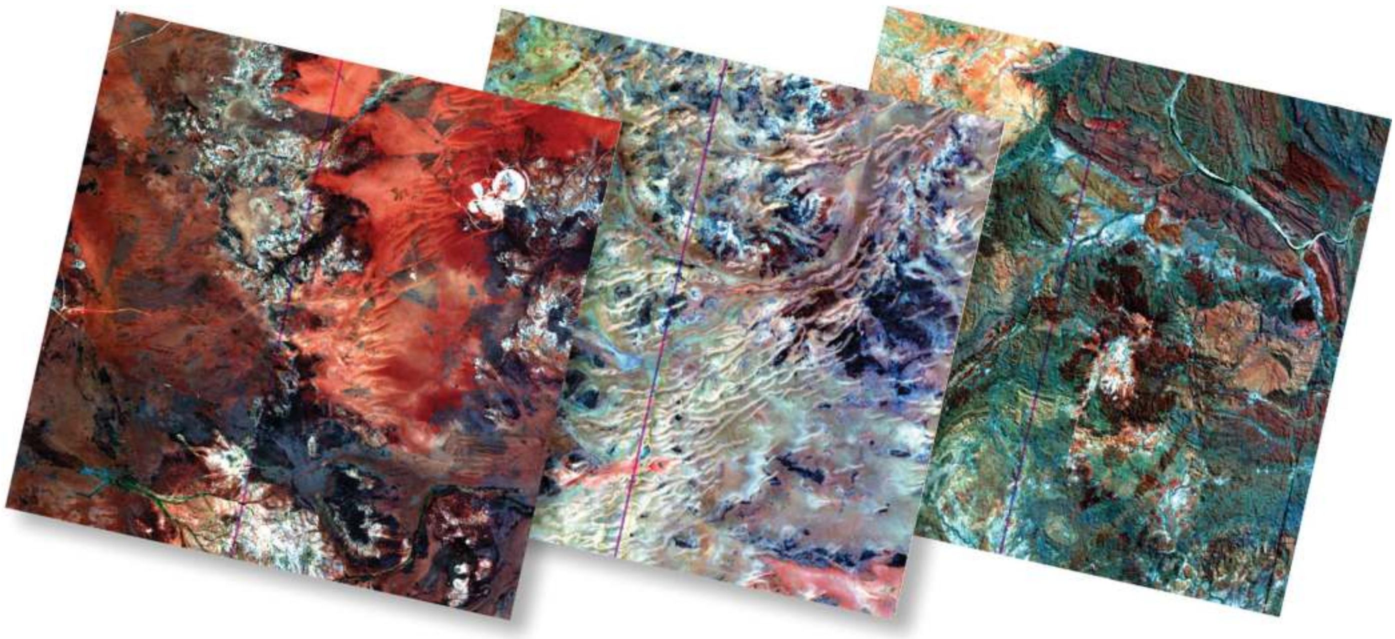
The Discovery programme (in CSIRO Mineral Resources) works to develop new and innovative disruptive technologies that lead to cost-effective, environmentally sustainable mineral discoveries that contribute to Australia's future economy. Our current focus is on the translation of mineral system science into exploration vectors for geophysics, mineralogy, and regolith geochemistry and the development of useful tools for explorers.

The Discovery Innovation in Minerals Exploration (DIME) seminar is an industry-focussed seminar which highlights CSIRO Mineral Resources recent scientific and technological advances in mineral exploration. It will be hosted live at Beaumonde on The Point, East Perth as a hybrid 'in person' and 'online' event. Go to https://events.csiro.au/Events/2021/November/5/DIME-Seminar-STD-2022 for details, including details on how to register.

The seminar will comprise a series of talks on new applications across regolith science, mineral system science, new tools and technology for geoscience and a panel discussion and feedback session where participants can connect with CSIRO and influence our future direction. We'll outline the development of our Exploration Toolkit™, which will partner with SMEs to provide a platform of apps, data, and ML-driven solutions that will be accessible to exploration companies in the future. It currently includes the Australian hydro-gechemical data base, with CSIRO chemical exploration indices, the Mobile Petrophysical Logger data viewing/plotting and calibration tool, Data Mosaic, and will contain our vast calibrated Cloncurry multiphysics/chemistry/mineralogy dataset, and other decision support tools including the geophysical processing toolkit (GPT™).

The seminar will also incorporate a session on innovations in geophysics, including:

- An overview of new minerals industry applications developed through the Deep Earth Imaging Future Science Platform (Tim Munday)
- New techniques for high precision magnetite resource estimation utilising integrated petrophysics, mineral mapping technology and magnetic modelling (Jim Austin)
- Probabilistic modelling of magnetotelluric data over Gawler Craton (Hoel Seille)
- Use of the Mobile Petrophysical Logger to constrain geophysical modelling (Cericia Martinez)



False colour spaceborne hyperspectral imagery over part of the East Pilbara and the Eastern Yilgarn Craton, near and NE of Gruyere. Image credit: Carsten Laukamp.

Modern Applications of Geophysics - Mineral Case Studies: Reflections on the MAG21 symposium presented by the WA Branch of the ASEG

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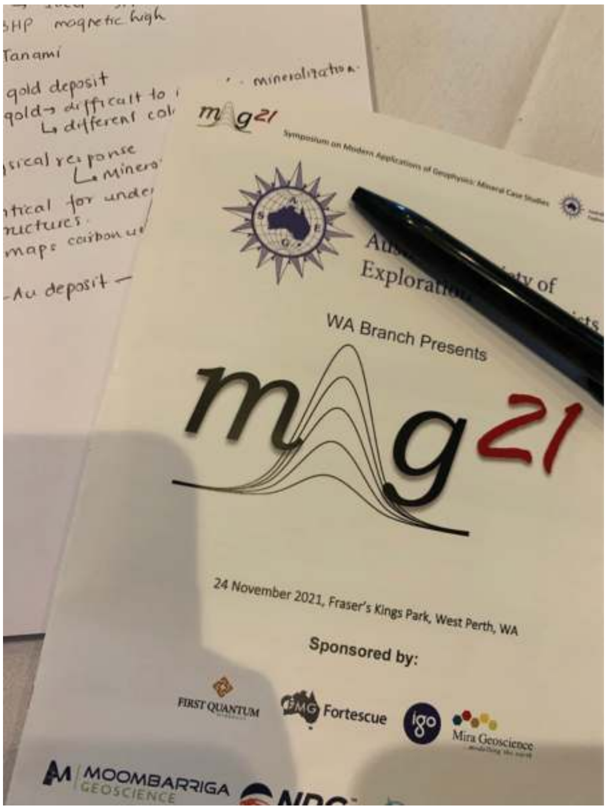
Abstracts



Summary

The inaugural symposium on Modern Applications of Geophysics (MAG21) was held at Fraser's Kings Park in Perth on 24 November 2021. The one-day face-to-face event targeting both geophysicists and geologists followed a similar format to the mini-workshop series on Airborne EM and Geophysical Inversion held in 2012 and 2014 respectively. Over the course of the day a great selection of mineral geophysics case studies was presented to a full venue. The broad and engaging range of topics featured examples of applications of geophysics from exploration and discovery to evaluation of mineral deposits throughout Australia, North and South America. Complementing this, attendees were able to admire a collection of rock and core samples from some of the depicted deposits, or mingle during the dedicated four hours of networking activities. Registration fees for this fully catered event were kept reasonable ($200 for ASEG and AIG Members, $75 for ASEG Student Members and $300 for others) thanks to the support of our generous sponsors; namely First Quantum Minerals, Fortescue Metals Group, IGO Limited, Mira Geoscience, Moombarriga Geoscience, NRG, Southern Geoscience Consultants and Xcalibur Multiphysics.

Case studies are crowd favourites, as they unite the interests of all exploration geoscientists. As industry practitioners, we should probably be better at documenting and publicising our experience. Even if the resulting case studies are only for internal circulation, they will make a great reference for new starters and seasoned staff alike. Good case studies are rare and precious, and unfortunately their authors tend to shy away from recording devices. That is the reason why MAG21 presentations were not streamed nor filmed, to the disappointment of many colleagues who could not be with us on the day. On the flipside, this policy attracted a strong participation from mining companies that would have otherwise declined the invitation to contribute due to the omnipresent pressure around permission to openly share proprietary information (which alone is a matter probably worth discussing separately).

Attendees also thoroughly enjoyed the opportunity to reconnect with colleagues in person, especially after the AEGC 2021 had to be converted to a virtual event. We were fortunate to be able to gather as a community whilst other state branches were facing much tougher restrictions, and we decided to respectfully make the most out of it. Whilst on the topic, we also would like to commend the organising committee who worked tirelessly to put this symposium together with only two months notice in an uncertain pandemic world.

A stellar list of speakers was invited to contribute to the technical programme. Their participation was greatly appreciated and exceeded expectations. Congratulations to Tim Dohey who was the deserving recipient of the best presentation award – as voted by the attendees! The abstracts for the 14 high quality talks are appended below, and most of the presentation material is available for download on the ASEG website. A small number of presenters were encouraged to "recycle" old talks in a session dedicated to "classics". This may come as a surprise to some as this would normally not be an acceptable practice at larger conferences, many of which request the presentation of novel work. MAG21 took a slightly different perspective, acknowledging that old case studies are still relevant to the industry, and a useful guide for the generations of applied geoscientists to come. Good case studies do not grow old, and robust exploration success stories need to be regularly narrated, especially if they have not already been captured in the scientific literature. A key takeaway message from the various stories told on the day was that the work leading to some of the biggest discoveries is not necessarily what would be considered as leading edge, innovative or "fancy". Several speakers even mentioned that in hindsight the discovery was not complicated, but achieved with the systematic application of traditional exploration methods.

MAG21 was very well attended with over 140 geoscientists. It was pleasing to see such a diverse crowd from different backgrounds within the exploration industry. It was particularly encouraging to see a strong cohort of student and graduate geoscientists - we hope to see these young women and men contributing as speakers at future events. The success and popularity of the inaugural MAG21 symposium has inspired us to make this a regular event. The format, timing and location of future 'MAG' events is not decided yet, but case studies will likely continue to be a central theme. Any feedback, suggestions or offer to help organising MAG22 will be appreciated!

The Oak Dam discovery

Katherine McKenna (BHP)

The Oak Dam discovery is an iron oxide copper-gold (IOCG) mineral system discovered in 2018 by the BHP Metals Exploration team. It is located in South Australia 65 km south south-east of Olympic Dam deposit. The project had originally been identified and drilled by WMC in the 1980s. The Discovery hole, AD23, was drilled in April 2018 and produced a discovery intersection of 425 m at 3.04% Cu (with associated gold and uranium), which included 180 m at just over 6% Cu. Use of the historical geophysical data including airborne gravity and magnetics, together with historical drilling and a mineral systems approach, led the exploration team to formulate a hypothesis. More detailed geophysical data was undertaken to aid in supporting the proposed systems model and allow for a more confident targeting.

"It's a story about good old fashion exploration geoscience", Katherine McKenna.

Deeper understanding of the Duketon Gold project through integration of district scale resistivity data

Tom Hoskin (Moombarriga Geoscience) and Celia Guergouz (Regis Resources)*

The Duketon Belt is a greenstone belt with significant known gold resources located on the boundary of the eastern Yilgarn Craton (Kalgoorlie and Kurnalpi Terranes) and the Burtville Terrane. Regis Resources own the vast majority of exploration and mining leases over the belt, operating three production centres fed by numerous satellite deposits. Regis continue to develop satellite projects across the belt as well as extending existing projects underground. Moombarriga Geoscience acquired 513 magnetotelluric soundings for Regis Resources during two field seasons between 2018 and 2020, providing deep electrical resistivity models across much of the belt. These models are compared with existing geophysical and geological data for the belt, to develop a model for the mineral system of the Duketon Belt.

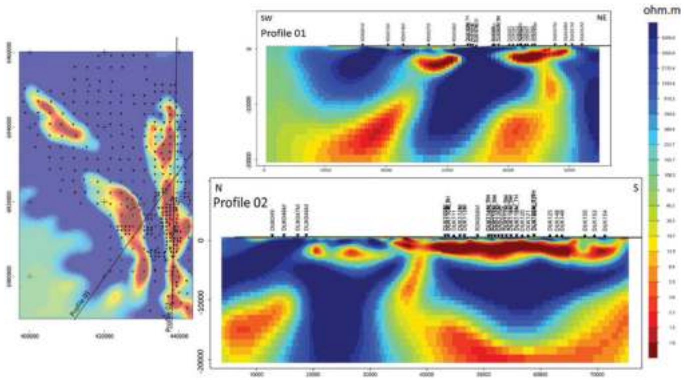


Figure 1. *MT resistivity inversion model across the Duketon greenstone belt.*

Interpretation of regional geophysical data for copper exploration, Curaçá Valley, Brazil

James Reid, Scott Napier, Jean-Philippe Paiement, Glenn Pears (Mira Geoscience) and Pablo Mejia (Ero Copper Corp.)*

Regional airborne geophysical data, including SkyTEM airborne electromagnetics, airborne gravity, aeromagnetics and radiometrics, have been interpreted to produce a 3D model of the Curaçá Valley, Bahia, Brazil. The Curaçá Valley is host to several operating mines and Cu deposits, including Pilar, Vermelhos and Surubim. Cu-(Ni-PGE) sulphide mineralisation is associated with mafic-ultramafic rocks exhibiting broad alteration and possibly associated with regional-scale structures. Airborne electromagnetics and airborne gravity surveys were originally conducted with the aim of direct detection of mineralisation or favourable host rocks. However, significant differences between the existing geological mapping and the new geophysical data were immediately recognised. In order to find new deposits, a revised interpretation of the geometry of the Precambrian units, major structures and intrusive sequences was required. A three-dimensional pseudo-lithological model was constructed based on integrated interpretation of the geophysical and geological data. As well as more conventional model building based on forward modelling and geologically constrained interpretation of the potential fields data, the airborne electromagnetic data was used for geological mapping and to provide additional structural information, based in part on the interpreted dips of extensive stratigraphic conductors. Radiometric data was also effective for refining geological boundaries, and classification of rock types. The regional framework developed during this phase of the work pointed to the possibility of a second mineralisation phase involved in the genetic model, highlighted areas of further interest for detailed exploration work, and complemented the geodata input for a machine learning based targeting exercise. The model and targeting outcomes are used in the recognition of prospective areas and helped to discover several prospects, including the Siriema Cu-(Ni-PGE) deposit, about 1.5 km south of Vermelhos mine.

"The end result of the geophysical modelling needs to be usable for the exploration geologist", James Reid.

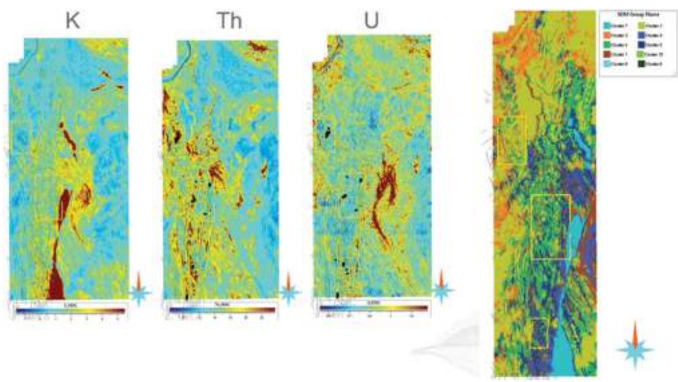


Figure 2. *SOM classification of regional airborne radiometric data.*

Geophysical response and exploration methods for Callie-style targets in Tanami, NT, Australia

Tim Dohey, Alan Hawkins, Andrew Crawford and David Maidment (Newmont Corporation)*

Callie is a world-class vein-hosted orogenic gold deposit located 650 km NW of Alice Springs, within a conformable

Paleoproterozoic sequence of sedimentary rocks. Gold is primarily contained within several preferential stratigraphic host units, and within parasitic folds of the moderately ESE plunging Dead Bullock Soak anticlinorium. Geophysics has proven to be valuable in mapping stratigraphic markers and fold geometry which act as controls on gold mineralisation in the near-mine environment. Modern geophysical techniques have also been key in exploring for similar under-cover signatures across the larger brown-fields search-space, particularly when guided by a petrophysical characterisation of the conformable stratigraphic sequence. High resolution airborne magnetics allow for litho-structural interpretation across the region, which is predominantly under cover, as well as 3D modelling to guide drill targeting. Recent low-noise airborne gravity gradiometry surveys have provided data with sufficient resolution for gravity to be used as a complementary dataset on a prospect scale for both 2D and 3D geological interpretation and targeting. Airborne electromagnetics has been used to map carbonaceous units within the stratigraphic sequence, map the depth of cover, and alteration. Passive seismic (HVSR) methods have also been deployed on a large scale to map the depth of cover. A depth of cover map generated from drilling, HVSR, and AEM allows for the effect of deep palaeochannels to be accounted for while interpreting affected datasets (both geophysical and geochemical). Acoustic impedance contrasts within the conformable stratigraphic sequence at DBS are sufficient to appear as significant seismic reflectors. A recent 3D seismic survey imaged the anticlinorium to depth and down-plunge, and also mapped parasitic folds along the limbs of the DBS anticlinorium that represent exploration targets.

> *"You have got to confront cover head on, and account for it", Tim Dohey.*

Geophysical response of the Atlántida Cu-Au porphyry deposit, Chile

Matthew Hope (First Quantum Minerals)

The discovery of the Atlántida Cu-Au-Mo porphyry deposit is a recent example of exploration success under cover in a traditional mining jurisdiction. Early acquisition of geophysics was a key tool in the discovery, and in guiding resource definition drilling, throughout the lifecycle of the project. Review of the geophysical response of the deposit with respect to its lithological distribution and petrophysical properties has allowed it to be fully characterised despite no mineralisation being exposed at surface. Data acquired over the project includes, induced polarisation, ground and airborne magnetics, gravimetry and petrophysics.

> *"Petrophysics is the decoder between the descriptive science of geology and the quantitative science of geophysics", Matt Hope.*

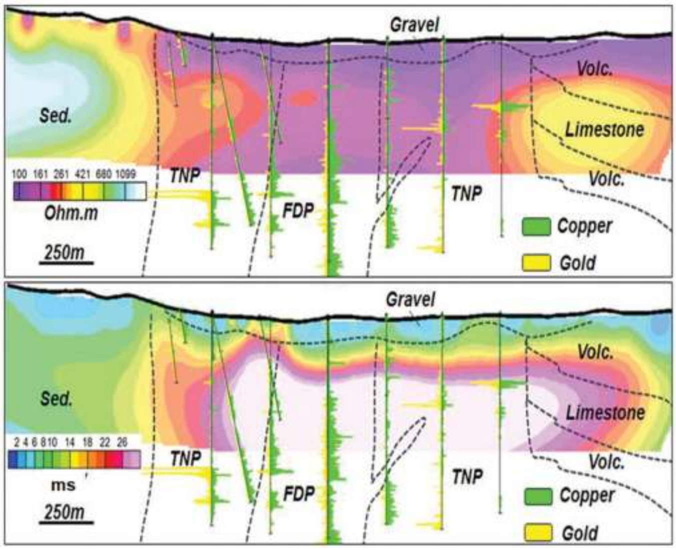


Figure 3. *Modelled DCIP resistivity (top) and chargeability (bottom) sections across the Atlántida deposit.*

Geophysical response of alteration and mineralisation at the Cadia Au-Cu porphyry system, NSW

Terry Hoschke (Alterrex)

Cadia is a large Au-Cu porphyry system located near Orange in NSW, Australia. The system hosts several deposits including Cadia Hill, Cadia Quarry, Ridgeway and Cadia East, with a total resource in 2017 of 44Moz Au, 8.6Mt Cu and 55Moz Ag. Magnetic surveys are important in mapping alteration as magnetite can be present with distal alteration and form a halo around the deposits. Magnetite is not generally present with the mineralisation, the exception being Ridgeway which is highly magnetic. Skarns and intrusions in the district can also be magnetic. Sulphides are typically zoned from bornite at the centre of the system to chalcopyrite to a pyrite halo. The pyrite halo is the likely cause of the IP anomaly at Ridgeway and Cadia East. The alteration is typically resistive. There can be pervasive feldspar and quartz alteration that can be extensive, as can be observed above Cadia East and Ridgeway. The resistivity may be lower in the ore zone if there are sulphide veins. This is the case at Ridgeway where in situ measurements and measurements on samples show the mineralised zone is relatively conductive. Geophysical techniques have proved useful in mapping alteration in this system and have been involved in the discovery of some of the deposits.

