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Australian Society of
Exploration Geophysicists

PREVIEW

NEWS AND COMMENTARY

FEATURE

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ADVERTISERS INDEX

ASEG CORPORATE PLUS MEMBER

ASEG CORPORATE MEMBERS

FRONT COVER

Students visiting the Moombarriga Geoscience booth at the AEGC 2019 High School Student Day. Photo taken by Cam Adams. See report recapping AEGC 2019 by Cam Adams for the ASEG Young Professionals Network for more information.

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Editor's desk

This year marks the 50th anniversary of the establishment of the Australian Society of Exploration Geophysicists. *Preview* is marking this golden anniversary with a new colour scheme (we will revert to the usual scheme next year, never fear) and by asking the current ASEG President, and current and past Editors of *Exploration Geophysics*, to nominate their "best of" papers published in the *ASEG Bulletin* or its successor, *Exploration Geophysics,* in the last 50 years. We are republishing these papers with an introduction that explains why they were chosen. Ted's choice appears in this issue – you will have to flick through to the feature pages to find out what it was!

David Denham (*Canberra observed*) considers government management of Australia's bushfire crisis. He also reviews the performance of the resources sector in 2019, which is more comfortable reading. Michael Asten (*Education matters*) introduces the first SEG Honorary Lecturer for 2020 – one of our own! Mike Hatch (*Environmental geophysics*) takes a look at fake science. Terry Harvey (*Minerals geophysics*) muses on whether force or finesse is more important in a resistivity survey. Mick Micenko (*Seismic window*) marks his own anniversary - and reviews flat reflections. Tim Keeping (*Data trends*) identifies compliance issues with the ASEG GDF2, and Ian James (*Webwaves*) brings us up-to-date with the use of the ASEG website.

Ian's data on the use of the *Preview* page on the ASEG website are particularly interesting. There were 2398 "unique viewers" of online versions of *Preview* in 2019 – more than twice the number of ASEG Members. *Preview*'s reach is also demonstrably global, with viewers accessing *Preview* from most of the world's exploration hot spots. No viewers in China apparently, but the data in this regard may be misleading, as viewers in China may be accessing the ASEG website using VPNs that locate them in another country.

Well done team - we must be doing something right – and Happy New Year to you all!!

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

President's piece

I wish our ASEG Members, corporate partners and affiliate societies a very happy and prosperous New Year. I also want to express my deepest concern and well wishes for all of our Members and their families and communities that have been affected by Australia's catastrophic fires.

We have all seen the horrifying media images and heard the heart-wrenching stories of loss of lives, homes and regional communities and loss of massive areas of biodiversity and wildlife. Australia's townships and regions, most well-known to exploration geoscientists, have been absolutely decimated by almost unstoppable firestorms. Communities across QLD, NSW, VIC, SA and WA are enormously grateful for the heroic efforts of the volunteer and professional firefighters on the ground and in the air, partnering with firefighters from Canada, NZ, PNG and the USA.

I am aware of a number of our Members who regularly serve in the volunteer fire fighting services and who have been contributing everything in their local community and risking their own lives over the past few months to protect human life and to save homes and townships. They have put their lives on the line to support fellow Australians in these extraordinary circumstances – our thanks and appreciation will never be enough!

In the past two months as Australia's fires have become more expansive, more voracious and more destructive, I've received emails from across the globe from friends, geo-colleagues and affiliate geophysical societies, expressing the highest level of concerns for Australians and our country and offering to help in some way.

One of the emails received by the ASEG was from Professor George Apostolopoulos, National Technical University of Athens and Chair of the EAGE Near Surface Geoscience Division, who reflected on the horrific loss of life and environmental impacts from the 2018 wildfires in Greece. He expressed his personal sympathies that Australia is now facing a similar devastating bushfire crisis, also with tragic loss of lives. Professor Apostolopoulos referred to the positive collaboration between engineers, geologists, geophysicists and other earth and environmental scientists in dealing with the aftermath of the 2018 Greek fires, including landslides and building collapses and flooding and pollution to water ways and reservoirs as a result of the destruction of landscape. On behalf of EAGE, he offered "I am sure that both ASEG and EAGE can find ways to collaborate on better dealing with natural hazards … my wishes for this disaster to end soon in Australia".

In late November, I attended Science meets Parliament 2019 (SmP), an annual event arranged by Science & Technology Australia (STA) and hosted in Parliament House, Canberra. As a Councillor of the Australian Geoscience Council (AGC), I had the privilege of supporting Professor David Cohen, President of AGC, who led the advocacy of major geoscience issues of relevance to Australia, on behalf of the geoscience member organizations of the AGC. I also had the privilege of joining with Marina Costelloe, our Immediate Past President, who is now a Board Member of STA, responsible for representing the Geoscience and Geographical Sciences.

STA is Australia's leading representative and active advocate for STEM professionals and STEM education at all levels. Science meets Parliament, celebrating its 20th anniversary in 2019, brought together more than 200 of Australia's most engaged scientists, technologists, engineers and mathematicians across disciplines, states and territories and backgrounds to foster science connections and opportunities and share their science with the Members of the Parliament of Australia.

STA delivered an impressive formal program, cross-disciplinary workshops and valuable networking sessions over two days, with high profile presentations from Professor Fiona Wood, former Australian of the Year, and Dr Alan Finkel, Australia's Chief Scientist, and an impressive presentation by Professor Lisa Harvey-Smith, Australian Government's Women in STEM Ambassador at the National Press Club Lunch.

The STA President Professor Emma Johnston AO, in completing her term of office, emphasized the importance of engagement with our Nation's leaders at SmP,

"the STEM sector is central to Australia's strong competitive economy, resilient environment, and healthy population. With evidence-based policy, strong support for scientific research, better retention of our best minds in Australia – we will be well on our way to globalsuccess. With more STEM-skilled women and men in the workforce, we will have a much stronger foundation for innovation, and Australia's environment, health, wealth and wellbeing will all prosper".

STA arranged for small multidisciplinary groups (3-4 scientists) to meet one-on-one with individual Members of Parliament – in my view an extremely valuable opportunity to raise the awareness of our political leaders on the latest in science and technology thinking and breakthroughs and innovations in Australian science. I heard from many other scientists at SmP that there was very constructive questioning from Members on the latest science on climate change and likely future impacts for our environment, wellbeing and economy and also on the possible link to the early onset of devastating fires across Australia, ahead of the traditional fire season.

The Australian Geoscience Council's key strategies discussed at SmP, centred on Geoscience Education, Geoscience Advocacy and Geoscience Sustainability, and both Professor Cohen and myself presented within small working groups and to two Members of Parliament on three major mineral geoscience issues for Australia:

- Critical metals for a low carbon high technology economy
- National research programs to support next generation mineral discoveries
- Continuing professional development of geoscientists

I'm writing this piece in mid-January, immediately after returning from several weeks travelling through the central highlands of Sri Lanka with family. I've been fascinated with Sri Lanka for some time because of an involvement I had some years ago in supporting the training and scientific exchange between the Sri Lankan Geological Survey and Mines Bureau (GSMB) and Australian geological surveys. The regional mapping and mineral resource identification of Sri Lanka has been undertaken over the past decades by GSMB with support from the British Geological Survey and other international researchers, including Australian geoscientists – the excellent national maps produced in 1983 for Mineral Resources, Metamorphic Terrains,

Structure and Tectonics and Geology were printed with assistance of the Department of Mines & Energy South Australia and are still on sale today as primary reference maps.

The GSMB has an active Exploration Geophysical Unit which is routinely involved in magnetic mapping, resistivity, ground probing radar, seismic reflection and electromagnetic surveys applied to minerals, water and environmental studies and location of buried military ordinance. The GSMB and the Exploration Geophysical Unit are continuing to look for foreign technical assistance and funding to support the development of programs to undertake modern high resolution airborne magnetic and radiometric surveys of the country.

My personal geoscience interest in this visit was to see the Precambrian Highland Complex Rocks which form the spectacular vistas of the central mountain ranges with the highest elevations at 2500 m. The geology and resulting "granitic" soils, landscape and climate provide the perfect environment for Sri Lanka's premium tea growing industry and the steep valleys and high energy rivers shed material containing heavy mineral sands and Sri Lanka's famous gemstones onto the southern plains as secondary alluvial deposits. The mountain peaks and steep cliff faces of migmatitic gneisses are truly impressive.

Of further interest is the impact and aftermath of the 2004 tsunami on Sri Lanka's coastal regions. The tsunami resulted in the deaths of 40 000 people and a staggering 2.5 million people displaced. Sri Lankans are a positive and resilient people – it's inspiring to see their amazing efforts in recovering from this tragedy. The impact of the tsunami around the Indian Ocean led to the establishment in 2006 of the Indian Ocean Tsunami Warning System that operates in collaboration with the Australian Tsunami Warning System.

The region around the southern city of Galle was really devastated by the tsunami – it's compelling to see the photos and to read the accounts in the Tsunami Museum and to talk to the people on the longer term impacts of this natural disaster. During our visit to Galle and elsewhere, many Sri Lankans expressed sympathy and support to the people of Australia facing the devastating bushfires.

In the next issue of *Preview*, we will look to the activities and celebrations for the ASEG's 50th year.

Happy New Year to all!

Ted Tyne
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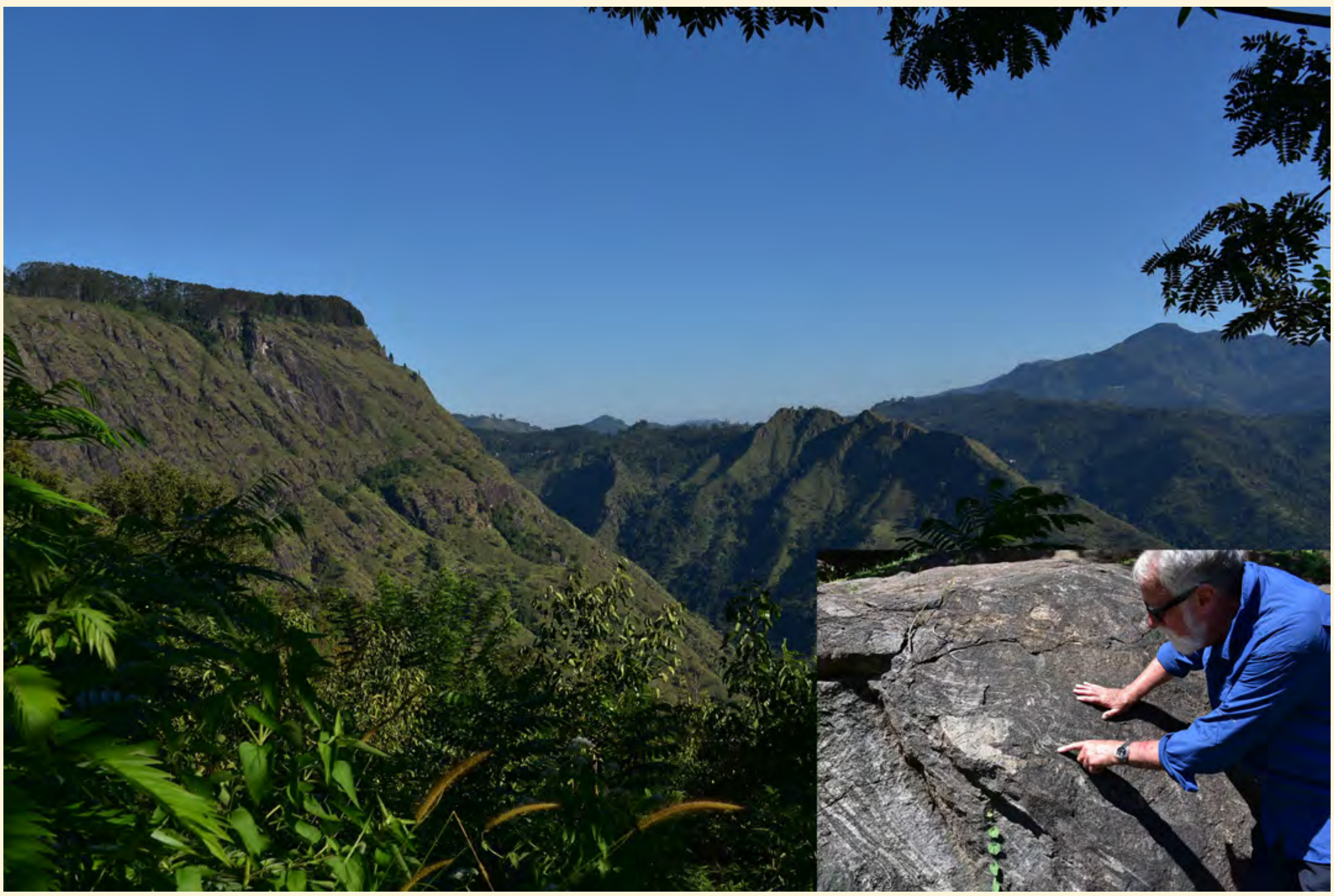

The Precambrian Highland Complex Rocks (granulite facies comprising migmatitic gneisses, quartzites, marbles and charnockites), once part of Gondwanaland, form the spectacular central mountain ranges of Sri Lanka. Inset: Large "elephant back" outcrops and steep cliff faces of migmatitic gneisses are impressive as rock art.