The remainder of the deer: Geophysics and the discovery of the southern extension of the Antler VMS Deposit, Arizona USA

Jarrad Trunfull (Terra Resources)

Located in mountainous terrain in Western Arizona USA, Antler is a high-grade stratabound Cu-Zn VMS deposit, with a long history of mining that stretches back to 1916. However, exploration efforts dwindled during the 1970s and there was no work done on the project for over 40 years. In 2020, New World Resources re-invigorated the project with a renewed focus on exploration, led by geophysics. Petrophysical

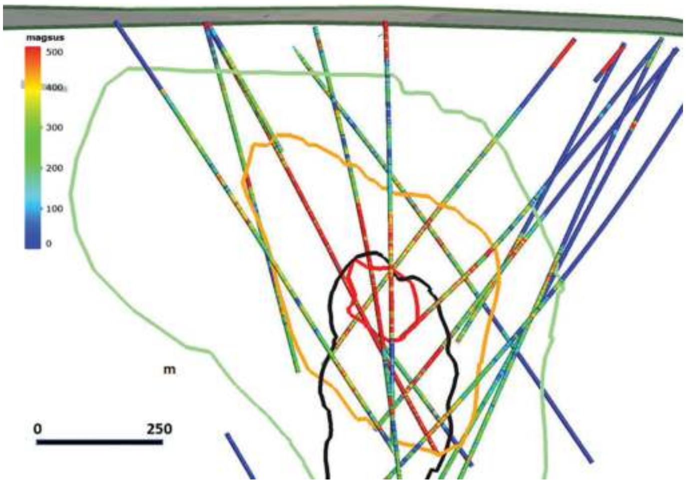


Figure 4. *Ridgeway deposit magnetic susceptibility. Units are 10^{-3} cgs. 3D modelled magnetic susceptibility contours 0.05 to 0.3 SI (Close, 2000).*

tests on drill core showed strongly anomalous properties in density, chargeability and inductive conductivity in the mineralised samples. Magnetic susceptibility was also anomalous within mineralisation, and in addition was measured to have a significant component of remanent magnetisation. High-resolution magnetic surveys utilised a drone platform for acquisition. The dipping magnetic bodies defined by the survey correlated well with the known mineralised lenses. Constraining 3D magnetic inversions with drill data enabled the mineralised lens to be defined to depth in 3 dimensions. Fixed-loop EM was utilised for direct-detection of conductive VMS mineralisation, but the results did not reach expectations. 3DIP was trialled next and was successful at delineating the known mineralisation to a depth of ~400 m in both in resistivity and chargeability datasets. Subsequent drilling in the central zone confirmed the priority IP/resistivity target was high grade mineralisation. Still searching for an 'indispensable' method for target detection at Antler – Terra Resources then utilised CSAMT deployed in Broadside configuration. The objective of the survey was to map deep-seated conductors over a wide area. The broadside method preferences highly-conductive bodies in a conductive host and minimises the response of less-conductive host units. In addition to lighting up the known mineralised lenses, the CSAMT survey defined a large conductor to the south with a significant depth extent – named the 'South Shoot'. NWC tested this new target with drilling, and in March 2021, announced intersections of thick high-grade copper-zinc-rich massive sulphide mineralisation in the South Shoot (ASX RELEASE 2 MARCH 2021).

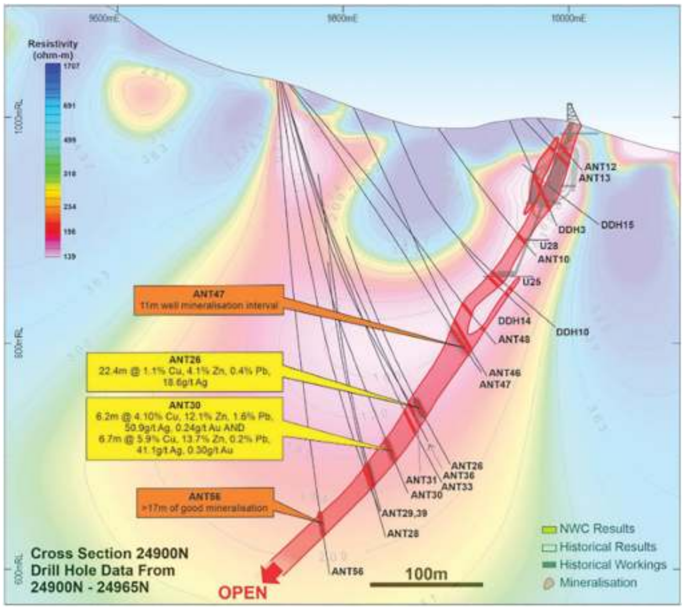


Figure 5. *Cross-section of CSAMT from line 24900N – with drill holes and select significant assay results from recently discovered "South Shoot" projected onto the section (New World Resources 2021).*

played a major role in the initial discovery, delineation and understanding of the Gonneville deposit under lateritic cover. Chalice originally staked the project in 2018 on the basis of a previously unrecognised, 26 km long, mafic-ultramafic intrusive complex interpreted from open-file aeromagnetic surveys. In 2019, a moving-loop electromagnetic survey conducted over a discrete 1.6×0.8 km magnetic anomaly detected multiple EM conductors, some of which were interpreted to represent a massive sulphide source. An RC drilling programme commenced in March 2020, with the first hole drilled into the strongest conductor intersecting massive, matrix and stringer sulphide mineralisation reporting 19 m @ 8.4g/t Pd, 1.1g/t Pt, 2.6% Ni, 1.0% Cu and 0.1% Co from 48 m downhole. Multiple high-grade massive-matrix-heavy disseminated sulphide zones have since been intersected in the Gonneville Intrusion, along with widespread, lower-grade disseminated sulphide mineralisation. Subsequent geophysical methods include detailed ground gravity, airborne magnetics, downhole (DHEM) and airborne electromagnetic (AEM) surveys. DHEM has identified multiple conductors associated with known, and potentially mineralised zones. Gravity and magnetic survey data and inversions have improved the understanding of the geology and structure of the intrusion. An AEM survey flown in late 2020 highlighted known mineralisation at Gonneville as well as identifying multiple new anomalies to the north within the broader Julimar Complex. Geophysical techniques will continue to provide a key role in exploring the Gonneville deposit, targeting extensions of known mineralisation as well as delineating new areas for continued exploration within the Julimar Complex.

The role of geophysics in the discovery of the Gonneville PGE-Ni-Cu-Co-Au deposit, Julimar, WA

Jacob Paggi (Armada Exploration Services), Kevin Frost and Bruce Kendall (Chalice Mining Limited)*

The Gonneville deposit is a significant new PGE-nickel-copper-cobalt-gold sulphide deposit discovered by Chalice Mining in 2020. Located only 70 km northeast of Perth, Western Australia, it represents the first major discovery of magmatic sulphide mineralisation within the Julimar Complex, in the newly defined Western Yilgarn Ni-Cu-PGE Province. Geophysics has

Geophysical signature of the DeGrussa Copper-Gold Volcanogenic Massive Sulphide deposit, WA

Bill Peters (Southern Geoscience Consultants)

The DeGrussa copper-gold Volcanogenic Massive Sulphide (VMS) deposit (14.8 Mt at 4.2% Cu and 1.4 g/t Au) discovered in 2009 is located 150 kms north of Meekatharra, WA. The initial discovery was from shallow drilling of a geochemical anomaly

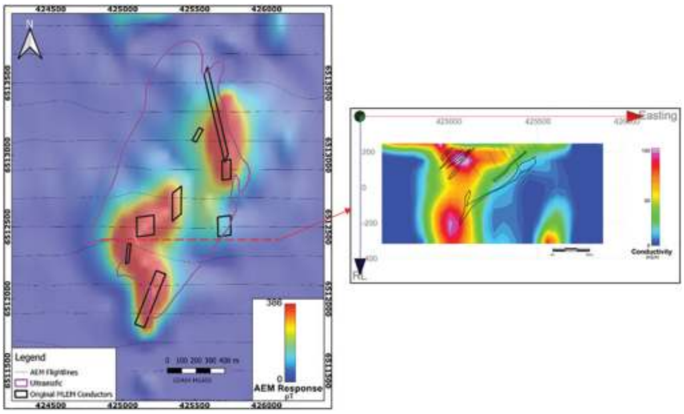


Figure 6. *AEM results over Gonneville deposit. Left: HeliTEM Bz channel 15 (2.9 – 3.7ms). Right: Differential conductivity section at 6 512 400 N.*

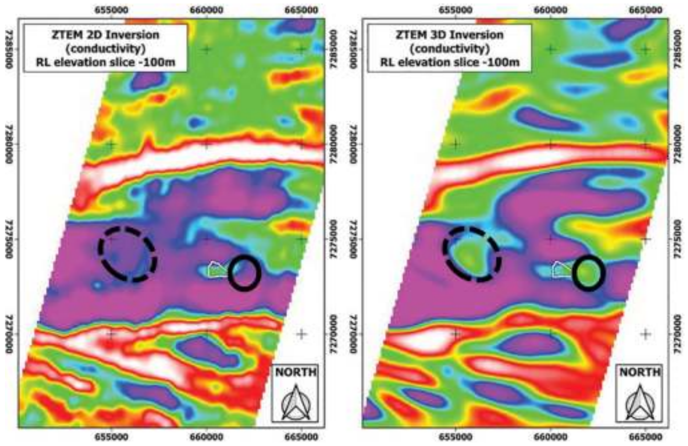


Figure 7. *ZTEM conductivity inversion results over Abra deposit (white outline).*

with a subsequent deeper vertical hole intersecting massive copper-rich sulphides from 98 m (near the base of oxidation) to 235 m depth. Initial down-hole electromagnetic (DHTEM) surveying showed this "DeGrussa" conductor to be relatively small; however, follow-up fixed loop (FLEM) and moving loop (MLEM) surface electromagnetic surveys identified a significantly larger nearby conductor called "Conductor 1". Spectacular high-grade copper-gold intersections in Conductor 1 have made DeGrussa one of the most significant copper discoveries in Australia in recent years. Subsequent DHTEM surveying led to the discovery of two deep faulted extensions to the known mineralisation (Conductors 4 and 5). Core physical property tests showed that EM was the best tool for detecting similar massive sulphide mineralisation in the area. Good contrasts in chargeability, resistivity, and density confirmed that induced polarisation and gravity surveying were also applicable methods. Surface MLEM, FLEM, SAM, gravity and magnetic surveys have been carried out. Of these, only the EM surveys have been useful for direct detection. Detailed airborne magnetic-radiometric and helicopter EM surveys have been flown. A weak but recognisable conductor was seen over the deposit in VTEM data.

The geophysical expression of the Abra sedimentary replacement Pb-Ag-Cu-Au deposit, WA

Jayson Meyers, David Stannard (Resource Potentials) and Angelo Scopel (Galena Mining)*

Abra is a high-grade sedimentary hosted Pb deposit located in the Paleoproterozoic Edmund Basin of Western Australia. It was discovered in 1981 and remained undeveloped until underground mining commenced in late 2021, 40 years following discovery. Mineralisation is 'blind' with the top of the deposit occurring at 250 m depth and consists of a stratiform apron of Pb-Ag-Ba mineralisation in a laminated iron oxide and barite altered dolomite and siltstone overlying a 'feeder zone' of chlorite altered, brecciated and veined carbonaceous siltstone containing Pb-Ag mineralisation in the core, transitioning to Pb-Cu and Cu-Au at depth. Abra is characterised by discrete geophysical anomaly responses in magnetic, gravity, TDEM and IP survey data. A +450nT magnetic anomaly is caused by magnetite within the lower part of the stratiform zone. Dense galena, barite, dolomite and iron oxide mineralisation in the apron, and galena in the feeder zone, surrounded by lower density sedimentary host rocks, resulting in a +1 mGal gravity anomaly. Airborne, ground and downhole TDEM surveying resolved known mineralisation as weak EM conductor responses and petrophysical testing on core samples show this is caused by galena. PDIP surveying resolved a +20 msec chargeability anomaly on the southern flank of the deposit, and this is related to disseminated galena, pyrite, chalcopyrite and alteration. AMT-MT 2D inverted data sections resolved the Abra as a broad weakly conductive anomaly, which was also resolved in 2D and 3D inversion modelling of airborne ZTEM data. 2D seismic reflection surveying resolved Abra as strong flat-lying seismic reflectors which are bounded and offset by faults and surrounded by a seismically bland zone. The seismic reflections are related to significant density contrasts between high-density stratiform mineralisation in contact with low-density sedimentary host rocks, as mineralisation and host rocks have similar seismic velocities. Passive seismic HVSR surveying resolved the top of the deposit as a subtle layer sitting below a flat impedance contrast horizon interpreted as weathered siltstone on top of diagenetically cemented siltstone. The deposit remains open at depth, and a new Pb mineralised zone was discovered at depth just to the north from testing a late time VTEM anomaly.

The geophysical signature of Nova-Bollinger; from exploration to mining

Bill Amann (Newexco Exploration)

Nova Bollinger is the
first economic intrusive hosted NiS PGE deposit found within the Albany Fraser. I present and discuss the exploration geophysics up to the mining stage of the project. Initially, highly encouraging geological and geochemical results required follow up which commenced with MLEM. Numerous anomalies were detected, of which one was selected for immediate testing. Maiden drilling returned massive NiS on target. Subsequent drilling and DHTEM showed Nova-Bollinger to be a significant discovery. Given a good budget and corporate enthusiasm further geophysical work was carried out to characterise the deposit(s) and to discover new lodes. This work includes gravity and IP and numerous forms of EM.

"Everything I say is not necessarily true", Bill Amann.

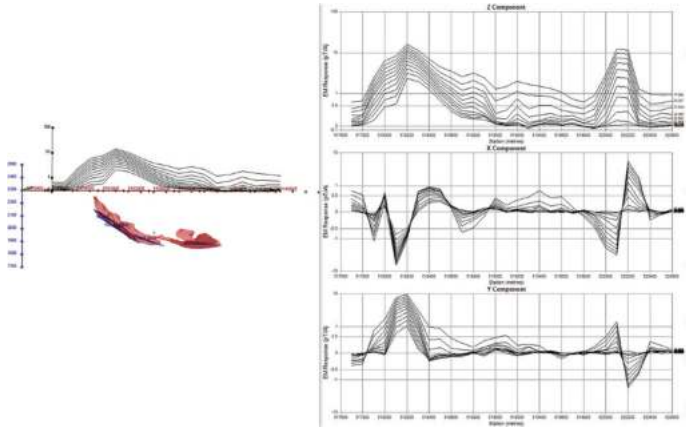


Figure 8. *MLEM 200m loop B field data (1Hz, >17ms) over the Nova-Bollinger deposit.*

The use of geophysics in the post-discovery of the Nova deposit

Andrew Fitzpatrick (IGO Limited)

IGO Limited acquired the Nova-Bollinger deposit post-discovery in 2015, and subsequently began acquiring tenements across the Albany-Fraser Orogeny (AFO) for magmatic nickel sulphide exploration. This paper discusses IGO's use of geophysical techniques from brownfield to belt-wide scale greenfield exploration across the AFO. Such techniques include 3D reflection seismic across the Nova mining lease, to belt-wide airborne and ground EM, gravity and magnetic surveys. The rationale of using the different techniques is discussed along with their merits and limitations in their use for exploring for such nickel systems.

Building 3D rock models from seismic at the Tropicana gold mine

Kevin Jarvis (HiSeis), Ockert Terblanche and Stephen Brown (AngloGold Ashanti)

Seismic imaging technology involves the propagation of sound waves into the earth with the objective to image changes in the subsurface. The sound waves are sensitive to changes in rock impedance which is the product of velocity and density. The final images represent the boundaries between different rocks with the amplitude related to the contrast in the impedance above and below the boundary. There is often both random and coherent noise in the data that further complicates how the seismic image relates to the subsurface. Understanding the seismic and what it reveals about the subsurface can be challenging. The conversion of the seismic into models of rock makes the results accessible to a larger audience. The key to making the conversion is to understand which rocks can be separated and to apply technology that can exploit all available data to build rock models. The technology chosen is geostatistical inversion, which is essentially geostatistical modelling with the addition of seismic data as an additional constraint. The geostatistical inversion exploits the detection limit of the seismic to build detailed rock models. Data from the Tropicana gold mine were selected for testing because it consists of a large set of deep drillhole data, several sonically logged drillholes, and good quality 3D seismic reflection data.

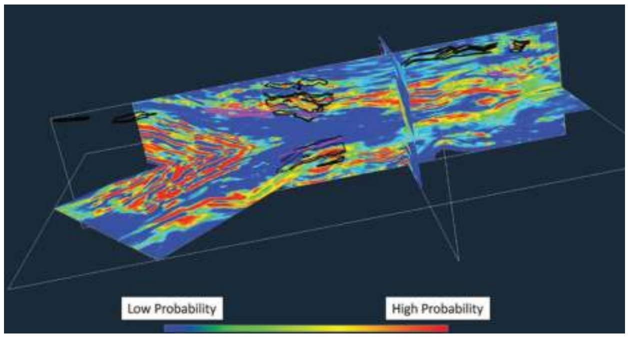


Figure 9. *Garnet gneiss probability volume from 3D seismic data over the Tropicana deposit. Garnet gneiss distribution from drilling in black. Gold mineralisation from drilling in pink.*

Laterite resource definition through geophysics, case studies from Ravensthorpe, WA

Chris Wijns (First Quantum Minerals)

The Ravensthorpe nickel laterite deposits in Western Australia are defined by different regolith layers that must be mined and processed separately. A surface caprock layer is waste material (and used as road base), beneath which are limonite and saprolite layers that are sent to separate processing streams. As the regolith grades into saprock below this, the mineral resource falls below an economic level. Within the limonite and saprolite, further variations in material properties affect processing results, including during the beneficiation, or physical upgrading stage. The boundaries between these layers are geometrically complicated, such that very close-spaced drilling would be required to define them to an accuracy relevant to mining. In an effort to mitigate wider drillhole spacing, different geophysical techniques have been trialled in attempts to trace boundaries between drill holes. Any technique must be rapid, with high spatial resolution, and preferably continuous, in order to cover the many kilometres of resource drilling and eventually be deployed in a mine pit during operation. Petrophysical logging serves as both a check on the surface geophysics and a potential avenue for predicting material behaviour where multi-element geochemical assays alone have failed. Conductivity and gamma logging, for example, characterise discrete zones that are not represented in the geochemistry or visual logging. Active and passive seismic, electromagnetics, and ground-penetrating radar show variable success in mapping different interfaces.

"Geophysics is a space filler between drill holes", Chris Wijns.

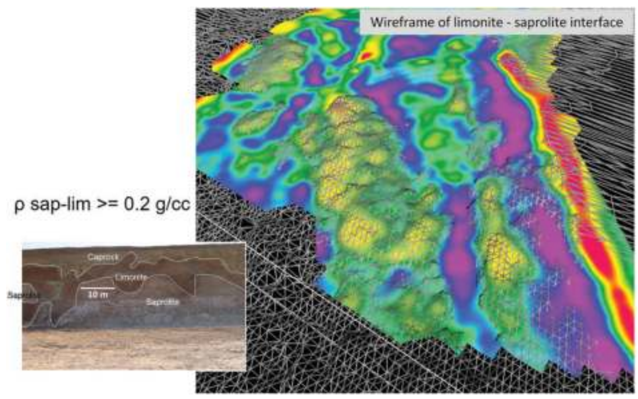


Figure 10. *Detailed constrained gravity model and regolith horizons at the Ravensthorpe mine.*

MAG21 organising committee, from left to right: Fionnuala Campbell, Michel Nzikou, Darren Hunt, Jarrad Trunfull, Partha Pratim Mandal, JJ Leong, Regis Neroni, Kevin Ung and Daniel Lindsey. Missing: Esmaeil Eshaghi.


Full house at MAG21

Tim Dohey receiving the best presentation award from Fionnuala Campbell


Networking at MAG21


Attendees inspecting display core samples during the sundowner.


More networking at MAG21

Canberra observed

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2021 in review: COVID-19 still dominates health

By January 2021 90 million people had been infected globally with COVID-19, and two million had died. In January 2022, according to Johns Hopkins University, there have been 324 million cases, 5.5 million deaths and 9.6 billion vaccine doses administrated (*https://coronavirus.jhu.edu/map.html*). Not a good read.

We thought, in the middle of 2021, that the Delta strain had been conquered. Then along came Omicron. It spread relentlessly around the world and became out of control in Australia. From July through to the first week of December the weekly number of cases were steady at about 10 000, then in early January it leaped to more than 500 000. Those who forecast 25 000 cases per day were accused of scaremongering, but in NSW alone the number rose to more than three times that amount. Case numbers took off after some of the States and the Commonwealth decided to lift restrictions on wearing masks, social distancing and curfews in early December.

We now have a situation where supply chains are breaking down, thousands of aged-care residents and people with disabilities have become infected, and the whole health care system is in crisis, with elective surgery postponed and ambulance waiting times going from minutes to hours.

The Australian Government did not foresee this situation, and as a result many people cannot access rapid antigen tests (RATs), or PCR tests and vaccines, because of the demand. It was a case of too little too late. The Commonwealth could have, and should have, been more prepared, instead of allowing situations to deteriorate before belatedly taking action.

Fortunately, because of the high vaccination rate (46 million administered to date) the peak of the infection rate should be in the next few weeks. We will have to see how this plays out, because nobody wants to re-impose restrictions.

I think the worst decision the Government made on Omicron was to charge for the RATs, except for those with concessions. Most other countries such as the US and UK do not charge for these tests and to date the PCR tests have been free, so why the parsimony? The health of the nation should be a national priority, but when you can spend billions on buying tanks when none of our current tanks have ever been used in action, one must question the priorities.