Executive brief

The Federal Executive of the ASEG (FedEx) is the governing body of the ASEG. It meets once a month, via teleconference, to see to the administration of the Society. This brief reports on the monthly meeting that was held in December 2019.

Finances

The Society's financial position at the end of December 2019:

Year to date income: $ 337 582

Year to date expenditure: $ 332 753

Net Assets: $ 848 521

Membership

At the time of this report, the Society has 588 Members renewed for 2020, it is good to see so many Members renewing early and taking advantage of the early-bird discount.

We encourage all our Members who haven't yet renewed for 2020 to do so as soon as possible.

2020 marks the 50th year of our wonderful Society whose success can be attributed to our excellent Member base – we look forward to another successful 50 years, which will only be made possible through your continued support – so remind your friends and colleagues and renew today!

Megan Nightingale
ASEG Secretary
fedsec@aseg.org.au

Notice of Annual General Meeting (AGM)

The 2020 AGM of the Australian Society of Exploration Geophysicists (ASEG) will be held at The Balcony Room at the Hotel Richmond in Adelaide on April 7, 2020. The meeting will be hosted by the SA Branch. Details will be supplied via email and the ASEG Newsletter. Drinks will be available from 16:00 and the meeting will begin at 16:30.

The business of the Annual General Meeting will be:

- To confirm the minutes of the last preceding general meeting;
- To receive from the Federal Executive reports on the activities of the Society during the last preceding financial year;
- To receive and consider the financial accounts and audit reports that are required to be submitted to Members pursuant to the Constitution and to law;
- To consider and if agreed approve any changes to the ASEG Constitution;
- To report the ballot results for the election of the new office holders for the Federal Executive;
- To confirm the appointment of auditors for 2019.

The AGM will be proceeded by a scientific presentation by a speaker yet to be determined.

Invitation for candidates for the Federal Executive

Members of the Federal Executive serve in an honorary capacity. They are all volunteers and ASEG Members are encouraged to consider volunteering for a position on the Executive or on one of its committees. Current members are listed in *Preview*; please contact one of them if you wish to know more about volunteering for your Society. Self-nominations are encouraged.

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 [Corporations] Act.'

The Federal Executive comprises up to 12 members, and includes the following four elected members:

(i) a President
(ii) a President Elect
(iii) a Secretary, and
(iv) a Treasurer

These officers are elected annually by a general ballot of Members. Dr David Annetts was elected as President-Elect in 2019 and as such will stand for the position of President.

The following offices are also recognised:

(i) Vice President,
(ii) the Immediate Past President (unless otherwise a member of the Federal Executive),
(iii) the Chair of the Publications Committee,
(iv) the Chair of the Membership Committee,
(v) the Chair of the State Branch Committees, and
(vi) up to three others to be determined by the Federal Executive.

These officers are appointed by the Federal Executive from the volunteers wishing to serve the Society. Nominations for all positions (except Past President) are very welcome. Please forward the name of the nominated candidate and the position nominating for, along with the names of two Members who are eligible to vote (as Proposers), to the President Elect:

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Nominations must be received via post, fax or email no later than COB Tuesday 10 March 2020. Positions for which there are multiple nominations will then be determined by ballot of Members and the results declared at the Annual General Meeting.

Proxy forms and further details of the meeting will be sent to Members prior to the meeting by email, and made available to Members on the Society's website.

ASEG Young Professionals Network: Recap of AEGC 2019

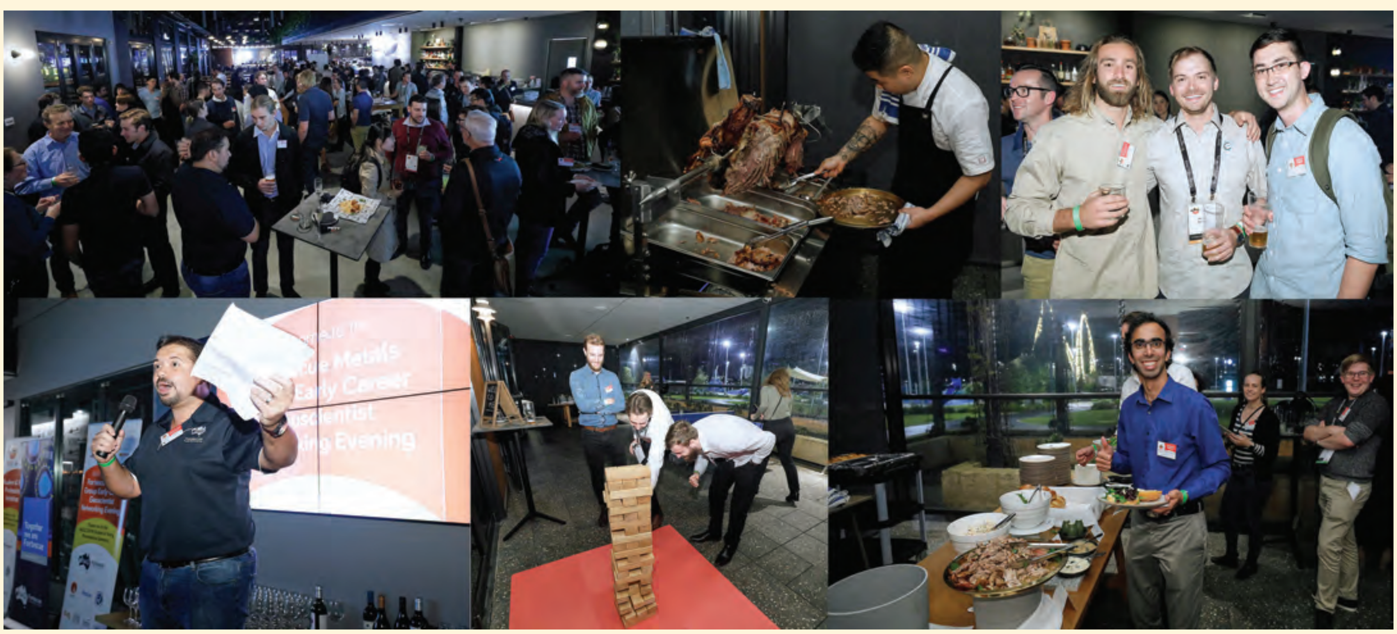
The AEGC 2019 Student and Young Professional Logistics Committee (from left to right); Michael Wentz, James Shuttleworth, Aldo De Rooster, Cam Adams, James Regan and Max Clarke (absent Gregory Poole).

The AEGC 2019 was a big week for many geoscientists, including students and young professionals. The AEGC 2019 had 70 student conference registrants, of which 26 were from interstate and six from overseas. Postgraduate students were an important demographic and contributed significantly to the technical programme – 22 oral presentations and 16 posters were made by students. Student interests were split almost equally between minerals and petroleum. Several students identified other interests including geothermal, hydrogeological and environmental. The student registrant category had the highest participation of women (just over 37%, vs ~23% for the whole conference delegation).

The AEGC 2019 ran a number of successful student and young professional initiatives. These initiatives would not have happened without the support of AEGC 2019's wonderful student and young professional sponsors: Our thanks goes to patron sponsor, Fortescue Metals Group; premier sponsors Sandfire Resources, Santos, and Portable Spectral Services; and corporate sponsors Pells Sullivan Meynink, Newmont Goldcorp, DownUnder GeoSolutions, and the Centre for Exploration Targeting with the School of Earth Sciences (The University of Western Australia). An additional thanks go out to Fortescue Metals Group, Santos and Sandfire for the donation of gifts for each of the student days. The AEGC 2019 student and young professional initiatives had many moving parts, and it wouldn't have been a success without helpers – my appreciation goes to James Regan, Max Clarke, James Shuttleworth, Michael Wentz, Aldo De Rooster and Greg Poole.

AEGC 2019 Early Career Geoscientist Networking Evening (2 September)

The Fortescue Metals Group Early Career Geoscientist Networking Evening has earned a place in the hearts of many geoscientists as a night to remember. Over 170 attendees registered with ~130 braving the rain (or bravely continuing from post-workshop drinks and the ice breaker) to join in the festivities at Australia's largest pub, The Camfield. There was a lamb spit roast cart to complement the endless supply of canapés and pizzas, giant jenga and table tennis on the terrace, and a generous bar tab that catered to all palates (including the scotch, cocktail and fine wine



Action shots from The Fortescue Metals Group Early Career Geoscientist Networking Evening (photos courtesy of David Broadway Photography).

drinkers!). Over 30 students tried their hand at the "new member society sign up" lucky draw for 3 x $100 gift cards (one for ASEG, PESA and AIG). The night was filled with plenty of stories and laughs. Many business cards were exchanged. Needless to say, there were a few sore heads, red-eyes, and sorry sights at the opening ceremony the next day. However, all was forgiven, as it was a truly great way to meet fellow AEGC 2019 attendees and build those networks.

AEGC 2019 High School Student Day (4 September)

Over 65 high school students and accompanying teachers attended the AEGC 2019 High School Day. Year 10-12 students from Gilmore College, IONA, and Kent Street Senior High School had a jam-packed day. Marita Bradshaw presented her special student-focused keynote talk "Australia in Seven Rocks" and also got to showcase some interesting specimens during the break. Career insight talks covered the complete spectrum of geosciences – our thanks goes out to Deepika Venkataramani, Rylan Fabrici, Rosie Sloan, Joshua Bell, Naomi Potter, and Thomas Harris for showcasing their professions. Two special "studying geoscience and university life" presentations gave an overview of local campuses and demystified (or confirmed) what really happens at the undergraduate level. Students were encouraged to ask sponsors and presenters candid questions over a buffet lunch. The day concluded with small-group tours of the exhibition hall.

AEGC 2019 Tertiary Student Day (5 September)

The AEGC 2019 Tertiary Student Day was a free event open to all tertiary geoscience students and all conference delegates. Students from TAFE and all levels of university attended. The AEGC 2019 Tertiary Student Day offered candid career talks from Stuart Badock, Paul Polito, Rosie Sloan, Robert Seggie and Aldo De Rooster. Some pragmatic advice aimed at those starting out in the industry was heartily given – There was a common theme that companies are expressly interested in graduates with a minimum of honours or masters. Fortunately, Alan Aitken (UWA) was on hand to explain tertiary education options after undergrad. The AIG National Graduate Group followed suit and promoted additional ways in which to develop professionally via their mentoring programmes and activities. The Frank Arnott Award committee launched its exciting new challenge and took the chance to allow the previous year's entrants to explain how the award helped their professional development and careers.

The expert Q&A panel was a hit, and it was great to have lots of students ask difficult but very important questions. We were very fortunate to have Simon Marshall, Steve Garwin, Natasha Hendrick and Bruce Craven as the panel experts. Students continued

A jam-packed AEGC 2019 High School Student Day (photos courtesy of C J Adams).

The Expert Q&A Panel. Seated from left to right; Simon Marshall, Steve Garwin, Natasha Hendrick, and Bruce Craven

their discussions with presenters, and chatted with sponsors (and familiar faces from the networking night) while having a buffet lunch – more business cards were exchanged and several bold students lined up job interviews. The afternoon was set aside for students to continue their conference experience and autonomously sit-in on afternoon technical sessions, view the posters, wander the exhibition, join the conference closing session and, importantly, continue to network at the farewell drinks.

AEGC 2019 workshop student placements

The AEGC 2019 Conference Organising Committee was more than pleased to offer 30 students placements for one of five specially selected workshops i.e. "Exploring presentation – extracting engagement" (W6), "QGIS for geoscientists"(W10), "Digital disruption in exploration" (W13), "Drill core data exploration and integration" (W14), or "Mentoring: Networking, confidence, diversity" (W17). Full Conference or Tertiary Student Day student delegates were eligible to apply. These placements were snapped up quickly, and importantly gave many undergrads, honours and masters students their first workshop (and conference) experience. A further two student placements were offered by the Women Geoscientists in Canada for W6, and 2 student placements by Geoscience Australia for W17.

AEGC 2021 and student bursaries

On a final note, ASEG, PESA and AIG offer grants to students to use for research purposes and to attend conferences. The AEGC 2021 in Brisbane will be an excellent conference for students to attend (or even present). In addition, it is worthwhile checking with state branches as many also offer their own bursaries (e.g. the ASEG WA Branch will be offering several generous bursaries for AEGC 2021). Please check your inboxes and university notice boards in early 2020!

See you at the AEGC 2021!

Cam Adams
AEGC 2019 Co-Treasurer, Student Chair and Young Professional Chair
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Welcome to new Members

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

First name	Last name	Organisation	State	Country	Membership type
Brad	Cox	Resource Potentials	SA	Australia	Active
Cameron	Fellows	Canadian Micro Gravity Operations	WA	Australia	Active
Rohtash	Kumar	Banaras Hindu University International		India	Active
Emmanuel	Onyebueke	Witwatersrand University		South Africa	Student
Andre	Souza	Curtin University	WA	Australia	Student
Ian	Unsworth	Contractor/consultant	QLD	Australia	Active
Luke	van Leeuwen	HiSeis	WA	Australia	Active
Qing	Yi	University of Queensland	QLD	Australia	Student
Siyuan	Zhao	Australian National University	ACT	Australia	Student

ASEG Branch news

South Australia & Northern Territory

Happy New Year to all!

The ASEG SA/NT Branch ended the decade with not one, but two Christmas parties! The first was a Christmas special edition of the semi-regular GeoFamily picnic, co-hosted with the GSA and AusIMM on 8 December at the Point Malcolm Reserve in Semaphore Park. Those who attended had an enjoyable time and were entertained with a number of activities including making Christmas decorations, origami, macramé plant hangers-complete with plants, and rock painting.

GeoFamily Christmas picnic 2019

GeoFamily picnics are held to promote a healthy work/life balance, professional networking activities, and allow everyone a chance to be involved in our professional organisations. The events are also a great way to foster a love of outdoors, adventure and nature play with the next generation of geoscientists. Keep an eye out for our next GeoFamily event (you don't need children to come along and enjoy these informal networking events with your peers!).

Our annual student honours night and Christmas party was on 12 December at the Hotel Richmond. This event was generously sponsored by Santos. **Bonnie Lodwick** from Santos spoke about the geophysics programs within Santos followed by four students who each gave fantastic presentations on their honours projects. The speakers, their affiliation, and their project title are as follows:

- **James Brown**, Geology and Geophysics, The University of Adelaide, "Analysis of fault growth in the Otway Basin using 3-D seismic analysis"
- **Celina Sanso**, Geology and Geophysics, The University of Adelaide, "Compositional controls on the thermal conductivity of metamorphic rocks"
- **Matt Linke**, Geology and Geophysics, The University of Adelaide, "Thermal Isostasy - Modelling Antarctic Surface Heat Flow"
- **Luke Haig-Moir**, Australian School of Petroleum, The University of Adelaide, "Design and Optimisation of Multi-stage Hydraulic Fracturing of a Horizontal Well in a Deep Coal Reservoir in the Cooper Basin, South Australia".

Congratulations to all of our speakers, but in particular to James Brown for winning the best presentation, and Celina Sanso, for runner-up. James and Celina both took home an ASEG sponsored monetary prize, and all four student speakers took home a bottle of the ASEG wine.

Student presenters at the annual SA Branch student honours night

Our branch is hosting Dr **Lisa Gavin**, Woodside Energy, an SEG Honorary Lecturer at the Coopers Alehouse on Tuesday 11 February, 5:30 pm for a 6:15 pm start. Lisa will be speaking about "Regional to reservoir stress-induced seismic azimuthal anisotropy". It's sure to be a great evening so mark it in your calendar.

And lastly, a friendly reminder to renew your membership for 2020! Last year the SA/NT Branch hosted 19 events, including one short-course, nine technical evenings or lunches with 19 different speakers, six of whom were from interstate or overseas. Most of these events were free to Members. We also hosted various networking events including our annual wine night and Melbourne Cup event. We look forward to delivering you another exciting year of technical, educational and networking events.

Kate Robertson
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Tasmania

ASEG Members might be interested in an Australian Geomechanics Society workshop on "InSAR and its application for understanding ground movement", which will be held in Hobart 12 – 14 February 2020. This workshop will provide end-users and those commissioning imagery a basic understanding of the technique and its limitations in order to improve success and avoid disappointment. The workshop will be delivered by Dr **Berhard Rabus** (Simon Fraser University), an expert in InSAR technology, and Dr **Nicholas Roberts** (Mineral Resources Tasmania), an experienced InSAR end-user. See details on the AGS website https://australiangeomechanics.org/courses/ags-tasmania-radar-interferometry-workshop/ for registration.

An invitation to attend Tasmanian Branch meetings is extended to all ASEG Members and interested parties. Meetings are usually held in the CODES Conference Room, University of Tasmania, Hobart. Meeting notices, details about venues and relevant contact details can be found on the Tasmanian Branch page on the ASEG website. As always, we encourage Members to also keep an eye on the seminar 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
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Victoria

Why, oh why does our plucky Editor inflict such a draconian deadline for submission of branch news to *Preview* as the first week in January?!?! Maybe if I pretend to forget to write the Victorian contribution as I did this time last year, Lisa will write a generic one for me? LOL. As I attempt to put pen to paper (who does this still?), I am trying my hand at angling on the Tambo River in picturesque Metung. At the same time, I am compelled to discover more about this regional area of the Gippsland Basin that was once Australia's premier hub of the oil and gas industry. Of course, no sooner had I started writing this piece that my line caught a snag – a common hazard on the amateur circuit I'm told.

Onto business! Our last speaker of 2019 was **Hammad Tariq**, whose talk was titled "Vertical Seismic Profiling" or 'VSP' to the layman. Hammad gifted the unusually large audience in attendance on that unforgettable November night a recital on exploiting VSPs to help unravel the subsurface under investigation. I counted at least 14 ways one could configure a VSP survey to achieve a specific outcome. Strewth! It reminded me of the Forrest Gump movie scene where Bubba tells Forrest the number of ways he could prepare shrimp. "Shrimp is the fruit of the sea. You can BBQ it, boil it, broil it, bake it, sauté it, there's uh… shrimp kebabs, shrimp creole, shrimp gumbo, pan fry, deep fry, stir fry, there's pineapple shrimp, lemon shrimp, coconut shrimp, pepper shrimp, shrimp soup, shrimp stew, shrimp salad, shrimp and potatoes, shrimp burgers, shrimp sandwiches." Anyway, you get the idea. There's probably VSPs for vegetarians too, I'm sure.

I hope all Members had a relaxing and enjoyable break during the festive season. We had a great line-up of presenters last year, but in 2020 I've decided to raise the ante. All presenters at a Victorian Branch Technical Meeting Night this year will go in the running to win $1 000 000 in cold hard cash when voted the best presenter for 2020*. Of course, I've yet to gain clearance from the Federal Executive Committee to empty their bank accounts but I'm sure I won't encounter any pushbacks whatsoever. Honest. Anyway, back to my drinking… I meant fishing ☺

* Payable at the rate of $1 per year over the next one million years.

Victorian Branch meetings are generally held on the third Thursday of each month from 17:30 in the Kelvin Club, 18 – 30 Melbourne Place, Melbourne. Meeting notices, addresses and relevant contact details can be found on the Victorian Branch page of the ASEG website.

Thong Huynh
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Western Australia

Firstly, as the new WA President representing the rest of the 2020 Committee, I'd like to wish you all a great new year. We, ourselves, had a very successful ASEG WA 2019 Branch Christmas party and AGM on December 11, with 30 Members attending. Although the General Meeting itself was short, decisions were made, budgets discussed, the 2019 Committee properly thanked, gifts were given, and the 2020 WA Committee finalised. The selfie below captures a bit of the energy that was there. The fresh and new 2020 WA Branch Committee is:

Todd Mojesky, President

Partha Pratim Mandal, Secretary

Mathew Cooper, Treasurer

Carolina Pimentel, Mentor programme officer

Tom Hoskin, University officer

Andrew Fitzpatrick, Golf officer and **Brett Harris, Amir Hashempour Charkhi, Karen Gigallon, Luisa Herrmann, Jennifer Market, Tasman Gillfeather-Clark, Darren Hunt**

Many thanks from the 2020 WA Branch Committee to the 2019 WA Branch Committee for all their contributions to the success of the Society here in WA. Again, best wishes to all in the New Year.

The 2019 WA Branch AGM and Christmas party

In WA monthly technical meetings are generally held on the second Wednesday of each month and highlight topics within the geophysical fields of petroleum, mining, exploration, near-surface, and hydrogeology. Please refer to the Events page on the ASEG website for details of upcoming presentations and events.

Todd Mojesky
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Australian Capital Territory

The ACT Branch held its Christmas Dinner on November 28 at the Rubicon Restaurant in Griffith, ACT. This followed an excellent talk by Dr **Babak Hejrani** on the subject of "Earthquake catalogues and 3D earth structure: a coupled problem". An interesting aspect of Babak's talk was the revelation that the International Seismological Centre (ISC) fixes the depth parameter of earthquakes arbitrarily, with peaks at 10, 33 and 35 km. This is done when the depth cannot be constrained and, as such, the values should not be interpreted. Babak also discussed his new earthquake catalogue for Papua New Guinea and the Solomon Islands and showed a high-frequency simulation of the 2016 Petermann Ranges earthquake in central Australia, based on 3D earth models.

Our program for 2020 is not fixed at present, but will certainly feature the presentation of the initial Dr Peter Milligan Student Award for Geophysics to **Rebecca McGirr** at our AGM, to be held in February or March. This presentation was postponed from November 2019.

Grant Butler
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New South Wales

In November, **Andrea Sosa Pintos** (CSIRO Manufacturing) presented a talk entitled "Nanosensors for groundwater quality monitoring in real-time". Andrea firstly described the development of chemiresistor sensor technology, while a nanosensor was passed around the audience (the sensor was very small indeed!). The presentation focused on the use of nanosensors to detect benzene, toluene, ethylbenzene and xylenes (BTEX) in groundwater underneath petrol stations, this method provides accurate, continuous data in real time, thereby eliminating risk of sampling errors and delayed assessment

of potential hazards. Further advantages of nanosensors include that they can be re-used and can detect both the volatile and non-volatile phases. These attributes enable nanosensors to be applied to various other environmental, food and biological monitoring applications. Andrea's presentation of this interesting and exciting technology resulted in many questions that were discussed over beer.

Keith Leslie *(CSIRO), Andrea Sosa Pintos (CSIRO manufacturing) and* ***Steph Kovach*** *(ASEG NSW secretary) at the November Branch meeting.*

December saw the replacement of the usual technical talk with a more festive annual ASEG NSW trivia night. This year a small trivia team put their heads together and came up with trivia questions that ranged from the topics such as the goldfields of the Klondike and the Australian 1 cent coin to geomancy (which does not involve the conduct of a romance across multiple oceans and continents). These questions were met with much enthusiasm by the knowledgeable audience. The winning teams received prizes, kindly donated by the Geological Survey of NSW and Bridgeport Energy Limited. Another vote of thanks goes to **Mike Smith** and **Josh Valencic** for their involvement.

An invitation to attend NSW Branch meetings is extended to interstate and international visitors who happen to be in town at that time. Meetings are generally held on the third Wednesday of each month from 5:30pm at Club York. Meetings notices, addresses and relevant contact details can be found at the NSW Branch website. All are welcome.

The NSW Branch Trivia night was kindly hosted and MC'd by ASEG NSW Member Mike Smith. Despite the scores being tied up at eight points per team at the half way point, Team 4 managed to nab the win with several correct (lucky multiple choice guesses) at the tail end of the evening. Congratulations to the winners (Team 4 – top image) and runners up (Team 3 – bottom image). The prizes comprised several exploration and oil themed 'short' reads provided by Bridgeport, and geological maps kindly provided by Geological Survey of New South Wales.

Mark Lackie
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Stephanie Kovach
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Queensland

The QLD ASEG Branch ended our year with a November technical talk, the wrap up of our 2019 mentoring program and a joint industry Christmas Party.

On November 12, **Matt Greenwood** of the GSQ gave a talk about open data promoting exploration in Queensland. There was a dozen people and plenty of questions. The GSQ has undergone several transformations in data management to enable better discovery and accessibility of the data it maintains. The talk focused on the development and benefits of the QDEX Data system and the principals of open and FAIR data that underpin the new Geoscience Data Modernisation Program. The GSQ has carried out a large number of data acquisition programs in the last few years, which many QLD ASEG Members have been busy analysing.

The 2019 joint Mentorship Program between ASEG and PESA wrapped up at the Charming Squire in Brisbane's South Bank on 22 November. It was a good excuse to catch up and relax at the end of a busy year. Participants exchanged ideas and stories and provided feedback for the 2020 Mentee-Mentor Program, which will be re-launched in March 2020.

The joint society Christmas Party (ASEG-PESA-FESQ-SPE-QUPEX) closed out the year on December 5, at Jade Buddha overlooking the Brisbane River. The event was well attended with over 220 people present. **Nick Josephs** gave a quick overview to the attendees on ASEG's 2019 local Branch meetings. There were drinks, quizzes and prizes given out with the party going well into the night. The overall mood was positive for the exploration geophysics industry in 2020.

The QLD Branch hopes everyone had a restful break over Christmas and New Year and wish all our Members well for the new decade ahead. As always, Members are encouraged to contact the Committee with any suggestions, and we're on the lookout for technical talks for 2020.

Ron Palmer
qldpresident@aseg.org.au

ASEG national calendar

Date	Branch	Event	Presenter	Time	Venue
11 Feb	SA-NT	SEG HL	Lisa Gavin	17:30	Coopers Alehouse, 316 Pulteney St, Adelaide
12 Feb	WA	SEG HL	Lisa Gavin	17:30	TBA
12-14 Feb	TAS	GMS InSAR Workshop	Berhard Rabus and Nick Roberts	09:00	Hobart
19 Feb	QLD	Tech talk	Lucy MacGregor	17:30	XXXX Alehouse, Black St, Milton, Brisbane
19 Feb	NSW	AGM	TBA	17:30	99 on York Club, 99 York St, Sydney
21 Feb	WA	GSWA Open Day	Various	08:30	Esplanade Hotel, Fremantle
11 Mar	WA	Tech night	TBA	17:30	TBA
18 Mar	NSW	Tech night	TBA	17:30	99 on York Club, 99 York St, Sydney
7 Apr	SA	ASEG AGM	TBA	16:00	The Balcony Room, Hotel Richmond, Adelaide

TBA, to be advised (please contact your state Branch Secretary for more information).