2021 in review: Commodity prices

Figure 1 show how the prices of four key commodities; gold, oil, iron ore and thermal coal, changed during 2021.

After reaching a peak price of $1943/oz in August 2020, the price of gold has steadily declined to $1787 at the end of 2021. It is still well above pre-2020 prices so at this stage it should not be a major concern.

The iron ore price was volatile throughout 2020-21. After several years when the price was in the $60-90/t range, it rose steeply from mid-2020 to reach a peak of $214/t in July 2021. These changes were mostly dependent on China and its economic health. As long as the politics of Australian relationships with China are strained, the future of the price of iron ore will be uncertain.

The price for thermal coal is no longer in steady decline, and the $50/t price in August 2020 seems a long time ago after it reached over $200/t in October 2021. The rapid increase is mainly due to China's rapid growth, insatiable demand for energy, and a shortage of coal supply. It's thermal coal production grew by 6% in 2021, and its demand for thermal energy grew by about 14%. China's ban on Australian coal imports appears to have had little or no effect on global demand. Consequently, the coal miners are proceeding with applications to expand their activities and in NSW five

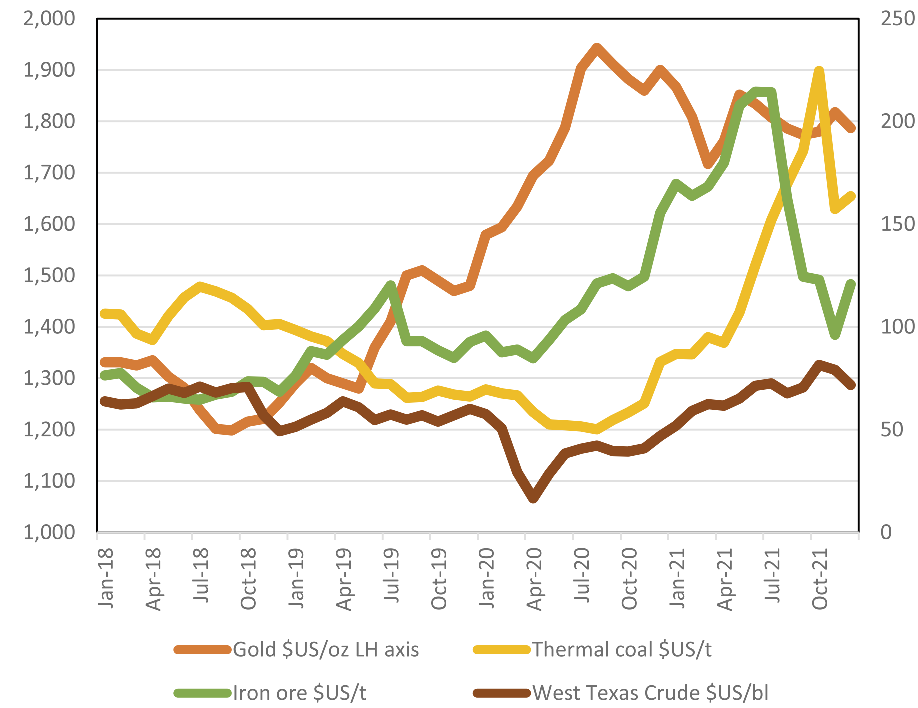

Figure 1. *Prices in $US for gold, petroleum, iron ore and thermal coal for 2018-2021. Data sources: https://ycharts.com/indicators/wti_crude_oil_spot_price, https://www.indexmundi.com/commodities/?commodity = iron-ore&months = 120, https://www.gold.org/goldhub/data/gold-prices, https://www.indexmundi.com/commodities/?commodity = coal-australian&months = 60.*

new proposals are under investigation (*SMH,* Jan 8-9). These applications appear to be incompatible with NSW's net zero greenhouse gas targets, and will generate about 1.8 billion tonnes of CO_2 if all projects are approved. But money has power.

The oil price is continuing to recover, from a monthly low in of $US17/bl in April 2020, to $US80/bl at the end of 2021.

2021 in review: Critical Minerals and Clean Energy Transitions

The importance of key metals in the transformation to clean energy made a big impact during 2021. The relevant minerals are mainly copper, lithium, nickel, cobalt and the rare earth elements. They will be needed for electric vehicles, batteries, wind farms, solar panels etc.

The International Energy Agency recently produced a special report on Critical Minerals and Clean Energy Transitions (*https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions*). It is recommended reading for all geophysicists working in the mineral industries.

It turns out that a typical electric car requires six times the mineral inputs of a conventional car, and an onshore wind plant requires nine times more mineral resources than a gas-fired power plant.

The production of many energy transition minerals today is more geographically concentrated than that of oil or natural gas, consequently the supply chains could be more vulnerable.

The IEA estimated that the demand for lithium, cobalt, nickel and rare earths will increase by a factor of three by 2040, if we are to meet the Paris Agreement goals. Furthermore, the discovery, extraction and processing must be done to meet higher environmental standards, because humans are inhabiting more and more of the earth's surface and we must try not to generate unnecessary pollution.

The opportunities are huge, and they are here now.

At the start of 2021, Iluka and Lynas were the only two companies in the top 150 companies on the ASX focusing on rare earths and battery minerals. At the end of 2021 four more companies joined the club (Challis Gold, Nickel Mines, Liontown Resources and Pilbara Minerals). They contribute about $20 billion in market value to the ASX, with Pilbara Minerals currently in the top 50 companies.

2021 in review: How did the resource companies fare?

The price of the commodities affects the performance of our resource companies. Table 1 shows how the value of the main resource-based companies in the top 150 ASX fared during 2021.

The numbers in the table are in $A billions. The percentage changes in market value during 2021 are shown, as well as how these changes compare with the 2020 results. The companies are grouped according to their main commodity interest. The three largest companies relied on iron ore prices. Note how their value fell.

The gold sector was less affected by the gold price decline because although the price has fallen steadily since August 2020, it only amounted to about 5% during 2021 and most companies did well last year.

Australian annual gold production has gradually increased from the 250 tonnes in 2012 to the record 325 tonnes in 2019. The 2020 number of 320 tonnes was the first break in this sequence. It is below the top two producers, Russia with 331 t and China with 368 t (*https://www.gold.org/goldhub/data/historical-mine-production*).

As you can see in Table 1, the petroleum companies are recovering nicely from the 2020 disaster year.

Yancoal remains the only 'coal only' company in the top 150 and did better in 2020. However, with increasing pressure to cut greenhouse gas emissions and the global shortage of thermal coal the long-term future of coal mining is uncertain.

The Government still hates universities

In December 2021, Stuart Robert, the Acting Minister for Education and Youth, delivered a bombshell to the Australian Research Council (ARC).

The ARC administers the National Competitive Grants Program, which invests about $800 million a year in the highest-quality fundamental and applied research across all disciplines other than clinical and medical research, which is funded through the National Health and Medical Research Council (NHMRC). Most of these funds are allocated to universities.

Table 1. Market capital changes in the value of the top 150 ASX listed resource-based companies in 2021.

Market capital changes for 2021				
	Jan 2021	Dec 2021	Change %	% in 2020
BHP	137.482	122.435	-11	+9
Fortescue	78.020	59.146	-24	+115
Rio	46.034	37.162	-20	+12
Yancoal	3.287	3.411	+4	-17
Woodside	21.881	21.264	-3	-33
Santos	13.060	21.371	+64	-25
Origin	9.017	9.228	+2	-45
Oil Search	7.708	8.394	+9	-33
Beach	4.117	2.90	-30	-31
Newcrest	21.050	20.023	-5	-8
Evolution Min	6.363	8.526	+34	+34
Oz Minerals	6.254	9.415	+51	+81
Northern Star	9.402	10.958	+17	+15
All Ords	6851	7779	+14	-1
Market Capital	369.72	379.87	+3	+10
Iron 0re +other	Coal	Petroleum	Gold	

Importantly, 40% of this allocation is committed through the ARC Linkage Program. This programme funds collaborative projects between universities and industry and community organisations. The aim is to stimulate the transfer of skills and knowledge to deliver public benefit.

The minister is now demanding that 70% of the Linkage Program funding goes to the Government's National Manufacturing Priorities.

His letter was very forceful:

"This Letter of Expectation identifies four key areas which I ask you to prioritise for immediate implementation, so that reforms can be in place before the end of 2022.

These areas are:

Supporting national priorities
Strengthening the National Interest Test (NIT)
Fast tracking implementation of recommendations from the review of the Excellence of the Research for Australia (ERA) and the Engagement and Impact (EI) assessments
Enhanced organisational governance."

Talk about telling the expert how to do her job!

There are several problems with the Minister's instructions. I will just mention two. The first is why should the ARC have to fund medical products when the NHMRC is allocated more funds than the ARC? It just weakens the ARC's funding position. The second problem is that the re-allocation of funds to the Linkage Program will suck funds away from basic research, which should be a core function of the ARC.

The Government should be encouraging researchers to look "outside the box" instead of trying to micromanage our basic research programme.

Education matters

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Education is motivation to continue learning

In this issue, we are continuing a series of interviews that we started in PV 214 and PV 215 with the industry leaders Emma Brand from Origin, and Ishtar Barranco from Chevron. Our next guest, Marina Costelloe from Geoscience Australia, shares her thoughts on what leaders in government institutions expect today from tertiary education in the field of earth sciences.

Marina Costelloe

MP: Marina, may I ask you to introduce yourself to readers, please?

MC: I am currently the Branch Head of the Mineral Systems Branch at Geoscience Australia (GA). I am leading the minerals component of the $225 million Australian Government's Exploring for the Future programme.

I joined GA in 2007 as a Senior Exploration Geophysicist, and have worked in areas as diverse as mineral exploration, groundwater, critical infrastructure, data science and earthquake monitoring, international nuclear monitoring and space weather. I represent the Geology and Geography Cluster on the Board of Science and Technology Australia, and represent Diversity and Inclusion on the Australian Geoscience Council. In 2018, I was the President of the Australian Society of Exploration Geophysics (ASEG), which was a huge honour. I am passionate about diversity, women in STEM and Aboriginal and Torres Strait Islander employment. I have a BSc and a Grad Dip Sci in geology and geophysics from the University of Sydney, and a MSc from James Cook University in Mine Site Rehabilitation (2004).

How did I become a geoscientist? That is a long story, but here is the shortened version.

> *"The resources industry, both private and public sectors, needs talented people coming out of university to help us address big geoscience challenges.... Growing talented geoscientists, physicists, chemists, spatial scientists and coders is important..."*

Growing up, a neighbour used to work in a laboratory (ALS) analysing geological samples and I used to do work experience with him. In Year 12, I worked with a land surveying company during the holidays. The surveyors got annoyed when, at every new work site, I would inspect the rocks and insist on taking some back to the office - they suggested I study geology not land surveying. When I went to university, the subjects that I most enjoyed were maths, physics and geology. I had some excellent lecturers that just kept me really engaged and, of course, there was the promise of adventure and travel. I was very fortunate to get my first job with a company called Geoterrex, where I focused on airborne radiometrics, airborne magnetics and airborne electromagnetics for about eight years during the nineties. I met the most amazing people, I worked across Australia and around the world. The late nineties saw me take a sharp turn into IT - there was not a lot of work in Australia for geophysicists at that time, but the world needed UNIX administrators. Anyway, moving to far north Queensland meant I could get back into geoscience complete a Masters degree in mine site rehabilitation, and start my own small business. During this time I had a son, and then moved to Canberra with my husband who I met at Geoterrex (he is a much better geophysicist than I will ever be).

MP: Marina, is tertiary education keeping up in the current rapidly changing minerals and energy resources landscape. My first two guests, Emma and Ishtar, were from the energy domain and from industry, you are from the mineral resources domain and from a government organisation. What are you looking for when hiring new recruits?

MC: That's a complicated question and I'll do my best to answer it.

There are several pathways into GA from university. One is the graduate programme, which employs around eight early career scientists every second year. There are also fixed-term and ongoing positions advertised when the need arises and resources allow. To help us drive new science, we have established strong links with universities and we have embedded university researchers to help us drive new science. In addition, we partially fund Masters and PhDs from time to time. We also work closely with Cooperative Research Centres, like the MinEx CRC, that bring together industry, government, universities and research organisations.

The resources industry, both private and public sectors, needs talented people coming out of university to help us address big geoscience challenges. Really big global geoscience challenges. Growing talented geoscientists, physicists, chemists, spatial scientists and coders is important for finding better solutions to these complex issues.

Healthy working relationships with universities, industry and other government agencies are vital, as together we are able to undertake excellent research, learn where the gaps are and pivot to where the research is needed. It is a win-win for students and universities, but there's also a win for the government and the broader Australian community, be that industry or the general public, to have high-quality graduates ready to enter the workforce.

Everyone is looking for talented graduates at the cutting edge of engineering, geology, geophysics, geochemistry, geostatistics, data analytics, coding and geospatial science (to name a few specialities). We need this diversity in expertise to work in a very adaptive way to solve some of the big systems issues that we are facing. In a time when we have a buoyant industry those skilled graduates are very hard to come by. I work with an outstanding team of geoscientists in the Mineral Systems Branch at GA, and we work to ensure that Australia will have a supply chain of minerals and critical minerals into the future. We have an exciting work programme, and new opportunities come up with every new project.

MP: What skills are you looking for in recent university graduates?

MC: It's really important to develop fundamental science skills at university. We are also looking for early career scientists to be adaptable and have a growth mindset. Some of the things I ask early career scientists include: What are you willing to learn? What would you like to grow into? What are your interests? What motivates and drives you? I think all sectors are looking for graduates who want to solve important problems and to keep growing throughout their career. There is plenty of room for both the deep domain scientist and the generalist at all academic levels and in a number of scientific disciplines. At the moment it's very hard to find geophysicists in the market place. The skills that physicists or programmers have often fill an important gap, and maybe we need to attract more physicists, mathematicians and coders to geophysics.

Geoscience Australia and the university sector have a very strong working relationship. GA is working on collaborative projects that will help fill future needs, we foster opportunities that help develop the types of skills that students and graduates should have.

Australia needs more geophysicists, geologists and geoscientists and other specialists for example, environmental scientists, geospatial scientists, mathematicians, coders, and the list goes on. Talented graduates with these skills are important for minerals, energy, near surface engineering, environment and other geoscience fields.

"We need people who are motivated by problems that are bigger than what one person can solve, motivated by adaptive challenges. We're looking for the people who really have the motivation to continue learning and be a part of the solution"

We need people who are motivated by problems that are bigger than what one person can solve, motivated by adaptive challenges. We're looking for people who really have a motivation to continue learning and be a part of the solution. We're also attracting people for whom the UN Sustainable Development Goals are important. This is a reflection of how personal values can really drive careers. Geoscientists, more importantly, geophysicists, can really make a difference in the world at the moment. Our early career scientists, as well as those with extensive experience, are highly valued and play a critical role in our work programme a programme that ultimately seeks to make a difference for all Australians.

"Critical minerals are really important and underpin the transition to clean energy, underpin the UN Sustainable Development Goals and underpin environmental social governance."

MP: How do you think the recruitment process itself has changed over the last ten to twenty years?

MC: I think that twenty years ago recruitment was about who you knew, your contacts and your experience. But in recent years, there's been a huge shift towards diversity and inclusion as well as authentic skills-based merit.

There is a huge demand for the types of technical skills that we require. We need to be, I think, creative in marketing our vacancies and the organisation to our prospective staff, or to the people who are looking for a job. It is a competitive market.

People are looking for very, very different things from a job than they were twenty years ago. And we've had to change. People are looking for work life balance. People are looking to do something that aligns with their values, something worthwhile, and something that they can share with their friends and family to show the impact of their work and how it is making a difference to our planet.

The job needs to be more than appealing and well paid. It also needs to have a vision, to be part of something, and to help the community, environment or planet.

The recruitment process has also changed, you don't just recruit somebody for a skill today, you are trying to attract someone that you can work with, who will adapt and grow into a role that is meaningful and successful.

Another change is the interview, from the makeup of the interview panels, to the questions that are asked to blind recruitment - there are checks and balances that make the process more equitable.

There's much more attention to workplace culture. So front and centre of recruitment is diversity and inclusion. You'll often have a diversity and inclusion question during an interview. The response is important. Is the applicant likely to contribute to a healthy workplace environment? Their response can win them the job, or put them lower down the list.

These days, there is also a lot more flexibility in a job. You might be employed as a geophysicist, but you can do a lot of work remotely, you can work flexibly. And working flexibly may mean working four days a week, part time, or job sharing. Parental leave is a right. I think there's a lot of benefits in flexible work arrangements and I know GA's staff really value and appreciate the flexible arrangements that are available to them.

MP: The energy sector is rapidly changing now. The minerals sector also faces significant transformations toward net-zero emission and critical energy minerals challenges. Do we expect revolution or evolution in tertiary education to ensure a smooth transition to what is required from our sectors?

MC: I'm not sure if it's a revolution or evolution. There is already a change in secondary and tertiary education. Attracting students is the bottom line for tertiary institutions. Starting at the secondary school level, and even earlier, is important to attracting students in the geosciences. There is also a change in how society gets information, we're getting much more of our education through media, through the news, or through advertisements, documentaries and social media. We're getting much more information about why the smooth and efficient transition to a clean energy future is happening and the benefits for a sustainable future.

There are also unique scholarships that are being offered to attract students to universities to study in disciplines seen as critical for the future of various sectors of the economy. For example, the Department of Defence recently offered. about 300 scholarships to undertake nuclear related Masters courses. The minerals and energy industry also funds scholarships, to fulfil their particular requirements.

Industry is also putting people through university after identifying talent at high school. They're offering them a package deal, putting them through university either here in Australia or overseas, depending on where the ideal course is being offered, then giving them a job at the end of their studies.

MP: Coming back to the mineral resources sector, does the clean energy transition affect what you are doing and how you are doing it?

MC: We're working on critical minerals here at GA, together with the state and territory geological surveys. We are investigating what critical minerals are found in association with the common minerals that we all know we need. So, for instance, copper. We need more copper to support a low carbon future, to support electric vehicles and other technologies. But what are the companion minerals that accompany copper that are also critical minerals that we need to supply to Australia and the world for the technology used in defence and the technology for wind turbines, electric cars and other clean energy solutions?

So we know we have to find more copper, but we also need these critical companion minerals. What minerals are usually associated with those metals and where do they end up?

Critical minerals are really important and underpin the transition to clean energy, underpin the UN Sustainable Development Goals and underpin environmental social governance.

"Digitalisation of the sector is what will drive the change. This is where we will find efficiencies. This is how we will be environmentally sustainable. Digital technologies are fundamentally changing how businesses and people work together."

The other thing we've got to think about is supporting minerals exploration in Australia. Investors are becoming environmentally conscious and they choose to invest in the infrastructure, exploration or mines that do undertake sustainable development, with the environment foremost in mind. Australia is well placed to continue to develop a sustainable mineral resources sector. One of the things that we're doing in Australia is looking at secondary prospectivity. That is, assessing mine waste piles and tailings and undertaking or supporting research into how we can utilise those neglected resources.

MP: That brings us to my next question. What role does digitalisation play in the clean energy transition? What kind of education is required to guarantee efficient digitalisation of the sector?

MC: This is the step change that we've been waiting for. We see more and more students and early career people who have high levels of programming skills. We're collecting smarter data, faster data, higher standards of data and data that is more readily accessible than ever before. We now have ready access to high-performance computers that can work with vast amounts of data. There are open-source artificial intelligence and machine learning algorithms. More and more new discoveries will be underpinned by excellent data and AI. Digitalisation of the sector is what will drive the change. This is where we will find efficiencies. This is how we will be environmentally sustainable. Digital technologies are fundamentally changing how businesses and people work together.

The pace of change is extraordinary. What you thought you couldn't do three months ago, not only you can do now - it's open source. It's redefining our traditional industry job profiles.

MP: How do talented early career scientists operate in the system? Do these people progress on their own? Or is guidance important? Sometimes these people would like to go their own way.

As an organisation, a research team, or a professional society, we need to motivate and excite everyone, and early career scientists are no exception. I suggest they seek a mentor, somebody who can help grow their talents, leadership skills, communication skills, and perhaps their programming skills. They also need to be mentored by somebody who can help them grow as a contributor to the organisation that they're working for. Early career people have so many skills that we want to grow and nurture.

MP: Marina, my last question is what kind of specialists are required to pursue the clean energy economy in Australia?

MC: This is a really good question, because we're looking at sustainable energy and sustainable infrastructure. For example, hydrogen is one of those future sustainable energy sources. So, the specialist group skills that we are looking for are a blend of traditional academic skills, and training in system-based thinking. How do the downstream and upstream sectors work together? How is hydrogen produced? How much do we need? What infrastructure do we need and where do we store it? Where are the markets? As well as the engineering side of things. How do we build? How do we drill? How do we store?

Driving a low carbon economy will require specialists who have advanced analytical skills. Particularly when it comes to optimisation of complex systems in finding environmentally friendly solutions. We will be relying more and more on geospatial solutions too.