ASEG Research Foundation

Attention: All geophysics students at honours level and above

- **You are invited to apply for ASEG RF grants for 2020.**
- Closing date: **28 February 2020**.
- Awards are made for:
  - BSc (Hons) Max. $5000 (1 Year)
  - MSc Max. $5000 per annum (2 Years)
  - PhD Max. $10 000 per annum (3 Years)
- Application form and information at: https://www.aseg.org.au/foundation/how-to-apply
- Awards are made to project specific applications and reporting and reconciliation is the responsibility of the supervisor.
- Any field related to exploration geophysics considered, e.g. petroleum, mining, environmental, and engineering.
- The completed application forms should be emailed to Doug Roberts, Secretary of the ASEG Research Foundation: dcrgeo@tpg.com.au

ASEG Research Foundation

Goal: To attract high-calibre students into exploration geophysics, and thus to ensure a future supply of talented, highly skilled geophysicists for industry.

Strategy: To promote research in applied geophysics, by providing research grants at the BSc (Honours), MSc, and PhD level (or equivalent).

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

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

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

Hans Lundberg: Canada's (and possibly the World's) first minerals geophysicist is inducted into the Canadian Mining Hall of Fame

Ken Witherly
Condor Consulting, Inc.
ken@condorconsult.com

Introduction

Hans Lundberg was a geoscientist whose career spanned the first half of the 20th century. He was part Indiana Jones, part Howard Hughes and part Jules Verne. He was born in 1893 in Malmö, Sweden and died in 1971 in Toronto, Canada. Early in his career, he discovered significant extensions to the Buchans ore body (Newfoundland Canada) and finished with a 'score card' of being directly involved in the discovery of mineral deposits worth $CAN5B in 29 countries, many of which became mines. He developed the first functioning airborne electromagnetic (EM) system for minerals prospecting and was an early adaptor of aeromagnetic survey techniques, including the first to apply helicopters to carrying magnetic sensors. He fostered the early development of airborne radiometrics, and experimented with an early version of airborne gravity. His interests were not confined to minerals and he provided consulting services for the oil industry. Besides the pursuit of mineral and oil deposits, Lundberg successfully applied geophysical techniques to hunt for evidence of early humans in what is now central Mexico, and to locating meteorite fragments inside a crater in the Arizona desert. He was an early proponent of the value of petrophysics to help design and interpret survey results. While never his primary focus, Lundberg played a critical role in advocating the early use of exploration geochemistry in Canada, encouraging a number of key scientists who were seen as laying the foundations for modern geochemical practice in North America. Lunderg's role was such that he has been called the father of Canadian geochemistry (Brummer, Gleeson, and Hansuld 1987). He presented over 70 papers on geophysical and geochemical technology at meetings in North America and Europe. He developed what we would now call 'best practice' as to how to conduct modern exploration, and had a strong entrepreneurial flare that allowed him to draw many investors into his projects. He shared a vision for the future of exploration that in many respects was uncannily accurate in describing the world fifty years ahead of the one in which he lived. While many significant contributors came after Lundberg, he stands as a titan who truly led the way. In 2020 Lundberg was inducted into the Canadian Mining Hall of Fame in recognition of his enormous contributions to the minerals industry and exploration in particular during its critical formative era.

Hans Lundberg at a joint USGS-GSC meeting on aeromagnetic technology in Ottawa, September 1946. The USGS was using Gulf technology, but Hans Lundberg built his own equipment to avoid patent issues.

A life lived

No formal biography or autobiography of Lundberg exists. If he kept a diary, it has not been preserved. While the official records show he travelled extensively, indirect evidence suggests he travelled much more than has been documented. The available record consists of dozens of professional papers spanning the 1920s – 1950s, plus a number of magazine articles about Lundberg, the most significant being in the *Maclean's magazine* (Newman 1957). As well, a collection of business papers donated to the Archives of Ontario provide some additional background on Lundberg's complex life. Given the importance of the Buchans discovery to the Newfoundland and Labrador economy and mining in Canada, Lundberg's role in this event was well documented. The exploration industry for much of Lundberg's early career (pre-World War 2) was for the most part a few individuals experimenting with techniques they had developed or modified from the work of others. Equipment manufacturing or survey companies did not exist in the form they do now. However, some comments from the era suggest that opportunists abounded and in the absence of any formal professional regulation, much practice of questionable value was carried out. Many of Lundberg's early career talks and publications were of a tutorial nature, as he tried to pass on the basics of survey systems and the best practice in their use. His technological reach expanded enormously post-World War II, when he could finally acquire high resolution geophysical data from an aircraft. While detailed records are lacking, there is more than enough evidence that Lundberg's teams travelled the world performing surveys for minerals and oil, both it seems on a straight fee-for service basis and for a possible piece of the action. While Lundberg made early contributions to airborne EM technology, in the 1950s he chose to, in effect, pause his own efforts and wait for the new technology that was being developed in Scandinavia. In this period as well, he developed an interest in airborne gravity. The complexity of airborne gravity measurement was not appreciated in this era, and Lundberg was seen to have attached his energies

and credibility to a problem that could not be solved. On the airborne EM front, in the later part of his career, he took considerable interest in the Barringer/Selco INPUT system and, in 1965, facilitated a successful test of INPUT over the Kiruna Mine in Sweden. His career wound down through the late 1960s, and when he died in 1971 the Lundberg Epoch was over.

Early career

Lundberg graduated from the Royal Institute of Technology, Stockholm, Sweden in 1917. His thesis was entitled "Electrical Prospecting". Lundberg's earliest contributions were carried out in Sweden on the application and interpretation of data from instruments designed for measuring electrical currents around sulphide deposits. Following the work of Conrad Schlumberger before WW I, Swedish physicists, led by G. Bergstrom, began developing prototype electromagnetic (EM) instruments that superimposed an applied electrical field and measured the resultant secondary field. Magnetic measurements were also obtained routinely using a variety of instruments. Lundberg and Harry Nathorst, while carrying out field surveys for an industry – government consortium, developed a new field variation of equipotential surveying that measured conductivity using two long, parallel electrical wires instead of the conventional two electrode mode. Designated by the Swedish Geological Survey as the Lundberg-Nathorst method, it proved much more sensitive and practical for field use in a cold climate and resulted in the discovery of two important orebodies in the Skelleftea District; Kristineberg in 1918 and Bjurfors in 1922. In this time frame Lundberg also showed an interest in conducting magnetic surveys from aerial platforms; he believed this would provide better access and faster coverage than afforded by ground surveys. To this end he experimented with instruments carried aloft by kites, gliders and large balloons. However, it was not until 25 years later, after World War II, that his vision of airborne geophysics could be practically realized.

In 1923 Lundberg joined the Swedish American Prospecting Corporation and for the next three years, carried out surveys in the US, Canada, Scandinavia, Belgium, France, Germany, Spain and Mexico. In 1926 ASARCO asked him to go to Buchans where he carried out equipotential surveys that resulted in several major mineral discoveries.

Mid-career: post-Buchans to World War II

During the period from 1926 – 1939, Lundberg continued working at Buchans and then broadened out when he started his own consulting business; Hans Lundberg Limited. It was during this time he developed a business model where his company could carry out contract surveys for a fee-for-service or take shares in the client company. If he invested, Lundberg would stay in until he could see if the company would take off or not and then move on, having no interest in being involved in the downstream development. In 1936, in Canada alone, his company worked in seventeen parts of Canada on 46 different projects. By 1940 he claimed to have been involved with 1 000 ground surveys covering 18 000 km^2.

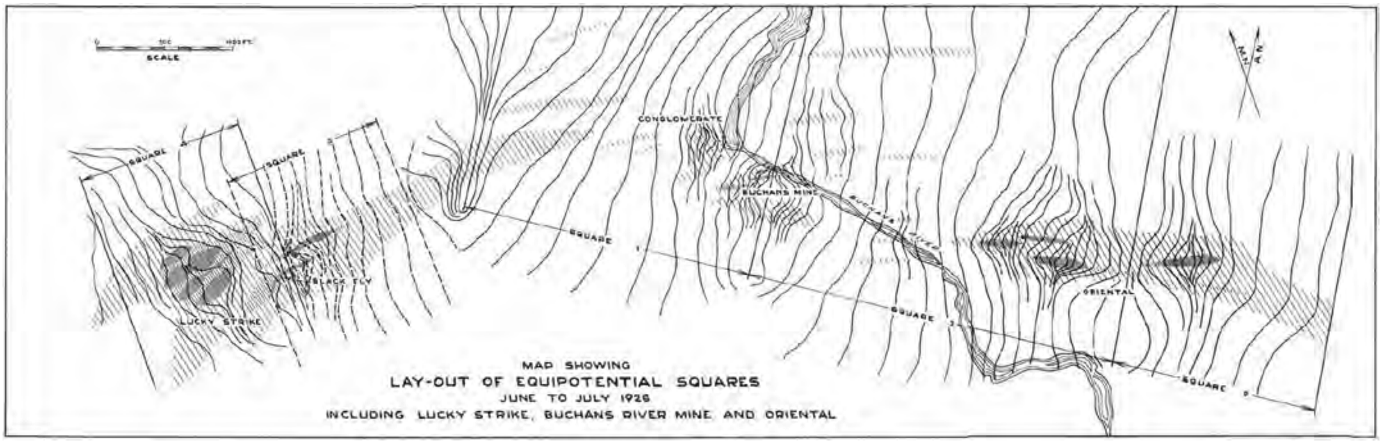
His interests were always varied and during this period he used his electrical techniques to locate 'lost' bootlegged champagne on a scion's estate. In 1937 he undertook a magnetic survey over the Barstow Crater in Arizona. Whereas previous efforts by another well-known geophysicist were inconclusive, Lundberg's survey produced clear evidence of a magnetic body located at the south end of the crater floor. Subsequent drilling in this location encountered blocks of Ni-Fe until, at 200 m depth, the drilling encountered an 'impenetrable' object, thought to be the main meteorite body.

In addition, during this time, he experimented with his ideas on using geo-botany, first around Buchans and then on other sites as a means to conduct geochemical exploration. He documented this work in an AIME publication in 1940.

War years

In 1942, Lundberg was asked by the US government to carry out an exploration program in Greenland to investigate the presence of the mineral cryolite (an uncommon mineral then used as a flux in the manufacture of aluminum) at that time a strategic mineral for the war effort. Greenland was deemed as "occupied territory" (Demark was occupied by Germany at the time) so Lundberg's clandestine mission was likely sponsored by the OSS (precursor to the CIA). Lundberg also authored a number of position papers regarding the war effort, including a co-authored paper with Norm Keevil Sr. entitled "Geophysics and the Ontario War Effort". In 1941 Lundberg also authored a paper entitled "Emanations over Oil Fields and Ore Deposits and Geochemical

Part of the Buchans crew (ca 1928): J. Ward Willaims is seated next to the doorway and Hans Lundberg is standing next to him. George Gilchrist is standiing on the left of the photo (source: Buchan Miners Museuem).



Hans Lundberg's iso-potential image from Buchans (source: Lundberg 1957).

Possibilities in Canada". This was the first Lundberg paper that discussed petroleum, a topic which he focused on in later years.

Post-war years

In the post-war era, Lundberg's "dream" of aerial geophysics developed rapidly. Governments and industry were intrigued with the concept of aerial geophysical surveys, and airborne magnetics was the first of these ideas to be implemented, largely due to work by the US Navy in refining magnetic sensors developed in the late 1930s by Gulf Research, which were commercialized in the post-war era. While most of the industry focused on fixed wing applications for airborne surveying, Lundberg was intrigued by the very new helicopter platform, and was the first to bring this technology into Canada for commercial use. His younger son Sten, a former RAF fighter pilot, became the first commercial helicopter pilot in Canada. In 1946, with great fanfare (*The Globe and Mail* 1946), Lundberg lead an expedition to "the north" where the new heli-borne magnetic surveying would be applied. In that year Lundberg also developed the first airborne EM system. While the system was very limited in its capabilities, it fired the industries' imagination and within a few years, two functional commercial systems were built; one by Lundberg for Conoco Oil who were looking for an innovative means to find petroleum, and the other by McPhar Geophysics for INCO. In the early 1950s, he began investigating the application of radiometrics to minerals and oil exploration, and then in the mid-1950s he championed technology which claimed to measure gravity from the air. This technology in the end provided unviable and Lundberg's reputation likely suffered as a result. As an explorer-geoscientist however, taking risks and not being overly concerned with the opinion of the community were likely critical factors in his career-long success at innovation and discovery.

Through the 1940s, Lundberg encouraged a number of younger scientists to study geochemical techniques for minerals exploration. This group, documented in Brummer, Gleeson, and Hansuld 1987, went on to form the foundations of modern exploration geochemistry in Canada.

The inquisitive Lundberg continued to provide his talents for "interesting" problems and in 1947 assisted with an anthropologic investigation near Mexico City. A piece in *Life* (1947) highlighted how Lundberg used electrical survey methods to find millennium-old early human burial sites.

The communicator

Lundberg's first paper was in 1919 and last in 1960; a total of 70 were in English and there are likely another 15 in Swedish (Lundberg was conversant in eight languages). Almost all of the papers involved an oral presentation as

Hans Lundberg and his son Sten (to the right of the Bell 47B2) standing next to the magnetometer that projects from the bubble (source: Bell Helicopter/Jeff Evans and Ned Gilliand Collections).

Bell 47B2 helicopter showing the magnetometer attached to the front of the bubble. Bell pilot Jay Demming is in the left seat (on the right in the photo) and Hans Lundberg is seated next to him (source: Bell Helicopter/ Jeff Evans and Ned Gilliand Collections).

well as a full paper. This required a large amount of often time-consuming travel, usually by train since the commercial airline industry was in its infancy during most of Lundberg's career. The early papers were very instructional in nature as Lundberg (as well as a few others) tried to educate the emerging minerals exploration community about what geophysics and then geochemistry could achieve. Lundberg made an impression on his audiences. An emeritus professor in his mid-80s from the University of Toronto was asked about whether he had encountered Lundberg. He remembered a talk Lundberg gave in 1951, when he was a student and Lundberg was speaking to a group of physics and geology students at an event called the "Skule Dinner". Lundberg related the story about finding the 'lost' cases of champagne. Being a good scientist, Lundberg did not undertake this exercise without a trial and had a number of cases with empty bottles buried to establish that a signature could be obtained with his equipment before he went after the real target. He was paid for his efforts in champagne.

Hans Lundberg conducting an iso-potential survey at Tepexpa in Mexico (source: Life 1947).

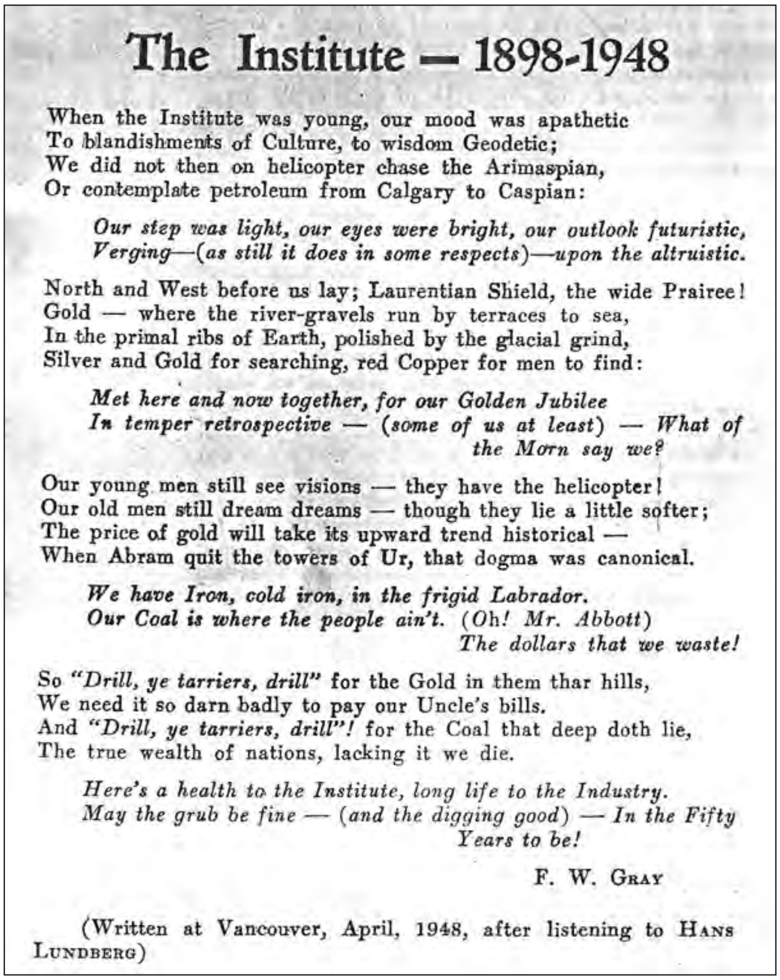
At a CIMM (Canadian Institute of Mining and Metallurgy) conference in 1948 Lundberg presented some of his ideas as to how exploration would look like in the future. Several of his "predictions" were:

- *To reach orebodies with geophysical methods, we gradually have to increase our range at depth. The so-called ' transient methods' have already shown, in encouraging experiments, that depths as great as 10 000 feet (~3 km Ed.) may be reached without too many difficulties.* ***.*** *Without much imagination, we may anticipate developments within the next few years to show remarkable new methods. All topographic mapping, as well as magnetic and electrical surveys, will be carried out from the air. For detail surveys, the helicopter-borne magnetometer and electrical equipment may render as much detail information as any ground survey. Regional studies employing radioactive and geochemical methods may cover very large areas in surprisingly short time.*
- *The habit of drawing maps that show two dimensions only will be succeeded by new stereoscopic projections so that the geophysical results will be seen in three dimensions, either on a screen or by using polarized light and specially prepared maps. Such maps will show, besides the topography, the position of the anomalous body at its proper position below the surface. In this way, when the orebody can actually be seen at depth, in this way it will be easy to aim drill holes or plan mining operations.*

This was in 1948 when much of modern exploration practice was still in its infancy. What Lundberg suggested has become common practice in the last decade, 60 years after he presented his ideas in Vancouver. A geologist in the audience was so moved by Lundberg's presentation, that he wrote a poem expressing the feelings that Lundberg's talk invoked in him; the CIMM published the poem following year (see following page).

In January 2020, Lundberg was inducted into the Canadian Mining Hall of Fame in recognition for his contributions to the Canadian mining industry and development of modern geophysical practice.

All references cited in this article plus more information on Lundberg's career is being assembled and will be posted onto the DMEC web site (www.DMEC.ca) under the "Resources" section in the next couple of months.



The Institute — 1898-1948

When the Institute was young, our mood was apathetic
To blandishments of Culture, to wisdom Geodetic;
We did not then on helicopter chase the Arimaspian,
Or contemplate petroleum from Calgary to Caspian:

Our step was light, our eyes were bright, our outlook futuristic,
Verging—(as still it does in some respects)—upon the altruistic.

North and West before us lay; Laurentian Shield, the wide Prairee!
Gold — where the river-gravels run by terraces to sea,
In the primal ribs of Earth, polished by the glacial grind,
Silver and Gold for searching, red Copper for men to find:

Met here and now together, for our Golden Jubilee
In temper retrospective — (some of us at least) — What of
the Morn say we?

Our young men still see visions — they have the helicopter!
Our old men still dream dreams — though they lie a little softer;
The price of gold will take its upward trend historical —
When Abram quit the towers of Ur, that dogma was canonical.

We have Iron, cold iron, in the frigid Labrador.
Our Coal is where the people ain't. (*Oh! Mr. Abbott*)
The dollars that we waste!

So "*Drill, ye tarriers, drill*" for the Gold in them thar hills,
We need it so darn badly to pay our Uncle's bills.
And "*Drill, ye tarriers, drill*"! for the Coal that deep doth lie,
The true wealth of nations, lacking it we die.

Here's a health to the Institute, long life to the Industry.
May the grub be fine — (and the digging good) — In the Fifty
Years to be!

F. W. Gray

(Written at Vancouver, April, 1948, after listening to Hans Lundberg)

Poem written by F.W.Gray after listening to Lundberg's 1948 presentation on the future of exploration.

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Ken Witherly (with glass of wine) and colleagues celebrating Lundberg's induction into the Canadian Mining Hall of Fame. Left to right; Norm Paterson, Frank Jagodits, Edna Muller, Mandy Long, Jenna McKenzie, Ken Witherly, Lynda Bloom, Emily Farquhar and Richard Smith. Photo taken by Tim Dobush.

Geoscience Australia: News

Geoscience Australia, in collaboration with the Geological Surveys of Western Australia, South Australia, Northern Territory, Queensland, New South Wales, Victoria and Tasmania starts the year with a packed geophysical acquisition schedule in the pursuit of world-class continental pre-competitive datasets of ever-increasing quality and type (Figure 1). As of January 2020, some highlights include:

AusAEM

The Australian airborne EM surveying programme (AusAEM) over northern Australia was suspended in October 2019 at 72% complete whilst the aircraft undertook work for the United States Geological Survey (USGS). Surveying is expected to re-commence in February with acquisition of the remaining ~ 19 000 line km (including industry in-fill) to be completed in 1 – 2 months.

Planning for AusAEM20 (see attached update from the GSWA) is well under way with tendering anticipated to commence in March and the first tranche of acquisition expected mid-2020.

Groundwater AEM

Various helicopter airborne EM surveys flown by SkyTEM® for groundwater studies have been publicly released and are available through Geoscience Australia's eCAT portal. Of note are the East Kimberley (Ord-Keep rivers region, WA and NT) and Southern Stuart Corridor (NT) AEM surveys which total ~ 17 000 line km. Upcoming releases include surveys from Howard's East (NT), Daly River (NT) and Surat-Galilee (Queensland).

Tasmanian Tiers

The proposed 66 000 line km Tasmanian Tiers airborne magnetic and radiometric survey took a step closer in late 2019 with the signing of a project agreement between Geoscience Australia and the principal funder: Mineral Resources Tasmania. While some operational challenges limit the optimum acquisition window to 3 – 4 months per annum, it is hoped that the acquisition can still go ahead this calendar year.

Updated national gravity compilation

Geoscience Australia is pleased to announce the release of the first product from the (re)compilation of Australia's gravity coverage, 2019 (Figure 2). From the metadata attached to the electronic catalogue release:

"This grid represents Free Air Anomaly values on the ground and ocean surface for the Australian region. The grid cell size is 15 arc seconds, or approximately 400 metres. The data are given in units of μms^{-2}, also known as "gravity units", or gu. The gravity data are referenced to the Australian Absolute Gravity Datum 2007 (AAGD07). The onshore gravity values were sourced from

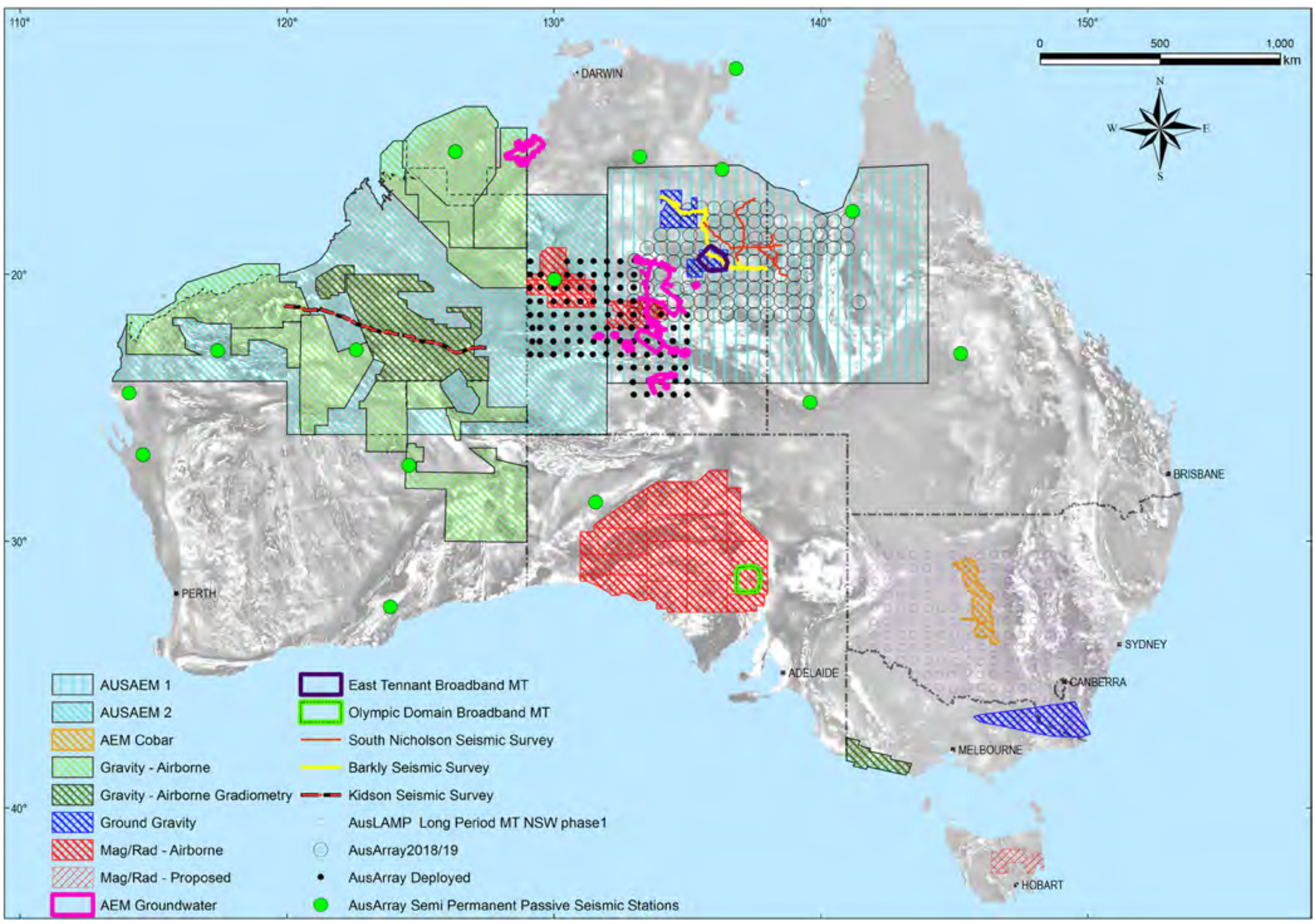

Figure 1. *2018 -2020 geophysical surveys – completed, in progress or planned by Geoscience Australia in collaboration with State and Territory agencies.*