It is an exciting time to be a geophysicist!

MP: Thank you so much for your time and interesting insights.

Environmental geophysics

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Welcome readers to this issue's column on geophysics applied to the environment. About three months ago I was contacted by Niels Christensen of Aarhus University fame, and one of the founders of the Hydrogeophysics Group at Aarhus. As part of a potential book idea, Niels had put together some reminiscences about his life that he called "Seven Scenes" – seven chapters in his life that shaped him as a geophysicist (and a person?). Unfortunately the book did not eventuate, so Niels looked to publish his memoirs elsewhere - and *Preview* came to mind. I really enjoyed the first two scenes (all I have seen so far), and thought it would be great to get them out for others to enjoy. My thanks to Niels for thinking of us! In this issue we start with a brief introduction from Niels followed by the first scene.

For those who don't know Niels, he is Professor Emeritus in geophysics at the Department of Geosciences, University of Aarhus. He works mainly with electrical and electromagnetic methods, especially their application to hydrogeophysics and other near-surface problems. His main interests are inversion of AEM data, fast approximate 1D and 2D inversion procedures, and the derivation of attributes from the inversion results that can assist interpreters. He is a resident and frequent visitor of Australia, and has been collaborating with CSIRO and Geoscience Australia.

Over to Niels…

Pivotal moments: Seven scenes from a geophysics adventure

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Introduction

During the period ~1980-2000, at the Department of Geoscience, Aarhus University, near-surface geophysics took a great leap forward with the development of several new electromagnetic methods, new instrumentation, novel field practices, and new inversion possibilities. All this happened through a unique combination of the right people at the right time, an explosive development in electronics and computer capacity, and a perceived need for mapping and monitoring groundwater resources. The development was characterised by a combination of research, teaching, practical inventiveness, and collaboration with local and regional administrative bodies who were willing to take chances by financially supporting new developments under the guarantee that, in case of failure, the work would be done in traditional ways.

Around the turn of the century, the successes brought about by the new possibilities - and, again, the right people at the national administrative and political level - inspired a political decision to start a national programme of mapping all the most important water resources in Denmark, a programme of unprecedented depth and scope when compared with other countries. Around this time, the HydroGeophysics Group was formed at Aarhus University to support and oversee the enormous mapping efforts to be conducted by the consulting companies who had adopted the new methods and approaches. The programme went on for 15 years and is now more or less brought to its conclusion.

The legacy of the national programme is a HydroGeophysics Group that from its first efforts has risen to become among the best and most respected research groups in the world for electromagnetic methods, IP and SNMR, and a nation that has the best possible basis for a sustainable use of its water resources.

It was my privilege to be a part of this development in its heyday, and below are some musings from a geophysical professional career.

Scene 1: The beginning: Berkeley 1987

… in which our protagonist goes to sunny California and comes home with new ideas.

It's a beautiful walk from the bus stop where I get off through the campus of University of California, Berkeley: well-kept green lawns and imposing university buildings each in its own style. I'm going to the Hearst Memorial Mining Building situated at the upper part of campus. It's not particularly big, but when you enter through the big heavy front doors, you arrive in an enormous entry hall that stretches from floor to ceiling through the entire building with imposing broad staircases spiralling along the outer walls; everything (I learned later) in the most beautiful Beaux-Art style.

As with most of the university buildings it is a donation, in this case from Phoebe Apperson Hearst, widow of senator and mine magnate George Hearst. It is my first day at University of California in Berkeley. I have received a grant from the Danish Natural Science Research Council, and four months lie ahead of me in sunny California!

On the second floor I find the geophysics section and I'm received by Professor Frank Morrison. Some months earlier, I had the audacity to write and ask if I could visit his department for some months. I did not know him beforehand,

and he certainly did not know me, I just knew it was one of the hottest places to learn. So there he was, Frank Morrison, suave, with his wavy hair, a touch of gray at the temples, like a movie star from the forties with a big smile and a spark in his eye. He took me under his wing and showed me around: "And here is the office and our secretary (I just caught a glimpse of a small personal computer in the corner with a student in front of it, and I was very impressed), and here is Ki Ha Lee (as taken out of a samurai movie by Kurosawa) and here is Carlos Torres Verdin. You will share an office with him". How lucky I was with that I found out later. "And here are some of the students: David Alumbaugh, Mike Wilt, Guimin Liu, Mike Hoversten". A big mouthful on my first day and an even bigger one later when I found out that I had just skipped a few grades and moved up into a different league.

My intention with going to Berkeley was to learn more about the Audio-Magnetotelluric Method with a controlled source (CSAMT). Until the beginning of the 1980s, DC geoelectrical soundings were by far the most frequently used electric/electromagnetic method in Denmark. However, the productivity of the method was limited: three people could do 6-8 soundings per day, and there were serious limitations in the depth of investigation and considerable uncertainties in the resolution of the subsurface resistivity, shortcomings in the form of equivalences characteristic for the method.

In the early 1980s, we developed the so-called AC-geoelectrical method at our department. The idea was to send an alternating current through the current electrodes at a series of frequencies instead of a direct current thereby achieving not only galvanic (as for the traditional DC method) but also inductive information. The combination of the two would make it possible to resolve some of the equivalences which plagued the DC geoelectrical methods, and we also had the intention to increase the depth of investigation. Due to high resistivity equivalence, the traditional DC geoelectrical method had severe limitations in resolving the thickness of layers of dry sand above the groundwater table. This was a very important parameter for the mapping of raw materials, which played a prominent role in the 1980s, and also in connection with hydrogeophysical investigations where the depth to the groundwater was of primary importance. In addition, we assumed that the addition of an inductive contribution to the response would permit the AC method to look deeper into the ground, at least if good conductors were present, such as the well conducting Tertiary clay which often formed the bottom of the aquifers in Eastern Jutland, Denmark. Initially, there were of course a lot of difficulties to be overcome with this new instrument, but by and large, it fulfilled our expectations. The instrument was developed by Kurt Sørensen (surprise!) together with our electronics engineer, Niels Breiner, and the rest of the electronics lab team, and it was the first computer-controlled instrument developed at our department, programmed by Frederik Husted Andersen. I wrote the software for inversion of the sounding data and developed an optimal field procedure.

However, after some time, it became clear that although the AC method produced data with better information than the traditional method and improved the obtainable subsurface resolution, the productivity was even lower than for the traditional DC method -the daily production was only about four soundings – and eventually that became the final nail in the coffin for the AC-geoelectrical method.

But then what? At that time, the local Aarhus County was responsible for mapping raw material and ground water resources, and over a number of years it had become quite clear that dense measurements over extended areas made not only a quantitative, but also a qualitative difference: it permitted a much more reliable interpretation of the near-surface geology and a better insight into the processes of its formation. It became a credo for our activities, first formulated by Verner Søndergaard: Measure densely over large areas! This was the background for my wishing to learn more about the CSAMT method, which might have the potential to improve productivity, in particular with respect to mapping of deep aquifers.

In Berkeley, I was, however, presented with the transient electromagnetic method. I knew very little about the method, but soon found it very fascinating. It is an inductive method and thereby good at resolving the presence of good conductors like clay and saltwater-carrying sediments, and a depth of investigation of 100-150 m was achievable with a central loop configuration on the surface of only

40 x 40 m. It all sounded very promising. I spent the next months with pencil and paper and programming, trying to understand the basic physics.

With regard to computer power and graphic visualisations, 1987 is a long time ago, and we have almost forgotten how it was – not to mention the incredulous faces of young people when you tell them about it! At that time, typically we had a non-graphical terminal connected to a mainframe computer that serviced a large number of people. Printing was on the old line printers with broad paper rolls and no graphics options, plotters did not exist, and graphics were handmade. The small Apple computer in the corner of the office was regarded with awe and you had to sign up for a time slot to get to use it. And imagine - it was possible to write real mathematical formulas on it!! Fantastic!! So, I did what everyone else did at that time: sat down with paper and pencil. In particular I was very interested in understanding the way current diffused downwards and outwards in the ground. That was the key to understanding the assets and drawbacks of the method. I calculated analytic approximations for the current in the ground, valid at early and late times, and produced computer programs that could print the values on the wide paper sheets. Subsequently I contoured the values by hand and made my first colour graphics illustrations using crayons. Below (Figure 1) you can see an example scanned from the original hand colouring from 1987.

To me, Berkeley became a pivotal time where my future – and eventually that of many other people - took a new direction. After the four months in Berkeley I arrived home with new excitement and new insights: We had to get a transient instrument! I exhibited the hand-coloured plots in our canteen and talked lengthily and with fervour about the transient method. And just as importantly, I came home with a much wider horizon and - with a word that did not exist at that time - a large network in the US. My world had become much larger and I enjoyed beautiful California immensely. Later, a PhD student of mine, Esben Auken, went to Berkeley for six months during his PhD and came home with the same exhilaration and excitement!

But how would we manage to get an instrument? It cost a quarter of a million Danish kroner and that was a huge sum at that point in time.

To be continued...

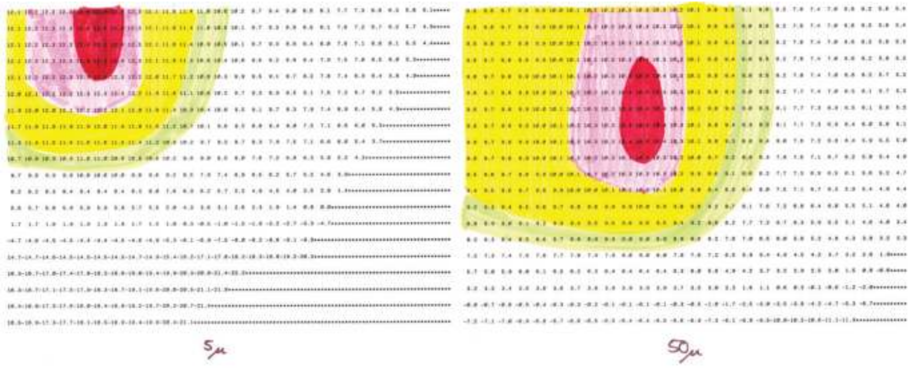
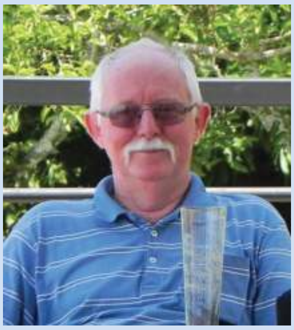


Figure 1. *Left: Subsurface current density at 5 µs. Right: Subsurface current density at 50 µs. The source is a vertical magnetic dipole on the surface. The plot frames show only half of the image. The lateral zero is the left vertical edge. The horizontal axis is logarithmic so that more distance could be covered in one plot; therefore, the somewhat distorted shape compared with linear plots.*

Minerals geophysics



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Hard rock seismics

The application of the seismic method to hard rock mineral exploration is a developing field, and *Preview* Petroleum geophysics Associate Editor Michael Micenko has devoted two recent articles to it (see *Seismic Window* in *Preview* Issues 210 and 213). Mineral exploration geophysics has benefited greatly from experience gained in oil and gas exploration geophysics, and the seismic method is definitely the domain of oil and gas exploration. But this experience has been almost entirely gained in sub-horizontally layered soft rock environments. Here I look at some aspects of seismics from a hard rock mineral exploration perspective.

The seismic method utilises boundaries between rocks of contrasting acoustic impedance (**acoustic impedance = seismic velocity x density**). The reflection seismic method has resolution at depth superior to the other geophysical techniques used in mineral exploration, has excellent depth penetration, and offers the opportunity to characterise hitherto unused rock properties *in situ*. Furthermore, metallic mineralisation and altered rock types can exhibit strong acoustic impedance contrasts with country rock. However, hard rock environments, typically those with steeply dipping (75^0-90^0) irregular boundaries and disruptive structures, can be far more complex and disordered than the layered earth environments commonly encountered in soft-rock exploration. It is these steeply dipping features which pose particular challenges to the seismic method.

To me, there appear to be two aspects to the problem of steeply dipping features – imaging and recognition.

Imaging: Vertical layers and boundaries cannot be imaged directly by conventional, straight wave-path reflection seismics. With the energy source and the geophone receivers all located on a level ground surface, it's just not possible - it is simply a matter of geometry (see Figure 1). Unless survey procedures and arrays are specially adapted, this non-imaging problem effectively applies to steeply dipping layers and boundaries too. The dip of layers and boundaries that can be directly detected can be expanded by displacing the geophone array in the down dip direction, but there are practical limitations to how far this can be taken. Also, as dip angles increase, azimuthal direction effects increase, implying that 3D arrays are essential for complex hard rock environments.

Recognition: Oil and gas exploration seismic section patterns typically comprise pervasive sub-horizontal reflectors mapping out the layered, relatively flat-lying stratigraphy. Steeply dipping structures are then inferred by tracing out the disruptions, dislocations and truncations of these sub-horizontal reflectors. When most of these reflectors are absent, as is often the case in hard rock environments, recognition and tracing of sub-vertical structures is not possible.

The end result of these factors is that sub-vertical reflectors will not normally be present in the seismic results. And in a complex hard rock, non-layered environment, in the absence of extensive sub-horizontal reflectors, inferring the presence of any sub-vertical structures will be that much more difficult. This disparity can bias the interpretation.

The question then is, short of acceptance of this limitation and putting it in the 'too hard basket', or restricting hard rock seismic surveys to environments where layering is to be expected, what can be done to address this?

From an interpretation viewpoint, a change of mind-set is needed to acknowledge that an apparent paucity of sub-vertical structures in a seismic section may merely be a function of limitations in the seismic method itself. Perhaps we need to be open to accepting subtler evidence for such structures. We could also draw on the considerable effort that has gone into interpreting the steep dip environments associated with salt tectonics and diapirism, and the work the oil and gas industry is doing on recognition and significance of different seismic textures. Steeply dipping boundaries between regions of different rock types may manifest as contrasts in styles of seismic textures, and thus be mapped.

From an acquisition viewpoint, the survey array needs to be expanded into the third dimension, with some geophones or shot points located at depth below the ground surface, and with the survey procedures and processing regimes modified accordingly. Given that many hard rock seismic surveys are carried out at mine sites, with the option to position geophone strings in boreholes or mine openings, this is not as far-fetched as it sounds. Specialist seismic survey companies are already working on this.

As I wrote at the beginning, this is a very basic look at hard rock seismics. The method is far, far more sophisticated than a mere mapping of reflectors. Would I consider using 3D seismics? Absolutely! But I'd make sure that everyone involved was fully aware of the difficulties that steeply dipping boundaries in non-layered, complex and disordered hard rock environments can pose.

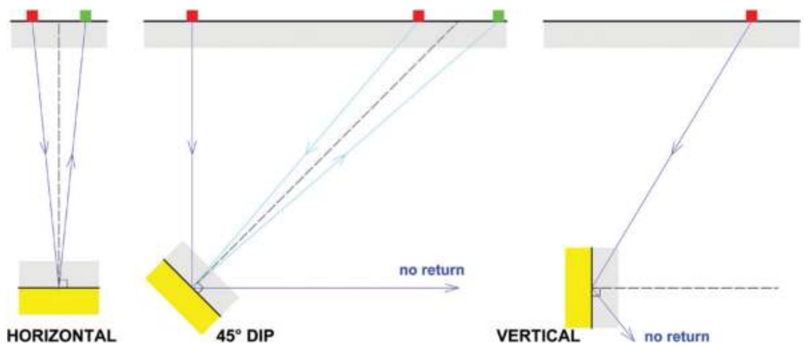

Figure 1. *Sample wave-paths for horizontal, dipping and vertical boundaries.*

Seismic window

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Inversion and HMPA

This article is about two techniques that were brought to my attention while I was networking late last year in two completely different venues. The first was at a traditional event with a few beers after work, while the second was in a modern but less fun venue called "LinkedIn". I have always found networking to be an important aspect of keeping abreast with technology and trends, and even though LinkedIn has no physical networking it still manages to disseminate ideas.

Inversion for compressibility

The first technique is to calculate rock properties such as compressibility using seismic inversion. Compressibility is the relative change in rock volume in response to a pressure change. It is a useful rock property and can be used to:

- estimate changes in pore volume as reservoir pressure declines with production
- to distinguish between low porosity and high porosity rocks
- identify gas filled sands

Seismic amplitudes only contain information on P velocity, S velocity, density and anisotropy, but other attributes can be derived once the P and S velocities and density are known. Seismic inversion has come a long way since I first encountered it in the 1980s. Back then it was a post stack process and the deliverable was a pseudo-seismic impedance log at each trace. We thought it was the bee's knees. But there was more information to be extracted and simultaneous inversion using pre-stack data, which has been around for several years, could produce both the P velocity and S velocity and in some cases density. Once these attributes are known, the Lame's parameters (λ and μ) can be calculated. Then, any of the rock properties shown Table 1 can be obtained. At last year's networking function I learnt that pre-stack inversion can output compressibility directly, thereby saving computer time and two-three weeks in the interpretation cycle. Another advantage is that the derived products are three times more sensitive to changes compared to AVO products such as V_P/V_S. But, perhaps the most benefit is obtained by providing engineers data in a form with which they are familiar – physical rock properties rather than geophysical conveniences.

Table 1. Relationships among elastic constants in an isotropic material (from Mavko *et al.* 1998). From left to right Bulk Modulus (reciprocal of compressibility), Young's Modulus, incompressibility, Poisson's ratio, P wave modulus, shear modulus.

K	E	λ	ν	M	μ
$\lambda + 2\mu/3$	$\mu\frac{3\lambda+2\mu}{\lambda+\mu}$	—	$\frac{\lambda}{2(\lambda+\mu)}$	$\lambda + 2\mu$	—
—	$9K\frac{K-\lambda}{3K-\lambda}$	—	$\frac{\lambda}{3K-\lambda}$	$3K - 2\lambda$	$3(K-\lambda)/2$
—	$\frac{9K\mu}{3K+\mu}$	$K - 2\mu/3$	$\frac{3K-2\mu}{2(3K+\mu)}$	$K + 4\mu/3$	—
$\frac{E\mu}{3(3\mu-E)}$	—	$\mu\frac{E-2\mu}{(3\mu-E)}$	$E/(2\mu) - 1$	$\mu\frac{4\mu-E}{3\mu-E}$	—
—	—	$3K\frac{3K-E}{9K-E}$	$\frac{3K-E}{6K}$	$3K\frac{3K+E}{9K-E}$	$\frac{3KE}{9K-E}$
$\lambda\frac{1+\nu}{3\nu}$	$\lambda\frac{(1+\nu)(1-2\nu)}{\nu}$	—	—	$\lambda\frac{1-\nu}{\nu}$	$\lambda\frac{1-2\nu}{2\nu}$
$\mu\frac{2(1+\nu)}{3(1-2\nu)}$	$2\mu(1+\nu)$	$\mu\frac{2\nu}{1-2\nu}$	—	$\mu\frac{2-2\nu}{1-2\nu}$	—
—	$3K(1-2\nu)$	$3K\frac{\nu}{1+\nu}$	—	$3K\frac{1-\nu}{1+\nu}$	$3K\frac{1-2\nu}{2+2\nu}$
$\frac{E}{3(1-2\nu)}$	—	$\frac{E\nu}{(1+\nu)(1-2\nu)}$	—	$\frac{E(1-\nu)}{(1+\nu)(1-2\nu)}$	$\frac{E}{2+2\nu}$
$M - \frac{4}{3}\mu$	—	$M - 2\mu$	$\frac{M-2\mu}{2(M-\mu)}$	—	—

HMPA (Hydrocarbon Modulated Pulse Analysis)

I noticed this technology on LinkedIn and thought I'd dive in and try to understand it. HMPA is interesting for two reasons – first, it claims to respond best to the thickest oil saturated reservoir section, which would make it an extremely useful tool and second, its description lacks any useful information. This potentially useful tool is described only as measuring "specific electrical signatures created when hydrocarbon energy is converted to electrical energy through a complex series of chemical processes at reservoir depth". That's a lot of words, but it tells me nothing except perhaps that the reservoir is behaving like a battery. The promoters of the technique claim there is no response to gas, but oil and water have a distinct but different signal. They describe HMPA as a black box technology, which means the workings are secret, or they don't know why it works.

Maybe it does work as advertised, but for now it's well and truly placed in my "funny methods" file. Figure 1 shows an example HMPA map showing a linear, channel like anomaly with dry holes at the edge and a discovery well in the centre of a feature.

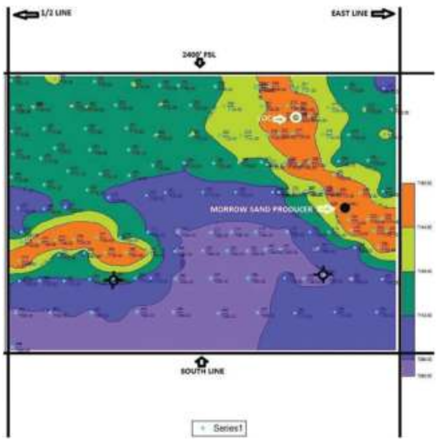

Figure 1. *Example HMPA map showing a linear anomaly interpreted as a channel with dry holes outside the feature and production well in the centre. HMPA is an electrical technology that does not identify structure it identifies oil reservoirs at depth.*

Reference

Mavko, G., Mukerji, T., and Dvorkin, J., 1998. *The Rock Physics Handbook*. Cambridge University Press.