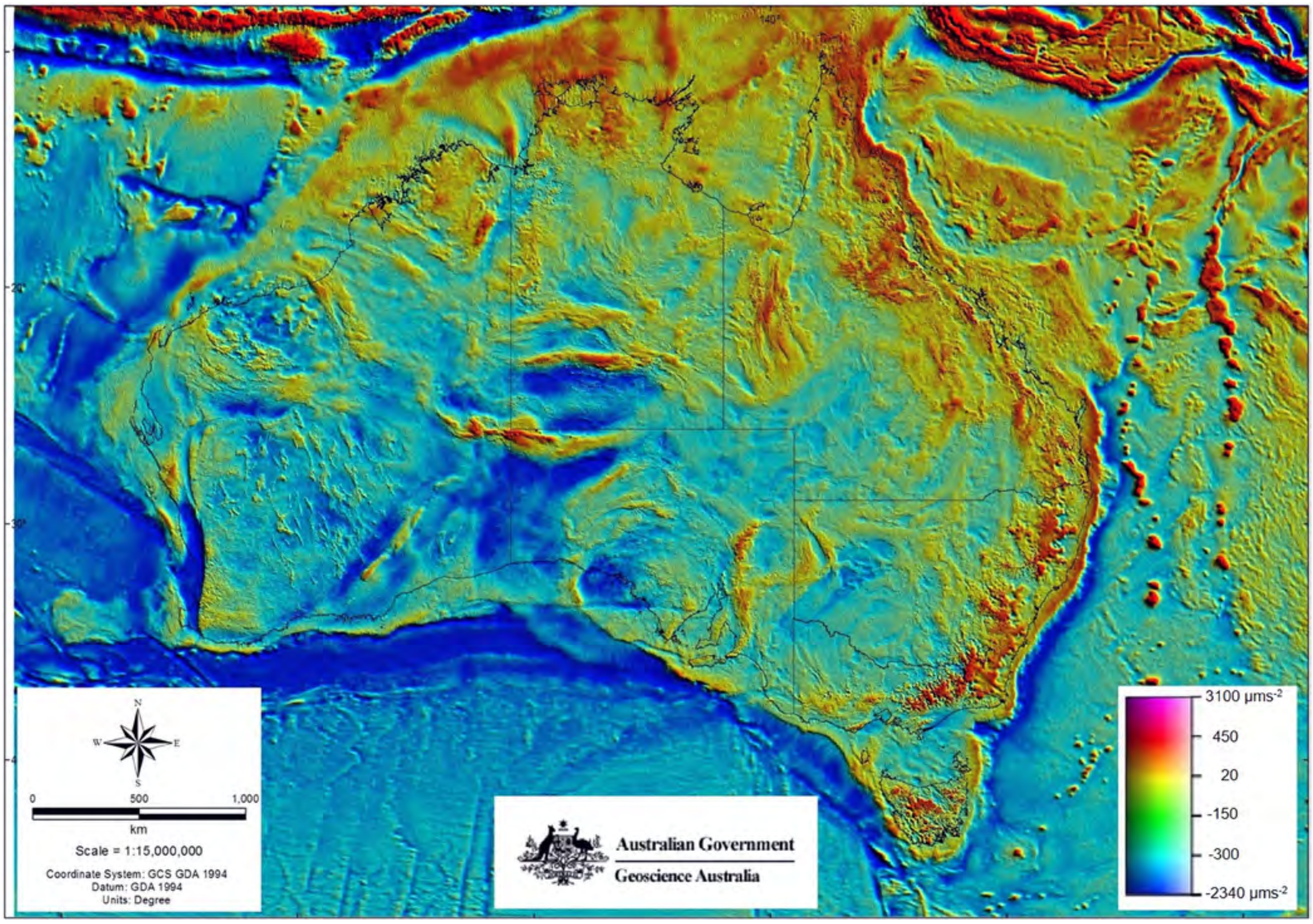

Figure 2. *Free-air gravity map of Australia, 2019 (Free Air Anomaly Grid of Australia 2019, 400 m cell size. Geoscience Australia, Canberra. http://pid.geoscience.gov.au/dataset/ga/133023).*

the ground-based observations stored in the Australian National Gravity Database (ANGD) as of September 2019. These data have been acquired by the Commonwealth, State and Territory Governments, the mining and exploration industry, universities and research organisations from the 1940's to the present day. Station spacing varies from approximately 11 km down to less than 1 km, with major parts of the continent having station spacing between 2.5 and 7 km. The ANGD contains over 1.8 million observations, of which nearly 1.4 million were considered suitable for inclusion in the calculation of this grid. The 2016 versions of the Australian National Gravity Grids were masked to the coastline. In contrast, in 2019 we chose to supplement the onshore data with offshore data that were sourced from v28.1 of the Global Gravity grid developed using data from SIO, NOAA and NGA at Scripps Institution of Oceanography, University of California San Diego. This provides valuable context to the onshore ground gravity data. This grid was produced by Geoscience Australia and GNS Science International Limited."

When completed, the 2019 compilation will be the first time that ground, marine, satellite and airborne data will have been merged to provide the highest resolution, seamless stitch possible.

The Free Air Anomaly grid of the combined ground, marine and satellite data is available for download via Geoscience Australia's electronic catalogue: https://ecat.ga.gov.au/geonetwork. Additional products, including the Bouguer reduced dataset and airborne data should follow in March.

South West McArthur, Barkly Gravity Survey, 2019

Geoscience Australia's Exploring for the Future (EFTF) programme and Northern Territory Geological Survey (NTGS) are pleased to announce the release of newly acquired gravity data covering the South West McArthur (northern dark blue hashed section in Figure 1). The survey infills existing 4 x 4 km gravity coverage to 2 x 2 km, over an area of 18 300 km^2 with 3303 new gravity stations. The survey supports GA's Tennant Creek-Mt Isa drilling programme to be undertaken at a later date, and NTGS's unlocking the Barkly Tablelands resource potential. The dataset is available via GA's electronic catalogue: https://ecat.ga.gov.au/geonetwork and will be incorporated into subsequent national compilations.

Geoscience Australia's GADDS

Last but not least, GA's new Geophysical Archive Data Delivery System (GADDS) is set for initial release end of March 2020. Along with a more user-friendly GIS interface for grids (similar interface as per the EFTF portal: https://portal.ga.gov.au/), there are plans to add the ability to 'clip, ship and zip' located and point data from GA's electronic catalogue.

For the moment, GADDS will continue to faithfully deliver located datasets for surveys archived before June 2019. For located survey data acquired afterwards, please contact GA's client services (clientservices@ga.gov.au) or Mike Barlow on mike.barlow@ga.gov.au.

Update on geophysical survey progress from Geoscience Australia and the Geological Surveys of Western Australia, South Australia, Northern Territory, Queensland, New South Wales, Victoria and Tasmania (information current on 10 January 2020).

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

Table 1. Airborne magnetic and radiometric surveys

Survey name	Client	Project management	Contractor	Start flying	Line km	Line spacing Terrain clearance Line direction	Area (km²)	End flying	Final data to GA	Locality diagram (*Preview*)	GADDS release
Tasmanian Tiers	MRT	GA	TBA	~Apr 2020	Up to an estimated 66 000	200 m 60 m N–S or E–W	11 000	May 2020	TBA	TBA	Agreement between GA and MRT is in place to commence work.
Gawler Craton	GSSA	GA	Various	2017	1 670 000	200 m, various orientations depending on structure	294 000	26 Jun 2019	Aug 2019	http://www.energymining.sa.gov.au/minerals/geoscience/pace_copper/gawler_craton_airborne_survey	QC and processing completed. To be released shortly.
Tanami	NTGS	GA	Thomson Aviation	14 Jul 2018	275 216	100/200 m 60 m N–S/E–W	48 267	2 Dec 2018	Jun 2019	195: Aug 2018 p. 16	Released
Mt Peake	NTGS	GA	MAGSPEC	10 Jul 2019	136 576	200 m N-S	24 748	Oct 2019	TBA	Aug 2019	Acquisition complete

TBA, to be advised.

Table 2. Ground and airborne gravity surveys

Survey name	Client	Project management	Contractor	Start survey	Line km/ no. of stations	Line spacing/ station spacing	Area (km²)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Kidson Sub-basin	GSWA	GA	CGG Aviation	14 Jul 2017	72 933	2500 m	155 000	3 May 2018	15 Oct 2018	The survey area covers the Anketell, Joanna Spring, Dummer, Paterson Range, Sahara, Percival, Helena, Rudall, Tabletop, Ural, Wilson, Runton, Morris and Ryan 1:250 k standard map sheet areas	Expected release before the end of Jun 2020
Little Sandy Desert W and E Blocks	GSWA	GA	Sander Geophysics	W Block: 27 Apr 2018 E Block: 18 Jul 2018	52 090	2500 m	129 400	W Block: 3 Jun 2018 E Block: 2 Sep 2018	Received by Jul 2019	195: Aug 2018 p. 17	Expected release before the end of Jun 2020
Kimberley Basin	GSWA	GA	Sander Geophysics	4 Jun 2018	61 960	2500 m	153 400	15 Jul 2018	Received by Jul 2019	195: Aug 2018 p. 17	Expected release before the end of Jun 2020
Warburton-Great Victoria Desert	GSWA	GA	Sander Geophysics	Warb: 14 Jul 2018 GVD: 27 Jul 2018	62 500	2500 m	153 300	Warb: 31 Jul 2018 GVD: 3 Oct 2018	Received by Jul 2019	195: Aug 2018 p. 17	Expected release before the end of Jun 2020

(*Continued*)

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

Survey name	Client	Project management	Contractor	Start survey	Line km/ no. of stations	Line spacing/ station spacing	Area (km^2)	End survey	Final data to GA	Locality diagram (*Preview*)	GADDS release
Pilbara	GSWA	GA	Sander Geophysics	23 Apr 2019	69 019	2500 m	170 041	18 Jun 2019	Final data received Aug 2019	The survey area is in the Pilbara region in the northwest of Western Australia. Data acquired will be compiled into an update of the gravity anomaly map of Western Australia and help characterise regional geological elements in the area.	Expected release before the end of Jun 2020
SE Lachlan	GSNSW/ GSV	GA	Atlas Geophysics	May 2019	303.5 km with 762 stations	3 regional traverses	Traverses	Jun 2019	Jul 2019	TBA	Set for incorporation into the national database by end Oct 2019
TISA	NTGS	GA	Atlas Geophysics	2 Jul 2019	7821	2 km × 2 km grid	31 285	Sep 2019	Nov 2019	TBA	Expected release before the end of Mar 2020

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
East Kimberley	GA	GA	SkyTEM Australia	26 May 2017	13 723	Variable	N/A	24 Aug 2017	Nov 2017	TBA	eCAT release http://pid.geoscience.gov.au/dataset/ga/130762
Surat-Galilee Basins QLD	GA	GA	SkyTEM Australia	2 Jul 2017	4627	Variable	Traverses	23 Jul 2017	Nov 2017	188: Jun 2017 p. 21	Not for release until Jun 2020
Stuart Corridor, NT	GA	GA	SkyTEM Australia	6 Jul 2017	9832	Variable	Traverses	12 Aug 2017	Nov 2017	188: Jun 2017 p. 22	eCAT release http://pid.geoscience.gov.au/dataset/ga/131098
AusAEM2, NT-WA	GA	GA	CGG Tempest	May 2019	59 098 with areas of industry infill	20 km	1 074 500	TBA	TBA	201: Aug 2019 p. 16	72% complete. Acquisition suspended until aircraft returns in Jan 2020
Cobar	GSNSW	GA	NRG Xcite	30 Sep 2019	6701 with areas of industry infill	2.5 and 5 km	19 145	19 Oct 2019	Jan 2020	201: Aug 2019 p. 17	TBA

TBA, to be advised

Table 4. Magnetotelluric (MT) surveys

Location	State	Survey name	Total number of MT stations deployed	Spacing	Technique	Comments
Northern Australia	Qld/NT	Exploring for the Future – AusLAMP	365 stations deployed in 2017-19	50 km	Long period MT	The survey covers areas of NT and Qld. *Ongoing*
AusLAMP NSW	NSW	AusLAMP NSW	270 stations deployed in 2018-19	50 km	Long period MT	Covering the state of NSW. *Ongoing*
Southeast Lachlan	Vic/ NSW	SE Lachlan	Deployment planned to commence in Feb 2020	~4 km	AMT and BBMT	~160 sites in the Southeast Lachlan
AusLAMP TAS	TAS	King Island MT	4 sites completed	<20 km	Long period MT	Covering King Island
East Tennant	NT	East Tennant MT	131 sites completed	1.5 – 10 km	AMT and BBMT	Released
Cloncurry	QLD	Cloncurry Extension	180 stations have been acquired	2 km	AMT and BBMT	Approximately 500 sites planned in the eastern concealed margin of the Mount Isa Province. This survey is an extension of the 2016 Cloncurry MT survey.
Spencer Gulf GA/GSSA/ UofA/AuScope	SA	Offshore marine MT	12 stations completed	10 km	BBMT	This is a pilot project for marine MT survey

TBA, to be advised

Table 5. Seismic reflection surveys

Location	State	Survey name	Line km	Geophone interval	VP/SP interval	Record length	Technique	Comments
South East Lachlan	Vic/NSW	SE Lachlan	629	10 m	40 m	20 s	2D - Deep crustal seismic reflection	This survey covers the Southeast Lachlan Orogen crossing the Victorian-NSW border. Data acquisition was completed in Apr 2018. Raw data and processed seismic data has been released and are available via Geoscience Australia.
Kidson	WA	Kidson Sub-basin	872	20 m	40 m	20 s	2D - Deep crustal seismic reflection	Within the Kidson Sub-basin of the Canning Basin extending across the Paterson Orogen and onto the eastern margin of the Pilbara Craton. The survey completed acquisition on 8 Aug 2018. Data released in May 2019.
Barkly/ Camooweal	NT	Barkly sub-basin	812	10 m	30 m	20 s	2D - Deep crustal seismic reflection	Acquisition of 2D land reflection seismic data to image basin and basement structure in the Barkly region of the Northern Territory. Data acquisition was completed in Nov 2019. The data is expected to be released first half of 2020.