Data trends

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Visualisation trends

In 1993, ID Software founder John Carmack revolutionised 3D computer games by working out how to display pictures fast in 3D. That made him rich, but he became richer by allowing customers to modify the game code. Companies could license his game engine and get on with their own ideas, instead of reinventing the game display engine.

Today explorers want a program that lets them display the results from all other programs in one place, and GIS appears to be the chosen one - no doubt in part by allowing users to add functions with the Python and C# programming languages.

After dominating environmental, military and infrastructure mapping worldwide, the GIS players are making 3D the default in datasets. To paraphrase a recent plugin demonstration, such programs make it easy to bring big and very different datasets into the one setting, from obscure local council maps to 3D drilling models skinned with (displaying) the core photography (https://youtu.be/tj-IWFMcj54?list = PLD0bNzH8b-H1HnjckeM3HTuQf7WJewpXL).

Enormous libraries attached to some GIS software allows users access to the same functionality as computational physics, chemistry and AI. A single point of viewing combining exploration with scientific computing. As such, Geosoft and Profile Analyst now offer commercial GIS plugins, and Intrepid can be called from Python.

However, it is not all over yet. Computer game engines are sophisticated interactive software with sophisticated physics functions, and augmented and virtual reality are standard. They deal with multi-resolution data quickly, and are concerned with how to best allow people to interact with 3D models. Aerometrex offer a plugin for the Unreal Game Engine (https://aerometrex.com.au/resources/blog/photogrammetry-game-engines-and-geospatial-industry/) and ESRI offer direct export to the DATASMITH Unreal file format (https://doc.arcgis.com/en/cityengine/latest/help/help-export-unreal.htm).

Could one industry swallow the other? Hexagon Geospatial appears to have annual income similar to the Electronic Arts (EA) game company. Call it a draw for now, but will graphics cards make a difference?

GPUs (Graphics Processing Units) are video hardware accelerators that evolved with computer games to become the fastest crunchers of math, physics and AI operations in your computer. Nvidia is the best known GPU maker, and boast accelerating seismic processing and fault detection for Shell by 40% (https://blogs.nvidia.com/blog/2017/03/15/transforming-oil-and-gas-industry/). They want to buy ARM, who make most mobile device chips, and particularly Google's Tensor chip dedicated to machine learning in mobile phones. There could be a lot of scientific programming packed into your graphics cards in the near future.

Game engines are free, designed around GPUs and compile for computers, phones and tablets, running Windows, Linux or Mac. The workflow for GeoVReality from the University of the Chinese Academy of Science (Figure 1) demonstrates the current complicated pipeline for getting a dynamic geology model to your Oculus Rift VR goggles (https://par.nsf.gov/servlets/purl/10253876). That could quickly reduce to a plugin requiring only your graphics card to turn data into a model.

I will be interested to see which 3D formats will dominate an age in which explorers will expect more accessible 3D, AR and VR.

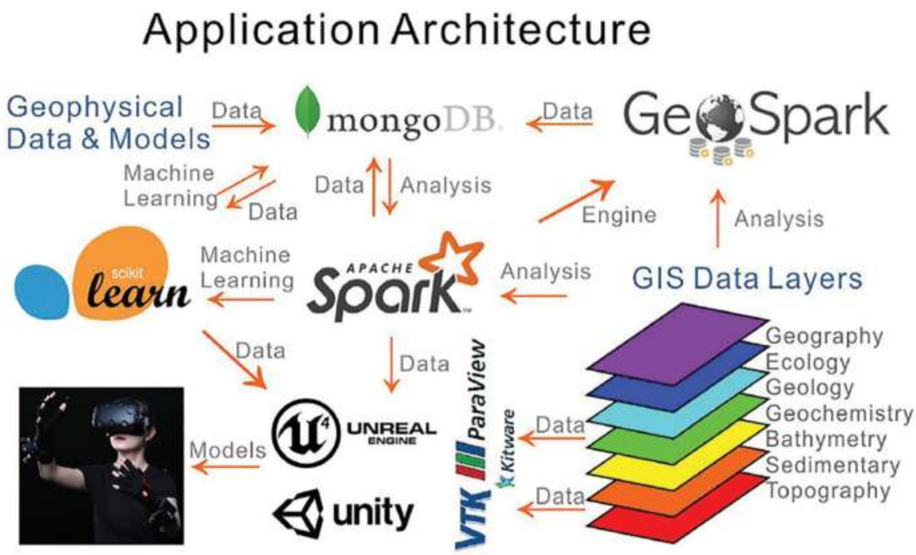

Figure 1. *Application architecture flow chart of the GeoVReality project at the University of the Chinese Academy of Science.*

Choosing a cloud database solution for managing AEM survey datasets

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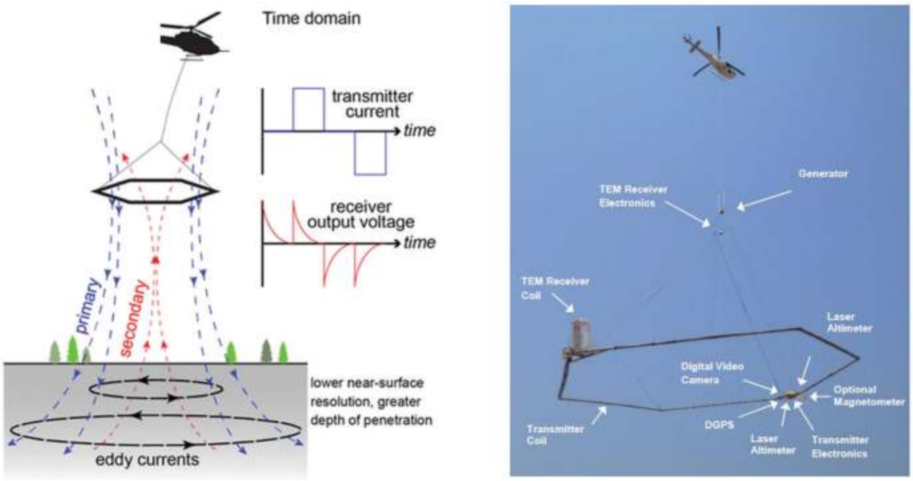

Figure 1. *Collecting AEM data (from https://www.hgiworld.com/methods/airborne-electromagnetic-method-for-large-scale-geophysical-characterization-aem/)*

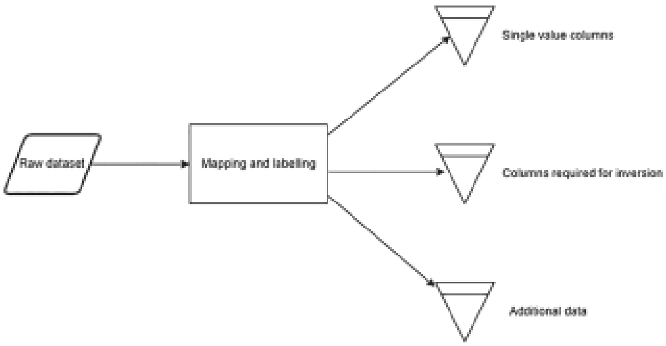

Figure 2. *Processing AEM data*

Airborne electromagnetics (AEM) is a method used for mineral exploration around the world, and is popular for its non-invasive nature and ability to provide extensive ground coverage (Figure 1). This popularity has led to a fair bit of investment over the years, and created competing AEM systems. This means AEM datasets can originate from a variety of systems, use different naming conventions, different domains (time/ frequency) etc. This can make running inversion algorithms and storing datasets at different stages of their lifecycles challenging.

To meet this challenge, and to be able to process datasets coming from most AEM systems, we can add additional steps to define the system and process the raw dataset. This will enable us to come up with a uniformed structured format for the data, but will also mean that we might have some leftovers from the processing that don't completely fit in with the format. We may want to keep these leftovers around for future use. In theory this data will be available in the raw dataset files anyway (as we should keep the old copy), but is much more valuable and interpretable when it is associated with metadata – context and labels to provide additional insight. So, instead of discarding columns that we feel may not be required for the specific inversion we are running, we should allow the user to edit labels and add information before storing the entire dataset.

This leads us to datasets without a fixed number of columns. Also, row consistency may be impacted as data may not be available for all the rows. We can prompt the user to rethink their input if this is done for required fields, but the same isn't true for optional ones. In some cases, we may even want to store single pieces of information about the dataset, which would be just one value instead of being an entire column (Figure 2).

There are some options to consider. We can have multiple tables for datasets – one for single values, one for the required columns and another for any additional data. We can even make all of them SQL, using dynamic columns for additional data so that we can accommodate any number of columns. If we want to consider efficiency, a multi-table approach may be better than having one dynamic table with nulls for missing values – given that most queries will be to retrieve required columns anyway. Or, we could look for a NoSQL solution.

With NoSQL we can create documents without declaring the structure upfront. While writing data, we can put checks in place to verify we have the required number of columns, but beyond that we will have full flexibility with our dataset. Also, if the purpose of storing these datasets is to run inversion algorithms in future, we do not really need cross dataset querying capability. Single key value pair retrieval is competitively fast. Presumably we will write the dataset once and there will be minimal modifications – as most have been done in the processing stage anyway. This allows us to afford a BASE consistency model instead of a more mutation friendly ACID model.

Another important but decisive advantage NoSQL databases provide is the ability to scale horizontally. (Figure 3) Each object is self-contained and independent – as they are not structured like an SQL database. So, they can be stored on multiple servers without being

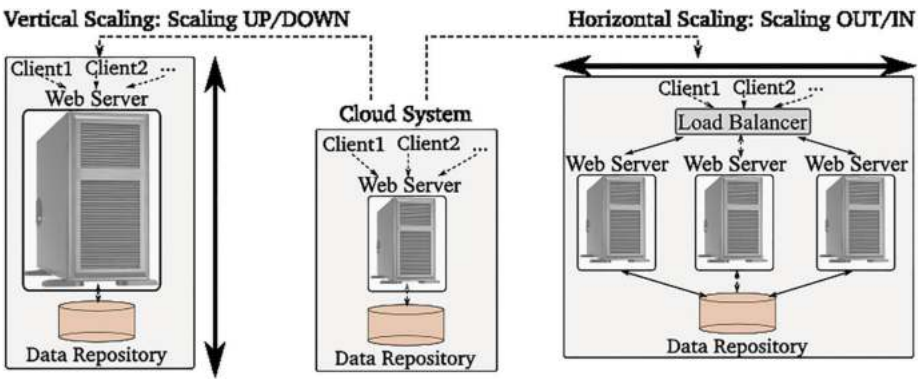

Figure 3. *Vertical vs Horizontal Scaling (from https://www.researchgate.net/figure/Vertical-Vs-Horizontal-scaling_fig3_293799134)*

linked. Hence when we have more data, we can just add more resources and scale based on our needs. Particularly considering the size of AEM datasets and more favourable billing outcomes with horizontal scaling on cloud – this can present an ideal solution. Also, a lot of cloud NoSQL database offerings come with some desirable SQL features – for example, DynamoDB from AWS having ACID-compliant transaction facility.

Now that we have picked NoSQL as our database of choice, we need to pick a cloud vendor and implementation for it. Or maybe we can pick a solution that can be supported on multiple cloud platforms? This process is far more painful and will require more compromise than if we just pick a cloud vendor and run with it. But there are some noticeable benefits.

Making a pluggable software solution can avoid vendor lock-in. In the case of building a processing toolkit that users utilise online, one with large datasets and long running algorithms, being locked into a single cloud vendor for life means losing out on important bargaining power. As the number of users scale and the cloud bill becomes bigger, having the ability to move to another cloud vendor can facilitate shopping around and reduce bills significantly. Cloud providers will certainly have different specialisations, quality, and pricing models (Figure 4). Depending on usage some may provide more benefits over the others, benefits that may not become very apparent before users start to scale.

In that case we can deploy our own NoSQL database in a Kubernetes cluster and use a NoSQL database image of our choice (for example, MongoDB or Cassandra). All cloud providers will have options for a flavour of Kubernetes,

Discounted Pricing For 1-Year Commitment With No Upfront Cost

Instance Type	AWS	Azure	Google	AWS pricing (per hour)	Azure Pricing (per hour)	Google pricing (per hour)
General purpose	m6g.xlarge	B4MS	e2-standard-4	$0.097	$0.0974	$0.0137
Compute optimized	c6g.xlarge	F4s v2	c2-standard-4	$0.086	$0.10	$0.0214
Memory optimized	r6g.xlarge	E4a v4	m1-ultramem-40	$0.127	$0.1482	$0.0205
Accelerated computing	p2.xlarge	NC4as T4 v3	a2-highcpu-1g	$0.614	$0.3093	$2.313

SIMFORM

Figure 4. *Pricing can differ across platforms depending on need (from https://www.simform.com/blog/compute-pricing-comparison-aws-azure-googlecloud/)*

and we can take full advantage of that. However, this requires a lot more engineering effort with set-up and maintenance – particularly compared with using a managed multi-cloud database solution like MongoDB Atlas or Astra DB. But, if the objective is to reduce engineering overheads, multi-cloud may not be a great idea as it will make the solution complex, and migrating from one cloud platform to another a challenge.

In that case, we can look at the native offerings from different cloud providers. AWS, Google Cloud and Azure are evaluated as they have majority of the market share in Australia and overseas (Figure 5), and when people generally talk about picking up cloud solutions the discussions mainly focus on one of these three.

For AWS, DynamoDB will be the top NoSQL candidate. It is fully managed, has a generous free tier, and will certainly cover development without costing much. It is designed to run high-performance applications at any scale and even have some characteristics of SQL databases, like being ACID complaint. Another option is Amazon DocumentDB. This is a MongoDB compatible database, purpose built for JSON data management. If you already have data in mongo that you wish to migrate to AWS directly, this can be a viable option. This also results in a low vendor lock-in, you can basically take your application and plug it with a MongoDB database hosted anywhere without much effort. However, if there are data sovereignty concerns (for example, data must be hosted in the Australian region) DynamoDB is more flexible as it is available in all regions, while DocumentDB, for now at least, is only available in a small range of regions. Also, DynamoDB scales better, with no limit on table size, while DynamoDB has an instance size limit (but it's still generous). So, if vendor lock-in can be fully embraced without any fear, DynamoDB is the way to go.

Google Cloud has an interesting range of choices. Whenever a conversation about NoSQL databases in Google Cloud comes up, Firestore ends to take a front seat. It is widely popularised by mobile application developers, and

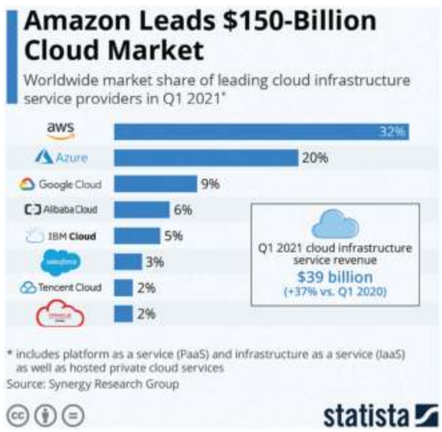

Figure 5. *AWS currently dominates the cloud market (from https://www.statista.com/chart/18819/worldwide-market-share-of-leading-cloud-infrastructure-service-providers/)*

useful to set-up proof-of-concept front ends very quickly, but comes with its own bag of problems that can make it unsuitable for storing AEM datasets. There are no backups, data duplication is an issue, no fixed latency (can be very high sometimes), and inadequate billing transparency amongst a range of other factors - none of which make it ideal for a production backend. However, there is Google Cloud Bigtable – a cloud native NoSQL wide-column store for large scale low-latency workloads that can fit well with AEM datasets. If we want insight from our data, it can also be plugged into BigQuery. However, there is an hourly minimum price limit – which means there will be mandatory minimum costs during exploration and development.

If we want to stay in Google Cloud but create a low vendor lock-in, kind of like DocumentDB in AWS, our best option would be MongoDB Atlas. This offering is from MongoDB and can be used in any cloud platform. This is an additional NoSQL database provided through Google Cloud Partner Services and comes with a free tier that can be utilised for testing out the service and development. It also supports AWS and Azure apart from Google Cloud, making migration for us much easier.

Azure has Cosmos DB on offer from the NoSQL range. Cosmos DB takes pride in fast read and write times, with single digit millisecond response time and 99.999 percent availability. As with AEM datasets we are mainly concerned with read and writes to the database, this can be a very fast and reliable option. Testing and development can also be free, which will keep it in front of many managed database solutions.

Azure also has a managed instance option for Cassandra, a very popular database. However, this tool may be too grand for the task at hand unless you have your own data centres and want to approach a hybrid on-prem and cloud strategy. In the hindsight this would be a no vendor lock-in option, and might usefully be considered for a very large platform with thousands of AEM datasets.

Just picking up a cloud vendor doesn't solve all our problems; we still must think about database tenancy options. For example, will all the databases from all the users stay in the same database table? Or should we have separate tables for each user? Should datasets belonging to the same user stay in the same table? Should this be the case even if we do not need to query across datasets, let alone query datasets across users?

These concerns prompt questions about possible needs and benefits. Having a database per user makes accidental data sharing across users impossible, this is useful as AEM data collection is a difficult task and there can be IP issues around data. Yes, it slows down engineering and requires a bit more skill and thoughtfulness to implement. But, for a sustainable product, security makes sense. Also, there is not a compelling need to make the datasets share a database.

After we split the database by user, the next question would be about how we store multiple datasets from the same user. When we are processing the data, running an inversion algorithm or wanting to map results, the processing stream is generally being set up with a specific dataset in mind. There isn't a big need to run queries or do analysis across all datasets. Considering how big a dataset can be, storing several in the same table can lead to having massive documents without reaping significant benefits. We could think about partitioning, or we could simply have a table per dataset. In NoSQL terms, that will be just a new document every time a dataset gets created. We will have smaller, succinct documents and read writes would be much faster. We can also achieve dataset isolation this way, and modifying existing documents becomes very infrequent.

At the end of the day, it will boil down to how much time and resources you want to spend on developing and maintaining a database solution. Deploying a NoSQL database on a Kubernetes cluster, achieving database multi-tenancy and a table per dataset, will require significant resource allocation. If you want to cut down on resources, the first thing to look at will be replacing the Kubernetes solution with a managed database - something like MongoDB atlas, managed Cassandra or DocumentDB. This will enable you to achieve low cloud vendor lock-in without breaking your back on engineering. If there is significant in-house knowledge about a particular cloud platform, most other resources already on the same cloud and there is little organisational incentive to switch cloud platforms/have multi-cloud solutions now or in near future, you could even go for a fully managed and integrated cloud database solution offered by one of the cloud platforms. This will keep the solution in the engineering comfort zone, while freeing up more resources to be used on the implementation of the database tables and applications.

Choosing a database solution for cloud applications presents a variety of options, all with their own pros and cons. It is important to evaluate organisational capability and product needs before making any decision. My personal pick of a solution for AEM datasets would be a NoSQL managed offering from one of the cloud platforms, but hey, the world is your oyster.

Shouv Sarker is a software engineer by training, and a passionate advocate of functional programming practices. He is currently working in the Mineral Resources team at CSIRO on an exploration and geophysical processing toolkit to assist with the interpretation and inversion of geophysical survey data. When he takes his programmer hat off, Shouv likes to write fiction, and get more screen time with video games

Webwaves

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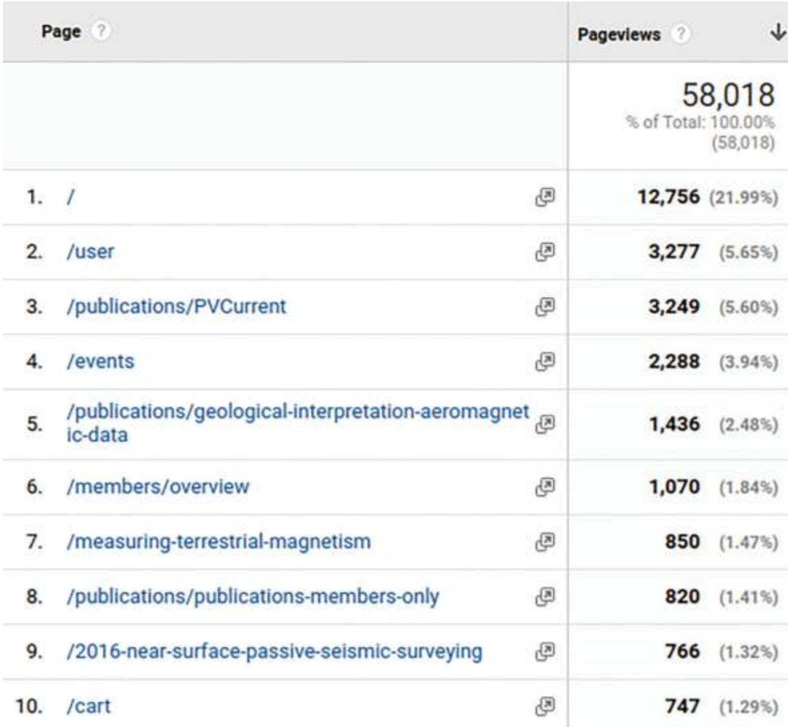
2021 in review: The ASEG website

In 2021, there continued to be additional virtual offerings from the ASEG due to restrictions imposed by COVID-19. For the YouTube channel (https://www.youtube.com/c/ASEGVideos) this included adding 24 additional videos from virtual and hybrid events. The YouTube channel userbase continues to grow, with subscribers now numbering 371, up from 229 in 2020. The channel had 6803 views in 2021, with views in Australia increasing by 60%. As we move into 2022, the ASEG intends to continue offering recordings of events on YouTube for those who are unable to attend in-person events.