Table 6. Passive seismic surveys

Location	Client	State	Survey name	Total number of stations deployed	Spacing	Technique	Comments
Northern Australia	GA	Qld/NT	AusArray Phase 2	About 135 broad-band seismic stations	50 km	Broad-band 1 year observations	The survey covers the area between Tanami - Tennant Creek –Uluru and West Australian Border. The first public release of transportable array data is expected by end 2019. See location map in in *Preview* 201: Aug 2019 p. 16
Northern Australia	GA	QLD/WA	AusArray	3 high-sensitivity broad-band seismic stations installed in Oct 2019	~1000 km	Broad-band 4 years observations	Semi-permanent seismic stations provide a back-bone for movable deployments and compliment the Australian National Seismological Network (ANSN) operated by Geoscience Australia, ensuring continuity of seismic data for lithospheric imaging and quality control. Associated data can be accessed through www.iris.edu

Geological Survey of South Australia: Gravity at Wheal Ellen (a whealy good project)

On Tuesday December 3, GSSA Geophysicist Philip Heath and Cadet Grace Smith travelled to the historic Wheal Ellen mine with the NExUS students to demonstrate the use of gravity in mineral exploration. The NExUS (National Exploration Undercover School) programme is a three-week course providing world-class training in mineral exploration. There were around thirty students from all around Australia learning a range of geophysical techniques including magnetics, electrical techniques, seismic, magnetotellurics, and gravity.

Silver, lead and zinc were mined at the site near Strathalbyn in the 1850s, and the property is now owned by Hillgrove Resources. The students used a CG5 gravity meter and a Sokkia DGPS to survey the area, and learned how the acceleration due to gravity can vary around mineral deposits.

The geology at Wheal Ellen strikes roughly N-S, and gravity data were acquired along a single E-W traverse. The position of the line was selected to cross immediately adjacent to the main mine shaft. Readings were acquired at intervals of 25 m. Data were processed at GSSA head office to produce a Spherical Cap Bouguer Anomaly from which a 1st order trend was removed. The final gridded data are shown in Figure 1, which displays an approximately 0.5mGal anomaly to the east of the main shaft.

The main mine shaft lies just to the north of the dark blue portion of the grid.

The gravity data have been tied to the AFGN via a new gravity survey point established at Mount Barker train station (Figure 2). The survey point was established via ABA tie to the Burnside Rugby Club AFGN point with two CG5 gravity meters. The survey point is unmarked, but can be found at the Mount Barker train station, immediately in front of the tap and next to a drainpipe, on the car park side of the building. In MGA coordinates, the site is at (approximately) 305212 m Easting, 6117747 m Northing, Zone 54. The average observed gravity at the site (from 10 measurements) is 9796755.694 μms^{-2} in the AADG07 datum. The standard deviation is 0.153 μms^{-2}

As always, all gravity data is available upon request.

Philip Heath
Philip.heath@sa.gov.au

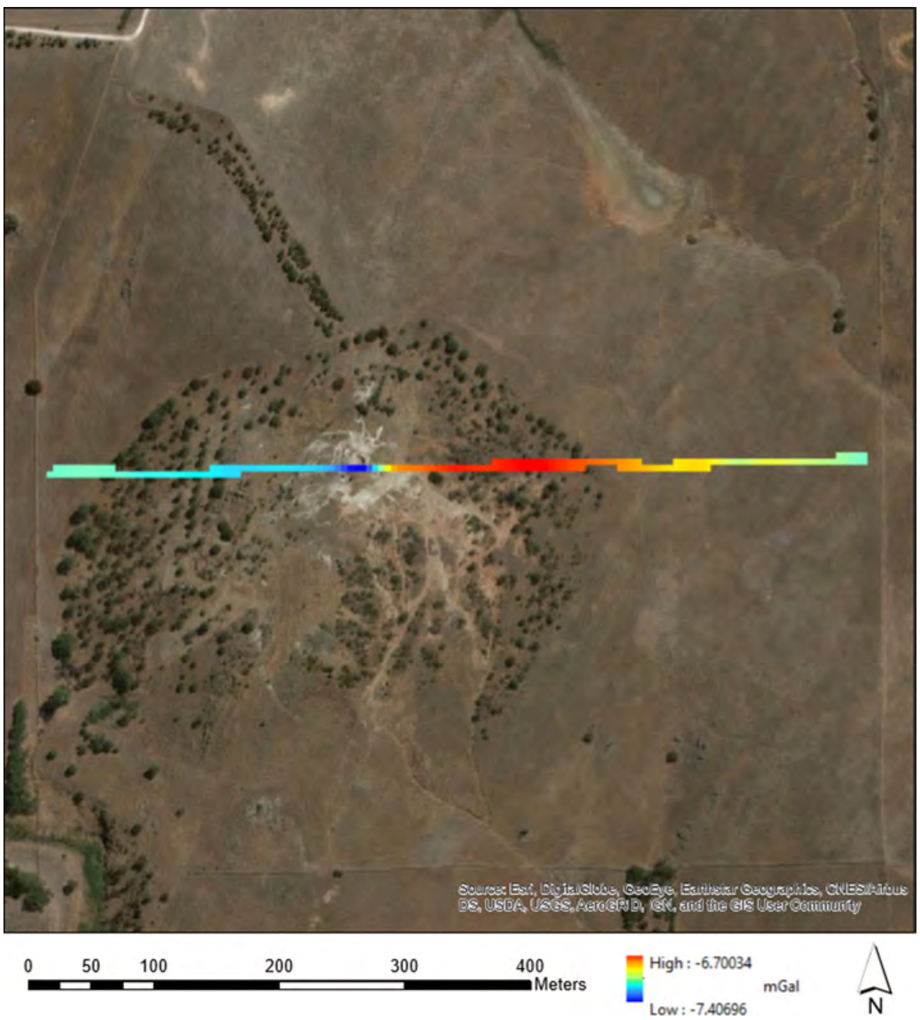

Figure 1. *Wheal Ellen historic mine and 1st order de-trended gravity traverse (AAGD07 SC BA). An approx. 0.5 mGal gravity anomaly can be seen on the survey traverse to the east of the main mine shaft.*

Figure 2. *The unmarked base station can be found at Mount Barker train station in front of a tap and adjacent to a drain pipe on the veranda. The gravity meter on the right in this image is on top of the site.*

GEOLOGICAL SURVEY OPEN DAY 2020

Friday 21 February 2020

8.30 am – 4.30 pm

Followed by a Sundowner

Esplanade Hotel, Fremantle

Cnr Marine Terrace and Essex Street

This is a great opportunity to hear presentations on the latest results from GSWA's geoscience programs, including collaborative work with CSIRO, Geoscience Australia, Curtin University, and the Centre for Exploration Targeting (CET).

Activities and results of the Exploration Incentive Scheme will be outlined including the launch of Round 21 of the Government Co-funded Exploration Drilling program.

Throughout the day there will be geological presentations, an extensive poster display, and demonstrations of online systems and technology innovations.

Register online at

www.dmp.wa.gov.au/GSWAOpenDay

For further information, call **(08) 9222 3646**

Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**

GSWA Open Day 2020 program – 21 February 2020, Esplanade Hotel Fremantle

8.15 – 8.45	REGISTRATION		
8.45 – 9.00	Welcome and opening remarks	Hon Bill Johnston MLA, Minister for Mines and Petroleum	
SESSION 1	***Chair: Jeff Haworth***		
9.00 – 9.20	The next generation of outcrop: MinEx CRC and the National Drilling Initiative in Western Australia	Richard Chopping	Exploration Incentive Scheme
9.20 – 9.40	Land Use Planning	Warren Ormsby	
9.40 – 10.00	Stratigraphic drilling in the southwest Canning Basin: GSWA Waukarlycarly 1	Leon Normore	Exploration Incentive Scheme
	Morning tea 10.00 – 11.00		
SESSION 2	***Chair: Michele Spencer***		
11.00 – 11.20	World's oldest regional salt seal in the Amadeus and Officer Basins: implications for subsalt helium and hydrocarbons	Peter Haines	
11.20 – 11.40	Western Australia: resourcing the world's new energy future	Trevor Beardsmore	
11.40 – 12.00	Loop 3D geological modelling: speeding up the workflow	Mark Jessel, CET	Exploration Incentive Scheme
12.00 – 12.20	The Eastern Goldfields High Resolution Seismic Survey: preliminary interpretation and tectonic implications	Ivan Zibra	Exploration Incentive Scheme
	Lunch 12.20 – 1.30		
SESSION 3	***Chair: Simon Johnson***		
1.30 – 2.40	In this session, seven 10-minute talks will be given on the following: Managing an abandoned mine as a future resource; AusAEM20–WA; Rare-element pegmatites in the Mineral Systems Atlas; The last gasp of King Leopold: new insights into the evolution of the West Kimberley; Exploring the link between a suture zone, an ophiolite, and a seahorse; A subduction origin for c. 2820 to 2735 Ma magmatism in the western Youanmi Terrane, Yilgarn Craton; Leading impactful research, meaningful collaboration and effective knowledge transfer	Tara Read, John Brett, Paul Duuring, Imogen Fielding, Catherine Spaggiari, Jack Lowrey, Anil Subramanya	Exploration Incentive Scheme
	Afternoon tea 2.40 – 3.30		
SESSION 4	***Chair: Klaus Gessner***		
3.30 – 3.50	Tectonic setting and exploration potential of the northern Capricorn Orogen	David Martin	Exploration Incentive Scheme
3.50 – 4.10	Smart exploration starts with Western Australia's rich data endowment: using the MINEDEX, WAMEX and WAPIMS databases	Nicole Wyche	
4.10 – 4.30	Interactive feedback session	Robin Bower	
	Sundowner 4.30 – 6.00		

REGISTER ONLINE

www.dmirs.wa.gov.au/GSWAOpenDay

Cost: $130
Time: 8.15 am – 4.30 pm
followed by a sundowner

GSWA 2020

For further information, please contact tel: (08) 9222 3646

Canberra observed

David Denham AM
Associate Editor for Government
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Bushfires epitomise the malaise of our political system

Nobody likes change

Governments usually adopt minimal responses to situations that demand change. That's because humans don't like change, unless there are obvious benefits. And politicians are no different on this issue.

However, there are occasions when change is forced upon us because the cost of doing nothing becomes too great. The bushfires over the festive period in 2019/20 have forced action. There is no doubt that these fires were made worse by our warming and drying climate over the last decades. There is also no doubt that the government had been warned.

Climate change should have been easy

The climate change issue should have been easy. In 1896 Svante Arrhenius calculated the extent to which increases in atmospheric carbon dioxide will increase the Earth's surface temperature through the greenhouse effect. The physics has not changed. What has changed is that we now have over 7 billion people on planet Earth and the greenhouse gas emissions have increased by almost 50% in the last 100 years. And that's a difficult challenge.

Economics of climate change are now critical

The economic impact of climate change on Australia was examined in detail by Ross Garnaut in 2008 and he forecast that fire seasons would start earlier, end slightly later and be more intense. He also said, "This effect increases over time, but should be directly observable by 2020". I am sure he never expected anything as ferocious as what we have just experienced. He also argued that, the earlier action is taken, the better the economic outcomes would be.

We now know that the winter rains over the southern part of the continent have been pushed farther south resulting in lower rainfall. We also know that away from the coast, where there are forests, approximately half the rainfall originates from transpiration of the trees. Consequently, if the trees are all burnt, the climate will become even drier and hotter.