The ASEG website represents the main digital portal to the Society. Website usage increased last year, with page views up from 46 830 views in 2020 to 58 018 in 2021. The *Preview* page (/publications/PVCurrent in Figure 1) continued to be the most popular page on the website, excluding the home page (/) and user page (/user). Views of the *Preview* page were flat on 2020, with a small increase from 3245 to 3249 views.

Other popular pages included the events page (/events), with views increasing from 1501 to 2288 in 2021. Otherwise, the technical content on the website remained popular, with the Isles and Rankin textbook webpage having 1436 page views, a large increase on the 659 page views in 2020.

Encouragingly, the latest addition to the ASEG bookshop, Doug Morrison's *Measuring Terrestrial Magnetism* book was the 7th most popular webpage, a very positive sign given the mid-year launch of the book.



	Page	Pageviews
		58,018 % of Total: 100.00% (58,018)
1.	/	12,756 (21.99%)
2.	/user	3,277 (5.65%)
3.	/publications/PVCurrent	3,249 (5.60%)
4.	/events	2,288 (3.94%)
5.	/publications/geological-interpretation-aeromagnetic-data	1,436 (2.48%)
6.	/members/overview	1,070 (1.84%)
7.	/measuring-terrestrial-magnetism	850 (1.47%)
8.	/publications/publications-members-only	820 (1.41%)
9.	/2016-near-surface-passive-seismic-surveying	766 (1.32%)
10.	/cart	747 (1.29%)

Figure 1. *Top ten pages on the ASEG website in 2021*

Other popular content continues to be the free workshop proceedings available at https://www.aseg.org.au/continuous-education/workshop-proceedings. After a period without any additions, 2021 saw the successful MAG21 symposium held in WA with proceedings now available on the website. Despite only being online for a month, these have been downloaded 130 times from users in seven different countries.

Table 1. Percentage of website users identifying as female

Year	Female users
2017	30.3%
2018	31.9%
2019	32.1%
2020	33.1%
2021	34.4%

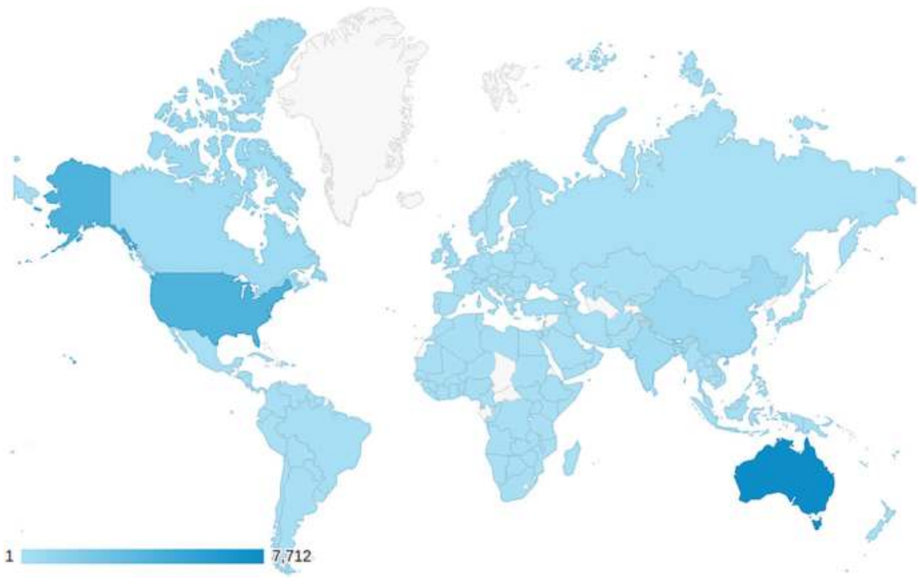
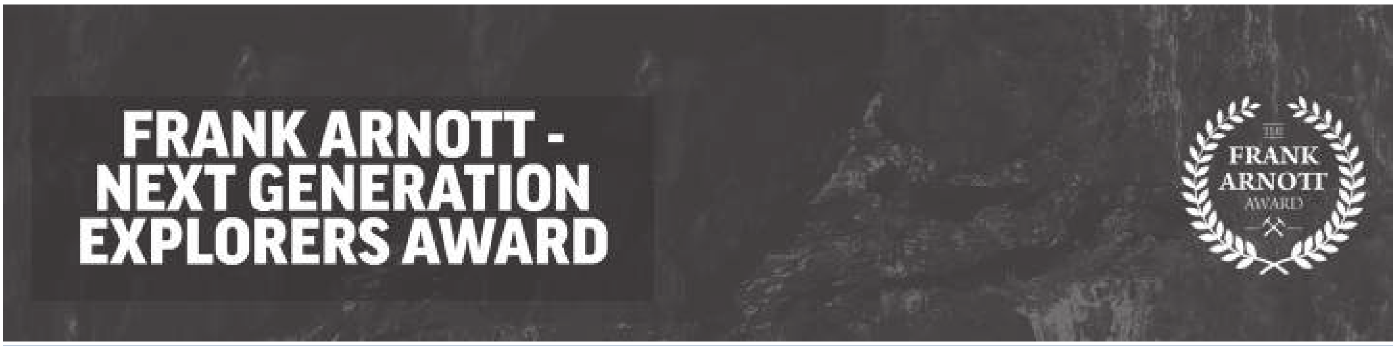


Figure 2. *Access to the ASEG website by country.*

The AGM in 2021 saw the ASEG electing our first cohort of all-female Directors. Google Analytics provides stats on estimated male and female viewer percentages and 2021 saw the trend of increasing female viewership continue. This saw views increase past one third of all views for the first time.

While the website continued to be accessed predominantly by Australian viewers, Figure 2 shows a world map with countries shaded by the number of unique users who visited an ASEG webpage in 2021. This highlights the global reach of the Society, although we are still missing some North Korean users.

With the ASEG website having maintained the same design since 2016, the Society plans to complete a redesign of the website in 2022. Some longstanding issues and difficulties should be fixed and improved, and the user experience simplified. If you would like to be involved in the Web Committee, please email webmaster@aseg.org.au.



Frank Arnott Next Generation Explorers Award 2022: Finalists announced

Six teams have been selected to advance to the finals of this year's Next Generation Explorers Award challenge at the Prospectors and Developers Association of Canada (PDAC) online convention.

As recently announced, PDAC has decided to reschedule the convention due to the current COVID public health restrictions in Ontario. PDAC 2022 will now be hosted in person in Toronto from June 13-15 and online from June 28-29.

In addition, **the 2023 NGEA™ challenge is now open!** We encourage everyone to organise a team and apply today!

The six finalists in 2022 are:

4-D Integration Team
Dène Tarkyth, Drew Heasman, Moslem (Moz) Azar Pour, Lavie Nguyen and Julia MacGillivray. *University of Saskatchewan, Canada*. Quesnel Trough Dataset

Team Create
Liam Maw (Institut national de la recherche scientifique), Taylor Tracey Kyryliuk, Marc Lorin Faßbender, Christopher Galley (Memorial University of Newfoundland) and Ryley Penner. *University of Ottawa, Canada*, Flin Flon Dataset

Team Shamrock
Joseph Frizon De Lamott, Alexandre LeBoulch (UQAC), Valentin Oge, Remi Naulot (UQAC), Théophile Cholet and Anae LeMarie. *UniLaSalle, France*. Tellus Programme Dataset

Muki Team
David Portocarrero (University of Tasmania), Marianella Guerrero, Renato Andre Santisteban Suarez, Alicia Rodriguez (mentor), Martin Emmanuel Tapia Peralta, Anderson Jose Pierola Rimac, Yamila Naydim Pari Rodriguez and Manuel Martin Ego Aguirre Madrid. *Universidad Nacional de Ingeniería, Peru*. Quesnel Trough Dataset

Terradeus
Robiah al Wardah, Tim Packulak, Sharlotte Mkhonto, Collette Pilsworth, Alutsyah Luthfian (The University of Auckland), Allie Surrette, Benjamin Saadia, McLean Trott and Neeraj Nainwal. *Queen's University, Canada*. Ngamiland, Botswana Dataset

GetAI
Halleluya Ekandjo (iCRAG), Robert Watson, Xiaolong Wei (University of Houston), Prithwijit Chakraborti & J. Caleb Chappell (Colorado School of Mines). *University College Dublin*. Tellus Programme Dataset

The origin of Bangui magnetic anomaly - one of the largest magnetic anomalies in the world

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Introduction

Over the last five decades, the African continent has experienced a considerable increase in fundamental and applied geological and geophysical research. Geophysical research is of great interest for understanding crustal architecture and the mechanical behaviour of the lithosphere, and for exploration for mineral resources. The analysis of ground, airborne and satellite geophysical data (gravity, magnetic, electromagnetic, seismic and seismological) allows for the definition of various geo-tectonic environments including rift zones, Archean shields and cratons. Furthermore, knowledge of geological phenomena can be enhanced by mapping of large-scale anomalies such as the Bangui magnetic anomaly in Central Africa (Godivier *et al.* 1962; Benkova *et al.* 1973; Godivier *et al.* 1980; Dorbath *et al.* 1981; Regan and Marsh 1982; Ravat 1989; Kochemasov and Chuprov 1990; Girdler *et al.* 1992; Ravat *et al.* 2002; Hemant 2003; Hemant and Maus. 2005; Ouabego *et al.* 2013; Haggerty 2014). The mapping of such anomalies and their geodynamical implications may increase the appetite for mineral exploration in these areas.

The Bangui Magnetic Anomaly (BMA) in Central Africa (Figure 1) is one of the largest magnetic anomalies in the world, but it is still not particularly well known and its origin remains controversial. This anomaly was the subject of my PhD thesis submitted to the University of Douala, Cameroon, and successfully defended in October 2021. The aims of my PhD research were to (1) map lithospheric structures in the North-Central African region; (2) analyse the crustal architecture and the mechanical behaviour of the BMA, (3) determine the geotectonic setting and crustal evolution in relation to the emplacement of a large-scale anomaly, and (4) establish relationships between mineral resources, the BMA and basement formations.

Geological setting

The African continent was formed several billion years ago, from the formation of juvenile crust to the stabilisation of the Archean craton, passing through phases of crustal remobilisations in the Proterozoic, the Pan-African accretion followed by the Mesozoic break-up of the Gondwana supercontinent, and Cenozoic widespread volcanism, uplift and continental rifting (Figure 2). As a consequence, the African continent is an amalgamation of Precambrian cratons separated by Paleo-Proterozoic mobile belts. It is surrounded by divergent plate boundaries, predefined during Mesozoic break-up of Gondwana and the coeval opening of the Southern and Central

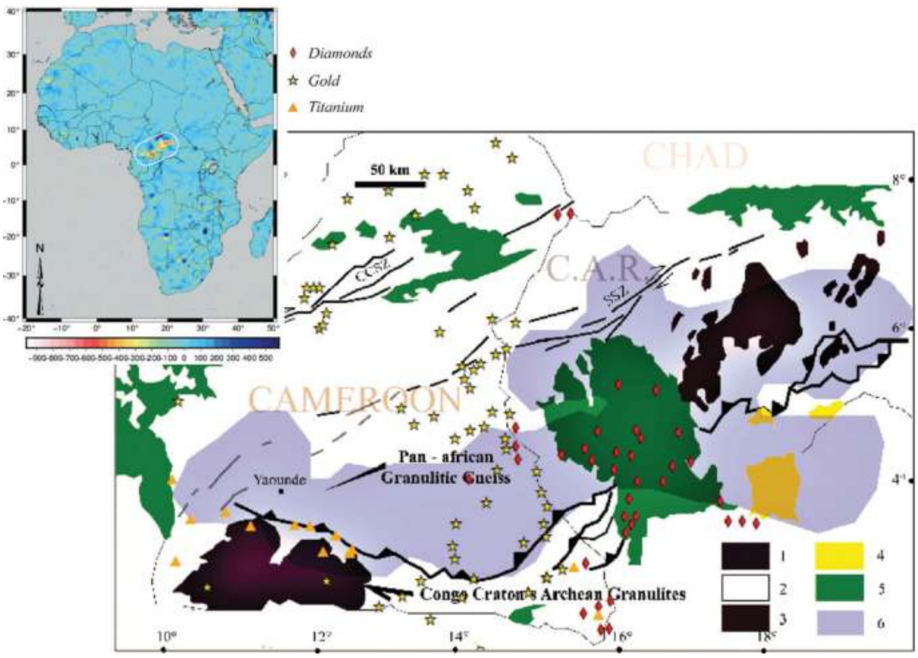

Figure 1. *The Bangui Magnetic Anomaly in Africa and it's spatial relationships with structural domains (modified after Pin and Poidevin, 1987; Njiteu* et al. *2021a). (1) Archean granulites; (2) undifferentiated Precambrian Formation; (3) Pan-African granulites; (4) sedimentary upper Precambrian foreland of Oubanguide; (5) post-African cover; (6) spatial extend of the BMA superimposed with some known gold, diamonds and titanium mineralisations, marked in yellow, red and orange symbols respectively. CAR: Central African Republic; CCSZ: Central Cameroon Shear Zone; SSZ: Sanaga Shear Zone.*

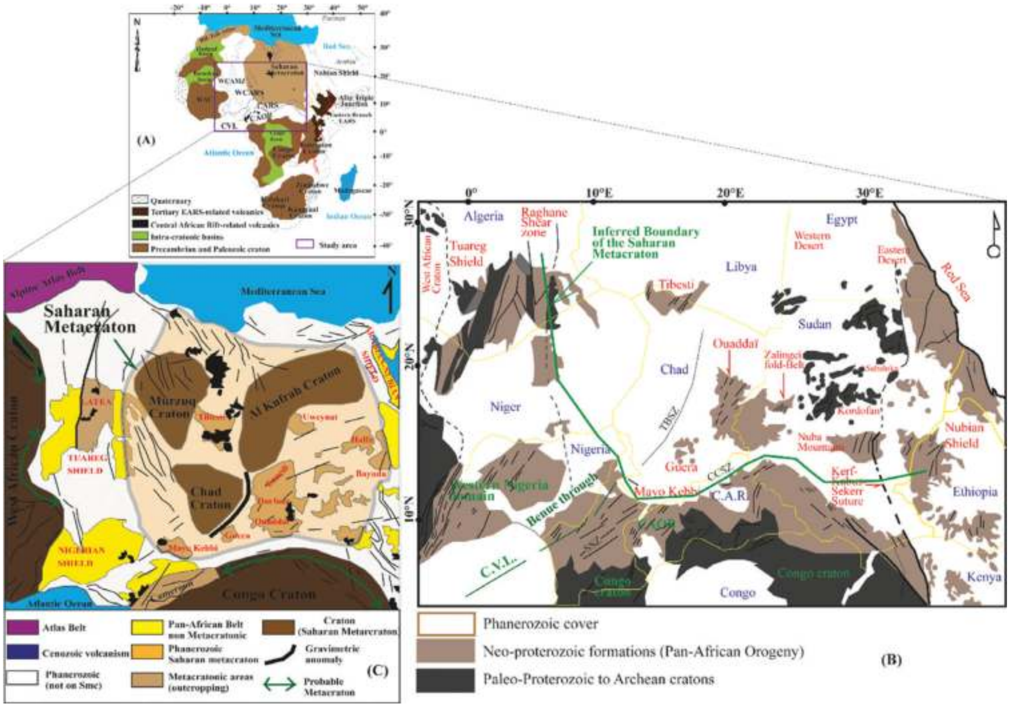

Figure 2. *(a) Simplified tectonic map of Africa (after Milesi et al. 2010), showing the location and extent of the Archean cratons, intracratonic basins and the surrounding Precambrian and Paleozoic fold belts, which were affected by rifting processes during Mesozoic and by Cenozoic volcanism. WCAMZ: West and Central African Mobile Zone, WCARS: West and Central African Rift System, CARS: Central African Rift System; (b) Simplified geological map showing the Central African Orogenic Belt (CAOB) in the West and Central African rift system (WCARS) and the Congo craton (modified from Abdelsalam et al. 2002). TBSZ: Tchollire-Banyo Shear Zone; SSZ: Sanaga Shear Zone; CCSZ: Central Cameroon Shear Zone; C.V.L.: Cameroon Volcanic Line; (c) Main rheological domains of sub-Saharan Africa centred on the Saharan Metacraton (modified from Liegeois et al. 2013). Smc: Saharan Metacraton.*

Atlantic. Currently continental break-up and rifting occurs along the boundary between the Nubian and Somalian plates, marked by the 5000 km long East African Rift System. The BMA overlies, along a major mid-axis ENE-WSW, the Neo-Proterozoic formations of South-Cameroon and the Central African Republic, individualised during the Pan-African Orogeny; as well as the Paleo-Proterozoic and Archean structures of the Congo Craton. The dominant outcrop lithologies in the Congo Craton are Tonalite-Trondhjemite-Granodiorite (TTG), charnockites, high-K granites and greenstone belts (Dostal *et al.* 1985; Nedelec *et al.* 1986; Feybesse *et al.* 1998; Shang *et al.* 2004; Owona, 2008). According to Dostal *et al.* (1985) and Poidevin (1991) the Archean domain of the Central African Republic is dominated by an orthogenetic basement in which multi-kilometre long greenstone belts, granites and epi-metamorphic series of iron-bearing quartzites appear.

The greenstone belts are mafic to ultra-mafic meta-volcanites (amphibolites, gneisses and metamorphosed Banded Iron Formations with magnetite; Shang *et al.* 2010; Ndime *et al.* 2019). However, the Banded Iron Formations (BIFs) form quite localised outcrops (about 200 km) compared to the wavelengths of about 1000 km of the Bangui Magnetic Anomaly. BIFs are formations that generally extend over a hundred meters and may be 1 to 2 km thick (Alexandrow *et al.* 1973). Although being characteristic of the Precambrian basement under the Bangui Magnetic Anomaly, these BIFs alone do not explain the magnetic behaviour of the crust. According to Boukeke (1994), the sources are deep, strongly magnetic and closely related to the Congo Craton structures. Two types of sources could explain surface observables: either the presence of mafic granulites or a demagnetisation effect.

The granulites are post-collisional remnants characteristic of the Eburnean orogeny. They outcrop at the northern edge of the Congo Craton in Cameroon (Toteu *et al.* 2006). These structures were taken up during a pan-African thermo-tectonic event in the mobile zone (Penaye *et al.* 2004; Toteu *et al.* 2004). According to Pin and Poidevin (1987) all Central African granulites are contemporaneous with the Congo Craton in Cameroon. Figure 1 shows the spatial distribution of granulites beneath the BMA. The high concentration of iron oxides in these granulites indicates that they derived from a very mafic parental magma (Clark 1999). According to Pin and Poidevin (1987) the crust in its lower part would have a more mafic composition than at the base of the surface rocks. The emplacement of mafic basalts in the lower crust during pan-African orogeny is a possibility. Granulites are stable at depths of nearly 50 km under conditions of high pressure and temperature (Boukeke 1994). Moreover, petro-physical studies on samples (Ouabego *et al.* 2013) have shown that mafic sources rich in iron have a particular natural magnetic remanence of about 4.3 A/m, which would make them potential sources.

The BMA actually covers a geographical area marked by major structural features other than the Congo Craton. Notably, the Central African Orogenic Belt is characterised by important regional shear zones including the Central Cameroon Shear Zone (CCSZ) and the Sanaga Shear Zone (SSZ). Regional phases of deformation (Rollin 1995; Feybesse *et al.* 1998; Ngako *et al.* 2003; Toteu *et al.* 2004) in the Central African Orogenic Belt have followed one another during pan-African thermo-tectonic events. These thermo-tectonic events have affected the Congo Craton in Cameroon and Central Africa, with the development of important thrust sheets. In general, the thrust sheets (Figure 2) as well as the regional shear zones (CCSZ and SSZ) define a mean ENE-WSW tectonic direction (Ngako *et al.* 2003; Toteu *et al.* 2004) similar to that of the BMA.

Previous studies

The scientific issues related to the BMA are discussed according (1) the aspects related to the geological context in Cameroon and Central African Republic; (2) the development of recent databases and (3) the complexity of some lithospheric structures.

The BMA is defined as a massive aberration revealed by various satellite (POGO, MAGSAT, CHAMP, SWARM), airborne and ground missions. The name derives from the capital of the Central African Republic "Bangui", where the minimum magnetic intensity was observed. From the MAGSAT to SWARM satellite missions in the 1950s to the present day, the BMA as mapped in the intra-continental domain also extends to Cameroon (Figure 1). Observations made by CHAMP (Maus *et al.* 2009; Meyer *et al.* 2017) and SWARM (Sabaka *et al.* 2018) satellite missions show that the geology of Cameroon and the Central African Republic is dominated by this gigantic magnetic anomaly, which appears to have three main lobes: a southern lobe observed in Cameroon; and the central and upper lobes observed in Central African Republic. Although the Central African Republic has already seen a number of studies describing and speculating on the source of the anomaly (Godivier *et al.* 1980; Girdler *et al.* 1992; Hemant and Maus 2005; Ouabego *et al.* 2013), the part of the anomaly within Cameroon has yet to be explored and characterised in order to (1) map lithospheric structures in detail; (2) study the behaviour of the BMA; (3) analyse the crustal structure; (4) determine the geotectonic context of the evolution of the crust in relation to the emplacement of an anomaly of such magnitude and (5) establish relationships between the mineral resources, the BMA and the basement formations. One of the major and essential large-scale concerns is the origin of the BMA.

The BMA is known as the second largest magnetic anomaly in the world and the largest in Africa (Godivier *et al.* 1962; Godivier *et al.* 1980; Ravat 1989; Meyer *et al.* 2017). The BMA in the intra-continental domain covers nearly two thirds of the Precambrian formations of the Central African Republic. Based on ground, airborne and satellite magnetic data, detailed mapping of this anomaly was possible. Godivier *et al.* (1962) estimated the spatial extension of this anomaly as well as its relationship with surface rocks from ground measurements. The U.S. Bureau of Naval Oceanography, through the MAGNET project on a profile of about 3 km long, had observed a dipole anomaly of more than 1000 nT. The COSMOS 49 satellite mission for the very first time in 1964 reported an anomaly of -40 nT at an altitude of nearly 350 km (Benkova 1973). The POGO (Polar Orbiting Geomagnetic Observatory) satellite mission similar to COSMOS 49 between 417 and 499 km altitude had revealed an intensity of -20 nT for the same anomaly (Benkova 1973). The first anomaly map of the global field from the MAGSAT mission data at an altitude of 375 km showed a minimum of -22 nT. At this scale the BMA is one of the most intense anomalies with a wavelength of nearly 1200 km and a mean ENE-WSW orientation from the Atlantic coast to longitude 30°E (Boukeke 1994).

The origin of the BMA is still not understood. Two theories have been proposed: meteoritic and geological. Godivier (1980), by superimposing the magnetic anomaly maps in Central Africa resulting from the analysis of terrestrial data at 525 km altitude by the POGO satellite, highlights the presence of a magnetic body buried in the crust. In accordance with this hypothesis Dorbath *et al.* (1981); Dorbath *et al.* (1985), based on seismic investigations, located the top of the potential source at 3 km and the base at 40 km in the "Bangui" locality. Similarly, the fact that a negative Bouguer anomaly of about -20 mGals coincides with the magnetic anomaly implies, according to Regan and Marsh (1982) a rooting of the sources in the upper mantle. Another hypothesis is the existence according to Girdler *et al.* (1992); Ravat *et al.* (2002) of a crater impact nearly 800 km wide and centred in Central African Republic.

Discussion on the origin of the BMA have evolved over time. The different geological and extra-terrestrial hypotheses were discussed by Boukeke (1994) based on information on the topography, global tectonics, seismology, crustal structure and the nature of the rocks. According to Marsh (1977) and Boukeke (1994) the theory of a crater impact cannot be accepted because no typical structure is recognisable. The idea of an intracrustal origin or sources rooted in the sub-continental mantle would be most likely, assuming that the BMA is caused by intrusions of mafic or ultra-mafic rocks in the crust. This hypotheses was challenged by Klokonick *et al.* (2010), who by analysing gradient zones based on EGM2008 data in areas where meteorite craters were suspected defined a circular surface similar to that described by Ravat *et al.* (2002) and earlier by Girdler *et al.* (1992). These developments demonstrate the conundrum to be solved in understanding the sources of this anomaly. The results obtained from geological modelling from the CHAMP satellite mission data (Hemant and Maus 2005) as well as petro-physical studies on rocks samples combined with magnetic field data (Ouabego *et al.* 2013) have suggested that the sources of the BMA are related either to metamorphic or mafic rocks.

The contribution of geophysics to the characterisation of lithospheric structures around the Bangui magnetic anomaly

Ground gravity data are scarce in central Africa. Many organisations such as the BGI (International Gravimetric Bureau) are working to produce gravity grids that combine the available ground gravity data (Ex-ORSTOM or IRD) and satellite data, or satellite-only gravity data. These gravity grids replace terrestrial measurements where the accuracy is uncertain because of topography, vegetation and accessibility - factors that have greatly influenced the acquisition of terrestrial data (Figure 3). There are geographical areas where it has not been possible to carry out measurements and thus to constrain lithospheric structures.

It is not easy to appreciate the contribution of satellite data relative to the contribution of the terrestrial data in many of the grids derived from the combined ground, marine and airborne grid gravity data (WGM2012, EGM2008, XGM 2019). This creates a real problem of the spatial representativeness of grids derived from combined measurements, compared with grids derived from the ground-only gravity data, which have been used in Cameroon to map lithospheric structures. The first ground gravity campaigns (1960 to 1967) were carried out by ORSTOM ("*Office des Recherches Scientifiques pour les Territoires d'Outre-Mer*") known today as the IRD. These campaigns covered an area of ~519 600 km^2 with a network of 3600 gravity stations, for an average density of 357 points per square degree. These campaigns led to the elaboration of the first Bouguer gravity

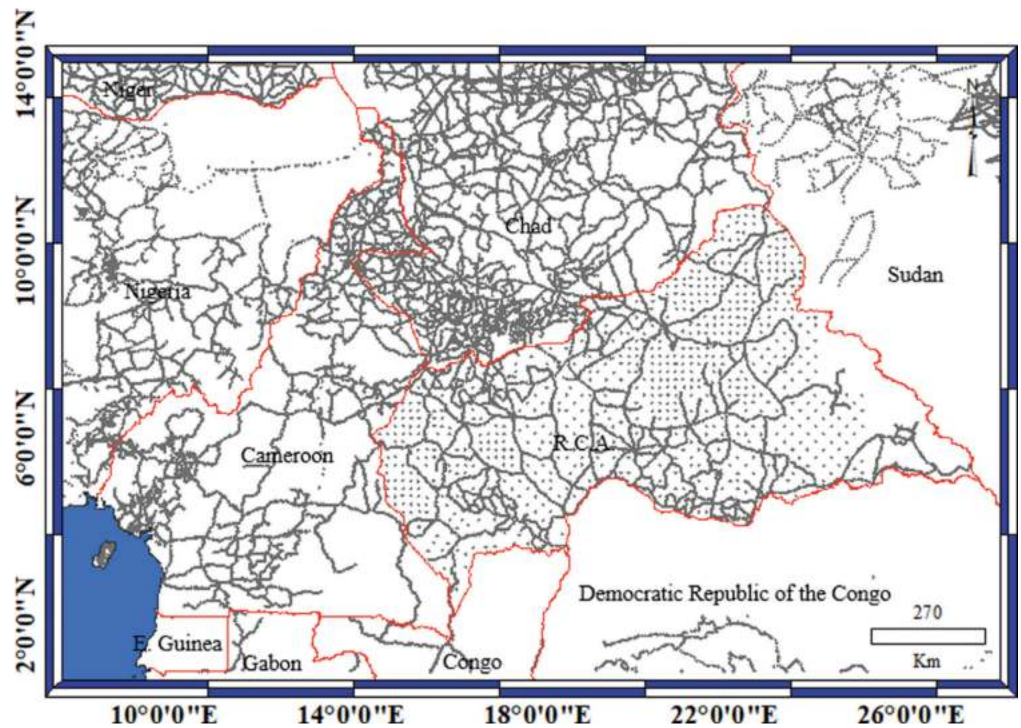

Figure 3. *Location of ground gravity station in North-Central African Region (Njiteu et al. 2021a)*

anomaly map in Cameroon (Collignon 1968). Using this map, Dumont (1986) maps the extension of the Sanaga fault, and specifies the northern boundary of the Congo Craton at 4°N of latitude over more than 100 km, also its NE-SW extension beneath the Sanaga fault. At the end of the complementary campaigns undertaken between 1968 and 1986 by the Princeton University and the ELF company, Poudjom Djomani (1993) and Boukeke (1994) showed through the analysis of a new Bouguer anomaly map that the Congo Craton is associated with a pair of parallel, positive and negative E-W anomalies: the positive anomaly lies to the North, on the mobile zone side, and the negative anomaly, to the South on the craton side. Boukeke (1994) showed by an Euler deconvolution applied to the Bouguer anomaly map, a series of NE-SW structures linked to each other and superimposed on the Sanaga fault. The determination of crustal thicknesses by spectral analysis allowed estimation of the Moho depth at 26 km on the boundary between the Congo Craton and the Pan African fold belt. Poudjom Djomani (1993) showed a progressive thickening of the crust from North to South Cameroon. These ground gravity data were completed by some additional campaigns undertaken by the Princeton University (1968), ELF (1980), University of Leeds and IRGM (Institute for Geological and Mining Research) between 1982 and 1988. The new database obtained, together with information from 1960 to 1988, supported the development of a new and more complete Bouguer gravity map, between 1°N and 14°N of latitude and 8°E to 17°E of longitude (Poudjom Djomani *et al.* 1995). Based on these data, gravity modelling at the northern edge of the Congo Craton suggests the presence of an E-W gradient zone that juxtaposes the Congo Craton to the south, and the Pan African belt to the north at a depth of ~20 km (Tadjou *et al.* 2009).

A first solution to the scattered coverage of ground gravity data would have been the integration of the satellite data into the terrestrial database. However, the problem with the integrated (satellite, airborne/ground) data remains the same: gravity anomalies are a coalescence of short and long wavelength signals. Using the EGM2008 gravity data Ngatchou *et al.* (2014) obtained a similar results to those of Poudjom Djomani *et al.* (1992); Boukeke (1994); Poudjom Djomani *et al.* (1995); Poudjom Djomani *et al.* (1997); Tadjou *et al.* (2009).

Ngalamo *et al.* (2017); Ngalamo *et al.* (2018), evaluated the Moho depths beneath the Congo Craton and the Central African Orogenic Belt (CAOB) in Cameroon, the lithosphere-asthenosphere boundary, and highlighted meta-cratonisation at the northern edge of the Congo Craton. However, according to signal processing, these results remain debatable or even limited. Moreover, the Congo Craton extends E-W between Cameroon and Central African Republic. Considering the southern limit of the Saharan meta-craton, Abdelsalam *et al.* (2002) proposed a generalised remobilisation of the crust between the northern edge of the Congo Craton in Central African Republic and the eastern margin of the West African Craton. The crustal structure in the North-Central African Region beneath the West and Central African Rift System (WCARS) and the Congo Craton remains poorly known.

In Central Africa, data related to lithospheric structures and their mechanical behaviour are very limited. Two major structures are particularly interesting: the Adamawa-Yade Plateau (Dorbath *et al.* 1985; Poudjom Djomani *et al.* 1997; Nnange *et al.* 2000; Tokam *et al.* 2010; Aubreya *et al.* 2015; Ebinger *et al.* 2017); and the Bangui Magnetic Anomaly (Godivier *et al.* 1962; Benkova *et al.* 1973; Godivier and Ledonche 1980; Dorbath *et al.* 1981; Dorbath *et al.* 1985; Regan and Marsh 1982; Ravat 1989; Ouabego *et al.* 2013; Launay *et al.* 2018).

Recent geophysical investigations based on gravity and magnetic data

Our study was built around three main databases: two gravity databases (ground data (Figure 3) and satellite-only data, GOCO6s and XGM2019) and a magnetic database (EMAG2-v3). Each of these datasets was subjected to separate processing.

The first processing stream consisted of terrain corrections applied to the ground gravity data (Figure 4a). These corrections were applied with an average density of 2670 kg/m3 , considering a digital elevation model extended over an area between 0°-22°N of latitude and 5°-50°E of longitude. All the data were interpolated with a 10 km step to obtain the Complete Bouguer. The Complete Bouguer obtained was used as the base for the first estimation of the Moho depths in Central Africa (Cameroon and Central Africa) using the spectral analysis method (Spector and Grant 1970; Bhattacharyya and Leu 1975; Tselentis *et al.* 1988; Poudjom Djomani 1993; Nwobgo *et al.* 1998; Nnange *et al.* 2000).

Given the (1) sparse distribution of ground gravity data (Figure 3) in some local areas, which is a consequence of the field conditions, (2) coalescence between wavelengths, informing on different crustal interfaces, satellite-only gravity data (GOCO6s and XGM2019) derived from the CHAMP, GOCE, GRACE and SLR missions have been used. A non-linear gravity inversion approach developed by Uieda and Barbosa (2017) was applied to these data. This approach allowed imaging and discussion of the crustal architecture in the North-Central African region based on successive filters; also analysis of the different geodynamic contexts of the BMA sources. The mechanical behaviour of the lithosphere can be easily analysed by estimating the coherence parameters between the topography and the Bouguer anomaly.

Magnetic data were extracted from the EMAG2-v3 global database resulting from the CHAMP satellite mission. Different digital signal processing methods were applied, depending on the amplitude and geometry of the observed anomalies. The first treatments consisted of a stable reduction to the pole of the magnetic anomalies (Figure 4b), pseudogravity and analytical signal. All of them allowed (1) location of the magnetic anomalies directly above their sources; (2) analysis of the geometry and the amplitude of the anomalies; (3) establishing correlations with the underlying geological formations. Subsequently, upward continuation and spectral analysis methods were used to determine the depths to the bottom of the magnetic sources. The location of potential sources was also determined by deconvolution along some selected magnetic profiles. Once the geometric parameters were determined, they were used to build 2.5D and 2.3/4D crustal models highlighting the magnetic intrusions beneath the BMA.

Results and discussion

The first result of this work was a complete Bouguer anomaly map for the Central African sub-region (Cameroon, Central African Republic, Figure 4a), which is an essential support for any other gravity analysis. This result allowed the observation of a coalescence of short and long wavelength anomalies, with amplitudes ranging from -100 to 20 mGals. These anomalies have allowed the characterisation of two major tectonic structures: the northern edge of the Congo Craton and the Central African Orogenic Belt (CAOB). A comparison of the results obtained from the Complete Bouguer map was made with reference to Poudjom *et al.* (1995); Poudjom *et al.* (1992); Boukeke, (1994). The similarity between the extension of the dominant tectonic structures (Cameroon Volcanic Line, Central Cameroon Shear Zone, Adamawa Plateau, Northern edge of the Congo Craton and the Southern Chad Basin) allowed the validation of the various preliminary results.

The evolution of the crustal architecture in the North-Central African region, the estimation of Moho depths (Figure 5a) and elastic thicknesses (Figure 5b), and the understanding of the mechanical behaviour of the lithosphere were among the other advances made in this thesis. The crustal architecture was determined by means of two different databases, and used different approaches (spectral analysis and a regularised non-linear inversion methods) to assess the regions crossed by the BMA. The results showed that the magnetic structures associated with this anomaly are strongly linked with the cratonic structures. Furthermore, the estimated crustal thicknesses between 15 and 45 km were compared to the

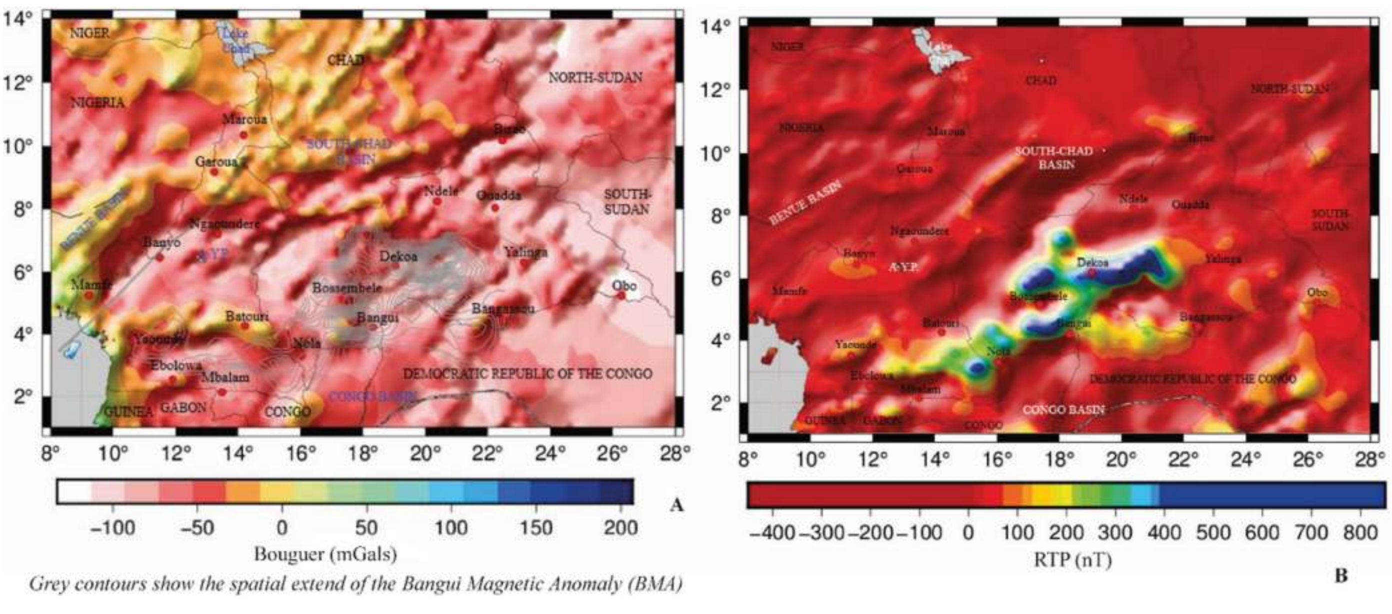

Figure 4. *(a) The Complete Bouguer anomaly; (b) the total magnetic intensity map reduced to the pole (Njiteu et al. 2021a)*

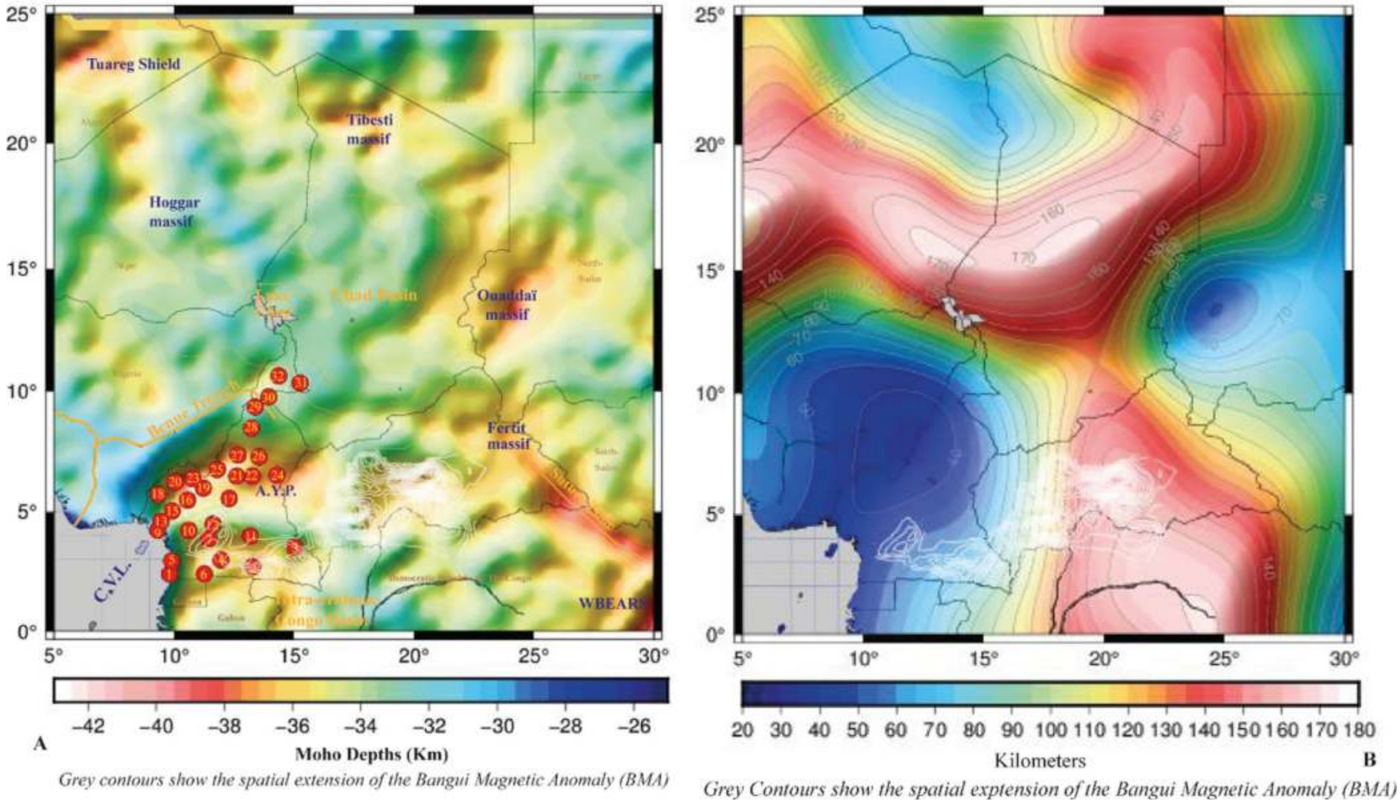

Figure 5. *(a) The estimated Moho depths superimposed by the locations of the seismic Moho depths; (b) the elastic thickness map (Njiteu et al. 2021b)*

values found at the edges of the Chinese and American cratons. The analyses carried out allowed the association of these low values of crustal thicknesses, as well as elastic thickness values, to the regional geodynamic phenomena (volcanism, earthquakes, thermo-tectonic events) that led to a partial loss of the cratonic structures.

Thus, we show that the evolution of the crustal architecture as observed today was strongly controlled by major crustal remobilisations. The partial destruction of the cratonic structures was best imaged by non-linear gravity inversion of high resolution satellite data (GOCO6s). This additional approach also highlighted the presence of remanent cratonic structures in the Sahara meta-craton, and thus confirmed the existence of three cratonic cores (Chad Craton, Murzuq Craton and Al Kufrah Craton, Fig.5b). These results were discussed based on very recent previous studies (Sobh *et al.* 2020; Sobh 2019; Ngalamo *et al.* 2018) by integrating seismic results (Tokam *et al.* 2010; Gallacher *et al.* 2012) and by comparison with global crustal models CRUST1.0 and GEMMA.

In the quest to understand the origin of the Bangui magnetic anomaly and the location and nature of the causative rocks, further results derived from the processing and interpretation

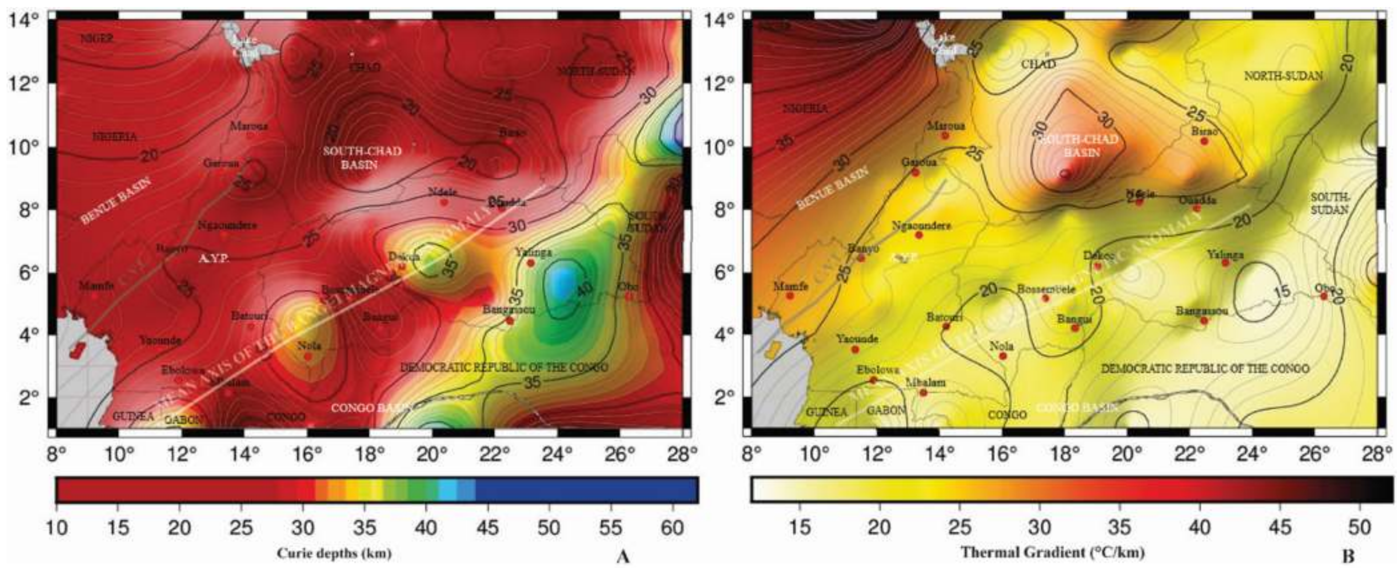

Figure 6. *(a) The estimated Curie depths; (b) the estimated thermal gradients in Central Africa and beneath the BMA*

of EMAG2-v3 magnetic data were considered. Preliminary magnetic results from qualitative processing (a stabilised reduction to the pole, upward continuation, horizontal gradient, vertical gradient, analytical signal, pseudo-gravimetry) show that (1) there are many sources for the BMA; (2) the sources of the BMA are closely linked with the Congo craton structures; (3) the BMA has a geological origin; (4) there is no link between the BMA and the surface rocks; (5) the petrography could vary from Banded Iron Formations to mafic granulites; (6) the BMA is a long wavelength anomaly associated with secondary anomalies preferentially oriented E-W; (7) the geodynamic processes of emplacement of sources of the BMA are related to the regional E-W and ENE-WSW tectonics that affected the Precambrian to Pan-African basement. The quantitative analysis was initiated by a geothermal approach. The Curie depths along the BMA, the estimation of geothermal gradients and heat fluxes were thus highlighted (Figure 6). Three potential sources of the anomaly along the major ENE-WSW direction were imaged, all located in the Congo Craton, at a maximum depth of 38 km ± 2 km. The 2.5D and 2.3/4D models thus revealed on nine N-S profiles selected at constant distance: (1) a magnetic crust indicative of a possible circulation of magnetic fluid; (2) mafic granulite intrusions, (3) BIF (Banded Iron Formation) intrusions.

Future issues

A direct economic outcome will be necessary to promote ongoing geophysical research in Central Africa; hence the ongoing search for links between the Bangui magnetic anomaly and mineralisation of importance in the sub-region. The acquisition of seismic and electromagnetic data, in addition to the magnetic and gravimetric data already acquired, would significantly help to quantify various parameters of relevance to the exploitation of mineral resources both in the Central African Republic and in Cameroon.

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Cyrille Njiteu has a BSc from University of Douala, Cameroon, and recently received at PhD from the same university. He is multilingual and speaks French as well as English. He enjoyed student membership of the ASEG and looks forward to continuing his association with the organisation.

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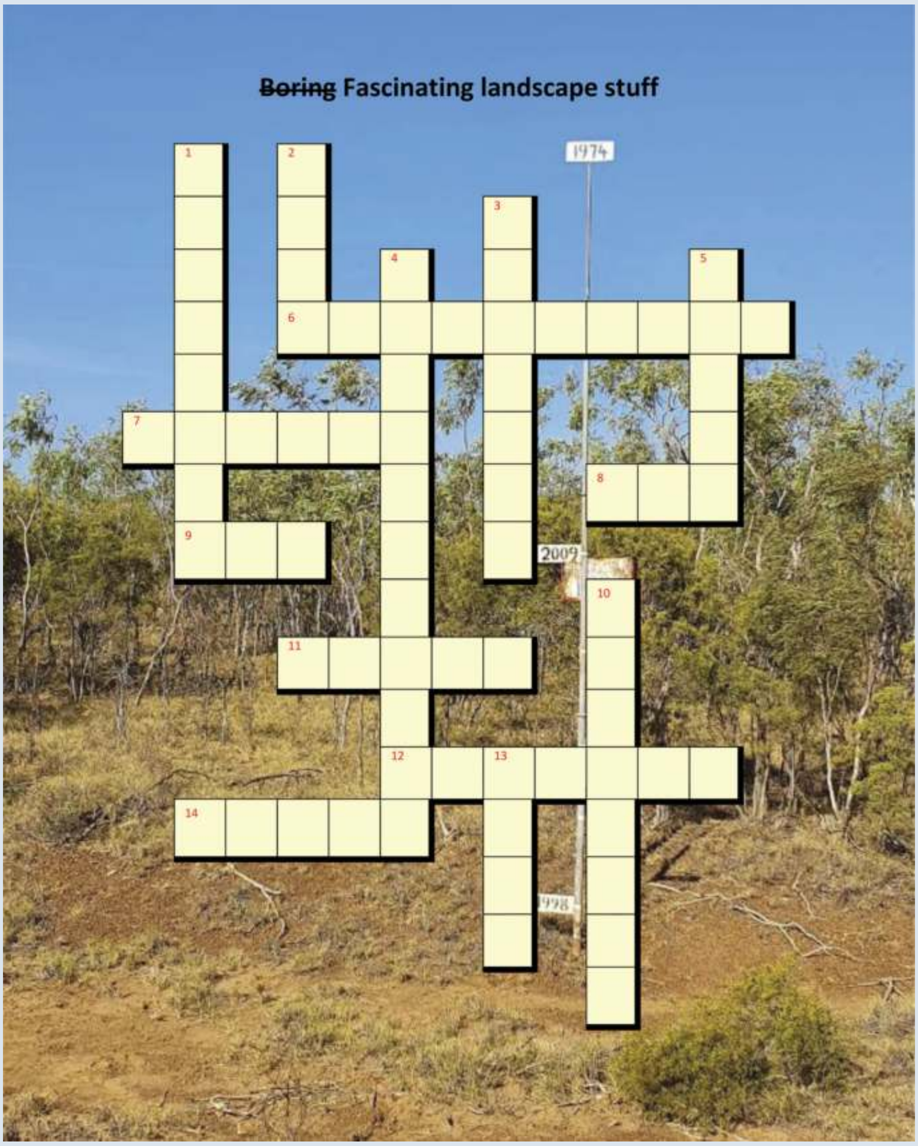
Preview crossword #18



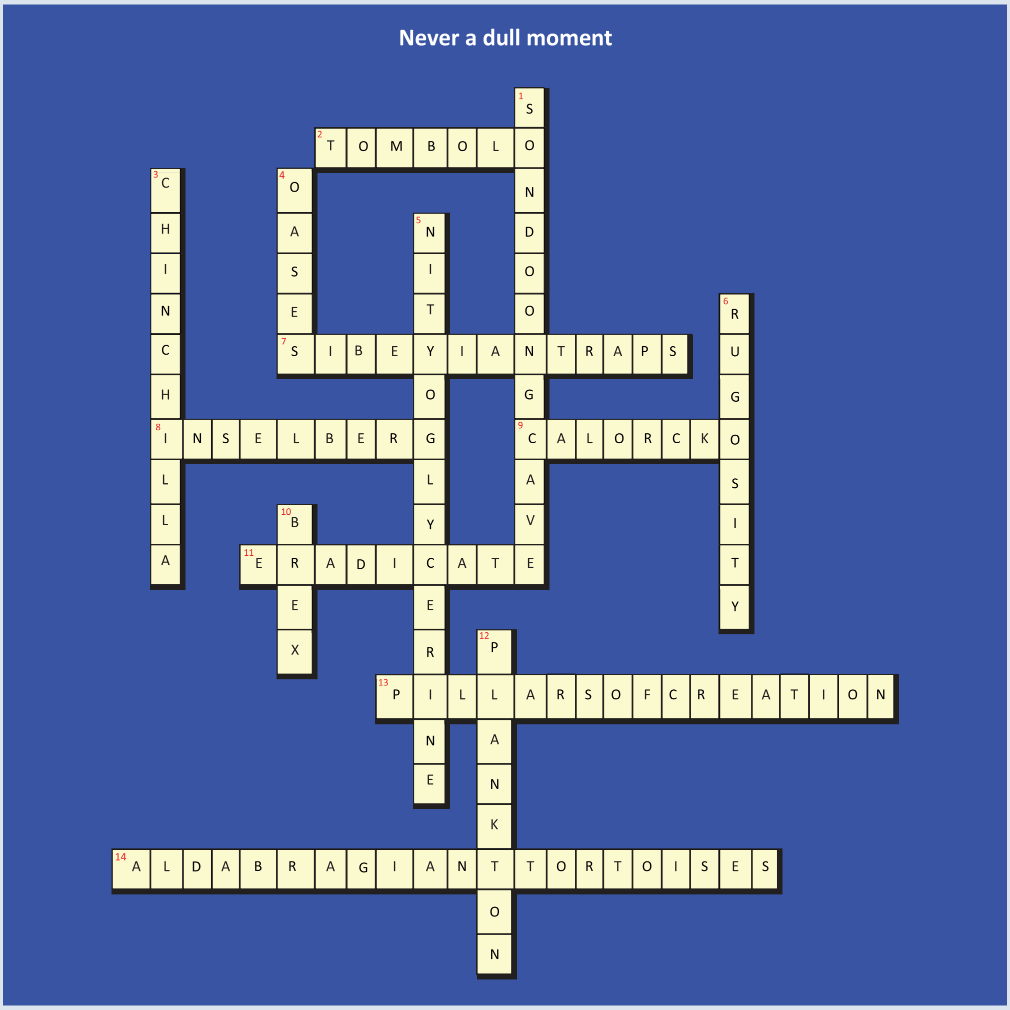
Across	Down
6 The shoreline, especially a former (relict) shoreline now elevated above the present water level	**1** Lying or formed at the base of a mountain or mountain range
7 A bizarrely shaped column, pinnacle, or pillar of rock produced by differential weathering or erosion in a region of sporadically heavy rainfall	**2** The fragmental products of *in situ* granular disintegration of granite and granitic rocks, dominated by inter-crystal disintegration
8 An ancient mound composed of remains of successive settlements	**3** Unconsolidated, juvenile, vitric, vesicular pyroclastic material
9 A high, isolated pinnacle, or rocky peak	**4** A mass of soil or other unconsolidated earthy material moved or disturbed by frost action, and usually coarser than the underlying material
11 A small, low-relief sand dune that lacks discernible slip faces and commonly occurs on sand sheets, in interdune areas, or in corridors between larger dunes	**5** A small, low, rounded hill rising above adjacent landforms
12 A small dome or mound on the surface of a lava flow formed by the buckling of the congealing crust near the edge of a flow	**10** A sudden cutting off or separation of land by a flood or by abrupt change in the course of a stream
14 A largely treeless, open, grassy area on high, broad interfluves and hillsides, commonly with shallow soils	**13** A low relief, broad volcanic crater formed by multiple shallow explosive eruptions

Play to win!!

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

Good luck!

Preview crossword #17 solution



Business directory

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Application for Active & Associate Membership 2022

INSTRUCTIONS FOR APPLICANTS

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

Section 1. Personal identification

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

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

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

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

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

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

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

Section 3. Academic and professional qualifications

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

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

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

Section 5. Membership of other societies

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

International:
❑ AAPG Grade ________ ❑ EAGE Grade ________ ❑ SEG Grade ________ ❑ SPE Grade ________

❑ Others ____

Section 6. ASEG Member record

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

❑ **Yes** ❑ **No**

Please complete this section for the ASEG Membership database.

Employment area:

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

Type of Business:

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

Section 7. Membership grades and rates

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

Section 8. *Preview & Exploration Geophysics*

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

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

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

❑ **Yes** ❑ **No**

Section 9. Promotional opportunities

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

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

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

Section 10. Declaration

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

*Signature:*______________________________ *Date:*________________

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

1. A Member shall conduct all professional work in a spirit of fidelity towards clients and employees, fairness to employees, colleagues and contractors, and devotion to high ideals of personal integrity and professional responsibility.
2. A Member shall treat as confidential all knowledge of the business affairs, geophysical or geological information, or technical processes of employers when their interests require secrecy and not disclose such confidential information without the consent of the client or employer.
3. A Member shall inform a client or employer of any business connections, conflicts or interest, or affiliations, which might influence the Member's judgement or impair the disinterested quality of the Member's services.
4. A Member shall accept financial or other compensation for a particular service from one source only, except with the full knowledge and consent of all interested parties.
5. A Members shall refrain from associating with, or knowingly allow the use of his/her name, by an enterprise of questionable character.
6. A Member shall advertise only in a manner consistent with the dignity of the profession, refrain from using any improper or questionable methods of soliciting professional work, and decline to accept compensation for work secured by such improper or questionable methods.
7. A Member shall refrain from using unfair means to win professional advancement, and avoid injuring unfairly or maliciously, directly or indirectly, another geophysicist's professional reputation, business or chances of employment.
8. A Member shall give appropriate credit to any associate, subordinate or other person, who has contributed to work for which the Member is responsible or whose work is subject to review.
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12. A Member shall be interested in the welfare and safety of the general public, which may be affected by the work for which the Member is responsible, or which my result from decisions or recommendations made by the Member, and be ready to apply specialist knowledge, skill and training in the public behalf for the use and benefit of mankind.

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Application for Student Membership 2022

INSTRUCTIONS FOR APPLICANTS

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

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

   Student Membership must be renewed annually.

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

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

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

Section 1. Personal details

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

Section 2. Student declaration

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

Section 3 Membership grades and rates

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

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

❑ **Yes** ❑ **No**

Section 5 Declaration

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

Signature: ______________________________ Date: ________________

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4. A Member shall accept financial or other compensation for a particular service from one source only, except with the full knowledge and consent of all interested parties.
5. A Member shall refrain from associating with, or knowingly allow the use of his/her name, by an enterprise of questionable character.
6. A Member shall advertise only in a manner consistent with the dignity of the profession, refrain from using any improper or questionable methods of soliciting professional work, and decline to accept compensation for work secured by such improper or questionable methods.
7. A Member shall refrain from using unfair means to win professional advancement, and avoid injuring unfairly or maliciously, directly or indirectly, another geophysicist's professional reputation, business or chances of employment.
8. A Member shall give appropriate credit to any associate, subordinate or other person, who has contributed to work for which the Member is responsible or whose work is subject to review.
9. In any public written or verbal comment, a Member shall be careful to indicate whether the statements or assertions made therein represent facts, an opinion or a belief. In all such comments a Member shall act only with propriety in criticising the ability, opinion or integrity of another geophysicists, person or organisation.
10. A Member will endeavour to work continuously towards the improvement of his/her skills in geophysics and related disciplines, and share such knowledge with fellow geophysicists within the limitation of confidentiality.
11. A Member will cooperate in building the geophysical profession by the exchange of knowledge, information and experience with fellow geophysicists and with students, and also by contributions to the goals of professional and learned societies, schools of applied science, and the technical press.
12. A Member shall be interested in the welfare and safety of the general public, which may be affected by the work for which the Member is responsible, or which my result from decisions or recommendations made by the Member, and be ready to apply specialist knowledge, skill and training in the public behalf for the use and benefit of mankind.

February	2022		
1–3	EAGE Digitalization Conference 2022 https://eage.eventsair.com/digital2022/	Vienna	Austria
March	**2022**		
20–23	Geo-Congress 2022 https://www.geocongress.org/	Charlotte	USA
23–26	OTC Asia 2022 https://2022.otcasia.org/welcome	Kuala Lumpur	Malaysia
April	**2022**		
5–6	Annual Geoscience Exploration Seminar (AGES) https://resourcingtheterritory.nt.gov.au/news-and-events/ages	Alice Springs	Australia
11–14	International Geological and Geophysical Conference and Exhibition https://eage.eventsair.com/saint-petersburg-2022/	St Petersburg	Russia
May	**2022**		
9–13	8th Mines & Wines Conference 2022 https://www.aig.org.au/events/8th-mines-wines-conference-2022/	Orange	Australia
23–27	EGU General Assembly 2022 https://www.egu22.eu	Vienna	Austria
June	**2022**		
5–9	83rd EAGE Annual Conference & Exhibition https://eage.eventsair.com/eageannual2022/	Madrid	Spain
12–17	19th International Conference on Ground Penetrating Radar https://learn.mines.edu/gpr2022/	Denver	USA
13–15	Prospectors and Developers Convention (PDAC) Face-to-face https://www.pdac.ca/convention	Toronto	Canada
28–29	Prospectors and Developers Convention (PDAC) Online https://www.pdac.ca/convention		Virtual
August	**2022**		
1–3	Diggers and Dealers https://www.diggersndealers.com.au/	Kalgoorlie	Australia
15–19	12th International Kimberlite Conference https://12ikc.ca/	Yellowknife	Canada
28 Aug–02 Sept	International Meeting for Applied Geoscience & Energy (SEG | AAPG IMAGE 2022) https://imageevent.org/2022/Save-the-Date	Houston	USA
September	**2022**		
18–22	Near Surface Geoscience Conference & Exhibition 2022	Belgrade	Serbia/Virtual
27–29	AIG Symposium: Structural Geology and Resources 2022 https://www.aig.org.au/events/aig-symposium-structural-geology-and-resources-2022/	Kalgoorlie	Australia
26–30	Australian and New Zealand Geomorphology Group Conference https://www.anzgg.org/conferences	Alice Springs	Australia
November	**2022**		
28–30	Sub 22 https://research.csiro.au/dei/sub22/	Adelaide	Australia
March	**2023**		
13–18	Australasian Exploration Geoscience Conference (AEGC 2023)	Brisbane	Australia

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