As we know, the recommendations from the Garnaut report were rejected. We keep getting told by the Government that we must do more fuel-reduction burns, which are state responsibilities. This is not good enough because, the latest bushfires engulfed the areas that had fuel-reduction burns, just as much as those which hadn't. Infernos like the one we are having to deal with now, just burn everything in their paths.

What is the government doing and what should it do?

So far, the government is committing $2 billion to the recovery effort. That is the easy part - spending taxpayer's money; and the *status quo* is preserved. No real change needed. What we don't know is what are its plans are for the longer term. I have four suggestions. We should:

1. Adopt an effective emissions reduction program to set a good example and spend money on advocacy to persuade other countries to reduce their emissions;
2. Plant more trees and stop land clearing to try and maintain our rainfall levels away from the coast;
3. Review our building codes to cope better with a warmer climate and
4. Review our land and water management to deal with the new climate norm.

As Donald Trump would say "Let's see what happens".

Water, the elephant in the room

Water management will be crucial and should not be left to the States and Territories. At present Australia's accessible capacity is about 81 000 GL and the accessible volume is about 35 000 GL. This is the lowest level since records were available on the BoM website in 2014 (http://www.bom.gov.au/water/dashboards/#/water-storages/summary/state). The Prime Minister should take the lead on water. It is a national security issue.

The big paradox

Never have people on planet Earth been so closely connected. Never have we had the information and knowledge to manage the planet in a sustainable manner. And never have we stuffed things up big time.

Instead of working together for a better future, we are ripping ourselves asunder. The US is not honouring international agreements, Brexit is tearing Europe apart and the United Nations is now just playing a bit-part on the world's stage.

Our government is very limited in what it can do to address this issue, but it should use its advocacy to reverse this trend. We are too vulnerable in a world with no rules.

2019 a good year for resource industries – unless you are mining coal

Most resource companies listed on the ASX did really well in 2019; unless you are investing in coal projects. The market capital of the resource companies listed in the top 150 companies increased by a 22% in 2019, and the ASX All Ords Index increased by a similar amount - 21%. A gain of over 20% in one year indicates a healthy resource sector, and a national economy in good shape. We all know that nothing can grow for ever at 20% per year, but we should use the good times to invest in more exploration for the harder-to-find resources we will need in the future.

Table 1 shows how the value of the main resource-listed companies in the top 150 ASX fared during 2018. The numbers in the table are in $A billions, show the percentage changes in market value during 2019 and how these compare with the 2018 results. The companies have been grouped according to their main commodity interest.

The larger companies, with a market capital of more than $10 billion all did well, particularly Fortescue, which turned a horror year of 2018 into a big success in 2019.

The gold sector has seen some rationalisation affecting the small to medium sized companies. For example, Saracen bought Barrick Gold's 50 per cent stake in the Super Pit at Kalgoorlie for $A1.1 billion. This resource is still one of Australia's biggest gold mines and currently produces more than 21 million ounces per year. That's worth about $US30 billion.

On the other side of the coin, OceanGold expects a lower output after it suspended production at its Didipio gold and copper mine in the Philippines, citing a dispute with local government, which allegedly wants to close the mine down. This will result in an annual drop in production about 55 000 ounces of gold from an expected output of 525 000 ounces.

Table 1. Market Capital Changes for 2019.

	Jan 2019	Dec 2019	Change %	% 2018
BHP	100.011	116.773	+17	+2
Rio	28.984	38.053	+31	-10
Fortescue	12.788	33.868	+165	-23
Yancoal	5.156	3.855	-25	-13
Whitehaven	4.514	2.567	-43	-3
New Hope	2.759	1.720	-38	+30
Woodside	29.348	32.951	+12	+1
Origin	11.401	15.128	+33	-32
Oil Search	10.878	11.313	+4	-11
Santos	11.393	17.414	+53	-1
Beach	3.064	5.861	+91	+2
Newcrest	16.187	22.780	+41	-9
Evolution Min	6.794	6.39	-6	+53
Northern Star	5.908	8.176	+38	+62
Ocean Gold	2.966	1.73	-44	+41
St Barbara	2.464	1.91	-22	+25
Regis Resources	2.426	2.19	-10	+11
Saracen	2.337	3.551	+52	+67
All Ords	5716	6936	+21	-8
Market Capital	274.89	336.11	+22	-3
Iron ore + other	**Coal**	**Petroleum**	**Gold**	

For those in the coal business, the situation does not look good. As global warming is now a real concern, several countries are abandoning the use of coal to generate electricity and there is a surplus of coal available for sale. Figure 1 shows that the price of thermal coal has almost halved from close to $US120/t in July 2018 to $US66/t at the end of 2019. The price for coking coal is also falling and is expected to drop from about $US200/t in 2019 to $US150 in 2020.

No wonder the market capital of Whitehaven, Yancoal and New Hope has fallen.

The Department of Industry's, *Resources and Energy Quarterly for December 2019*, painted a sober picture for coal (https://www.industry.gov.au/data-and-publications/resources-and-energy-quarterly-december-2019). It stated that:

> "The US coal sector has been impacted by a number of bankruptcies, as lower prices eliminate profit margins and as coal-to-gas switching accelerates in the US power sector — coal's share as a source of power generation fell to 23.5 per cent in August from 28.3 per cent a year before. US exports look set to fall further in the outlook period as coal mines shut."

His Department's report did not seem to worry the Minister Matt Canavan, who announced on 19 December 2019:

> "The $2 billion Carmichael mine is now in construction and will produce 10 to 15 million tonnes of high-quality thermal coal a year, ramping up to 27.5 million tonnes. Adani already has 800 people working across Queensland and the company estimates the Carmichael project will create around 1500 direct construction jobs and almost 7000 supporting jobs. More jobs will be created as the mine's capacity grows."

Overall the medium-term outlook for the resource sector looks good and the volatility that we experienced several years ago appears to be reducing.

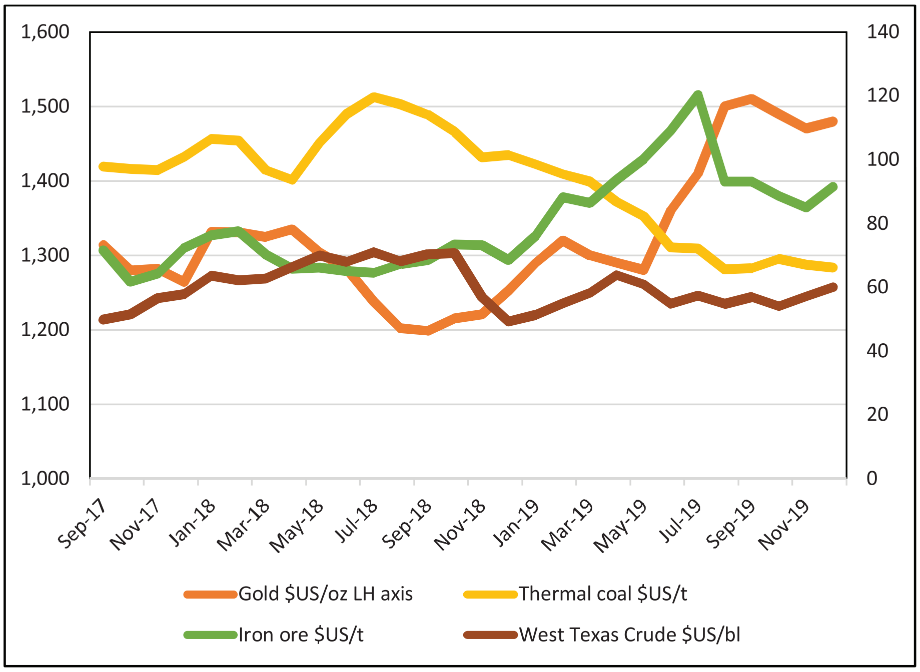

Figure 1. *Prices in $US for petroleum, coal, iron ore and gold for 2017-2019. Gold and iron ore prices continue to rise. Petroleum prices have not changed, and the thermal coal price has fallen consistently.*

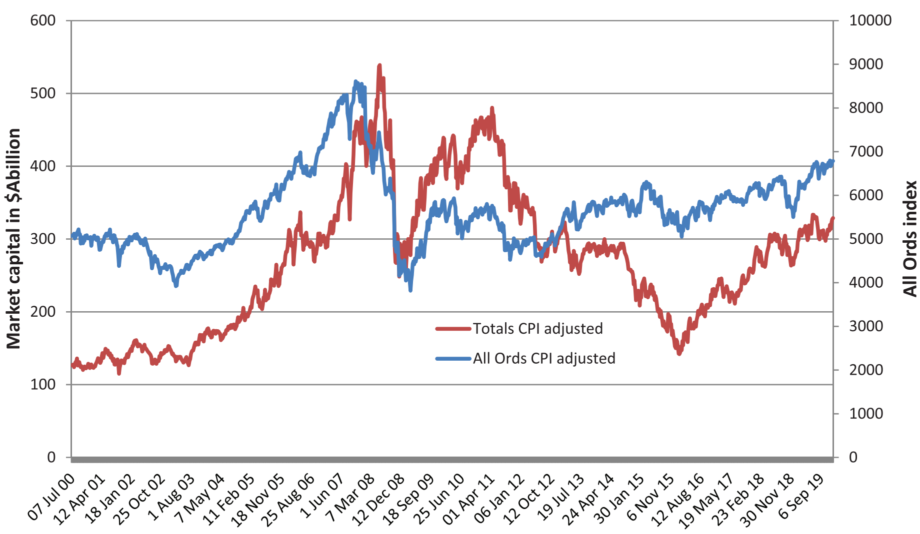

Figure 2. *Market capital of the resource companies listed in the top 150 companies on the ASX from July 2000 through December 2019 and the All Ords index, for the same period. The numbers have been normalised to December 2019 $A using the Australian Bureau of Resources Consumer Price Index (CPI).*

Figure 2 shows the trends over the last 10 years. The fortunes of the resource companies and the All Ords index remain closely linked, even though only 10 percent of the top 150 companies are in the resource sector. This indicates how important it is to have a strong Australian resource sector.

As stated in the Resources and Energy Quarterly for December 2019:

> "Resource and energy commodity exports in 2019–20 are forecast to set a record of $281 billion, before falling to $256 billion in 2020–21."

Of course, the Minister does not want you to know about the small fall forecast for the next financial year. He just says:

> "Australia's resource and energy export earnings are forecast to set a record $281 billion in 2019-20, up from $279 billion in 2018-19."

Even if the exports do fall in 2020-21, the contribution from the resource industries is crucial to our well-being and that is the important issue.

Education matters

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SEG Honorary Lecturer to teach on petroleum reservoir seismic anisotropy

One of our own former students, Lisa Gavin, has achieved a meteoric rise from her honours year at Curtin University in 2010 to become a Society of Exploration Geophysicists Honorary Lecturer for Australia and the Pacific South. She will be presenting her lectures in Adelaide and Perth, **11 and 12 February** respectively, hosted by State branches of the ASEG. The topic of the lectures is "Regional to reservoir stress-induced seismic azimuthal anisotropy".

Details of the lecture, venues and other guest lectures for ASEG and PESA branches are at https://seg.org/Education/Lectures/Honorary-Lectures/2020-HL-Gavin

In the decade since graduation Lisa has gained a PhD from the University of Western Australia, has worked as a petroleum geophysicist for Fugro Seismic Imaging, for Chevron, and is currently at Woodside Energy in Perth, Australia. Her PhD project was supported by an ASEG Research Foundation grant, and our Society is especially delighted to see our early support for her career contributing to her international recognition as an SEG Honorary Lecturer within the decade.

Abstract for the lectures

Lisa Gavin

In her abstract for her lectures Lisa writes:

Seismic azimuthal anisotropy is observed in many areas of the earth, and knowing where it is present is important because it affects the propagation velocity of seismic waves. Not accounting for velocity anisotropy in processing or inversion of seismic data can lead to incorrect images and physical property estimates, and, therefore, incorrect geologic interpretations. While anisotropy has historically been considered a complication, the effect it has on data can be utilised as a source of information, giving an indication of geologic features much smaller than the seismic wavelength.

In this lecture, I will focus on the North West Shelf (NWS) of Australia, an area with significant stress-induced azimuthal anisotropy. I will explain observations of azimuthal anisotropy across the NWS from the regional-to reservoir-scale. I first give a regional overview of seismic azimuthal anisotropy across the NWS using seismic exploration data. The results show that fast polarization azimuths and maximum horizontal stress direction trends correlate across a geographical area spanning almost 2 000 km, which compares well with published results from earthquake seismology studies. I also discuss why azimuthal anisotropy is detectable in some areas of the NWS and not in others.

I present a rock physics model that reproduces log azimuthal anisotropy observations in unconsolidated sand-shale sequences based on Vshale and depth. This method naturally introduces two new concepts; "critical anisotropy" the maximum amount of azimuthal anisotropy expected to be observed at the shallowest sediment burial depth, where the confining pressure and sediment compaction are minimal and "anisotropic depth limit" the maximum depth where stress-induced azimuthal anisotropy is expected to be observable, where the increasing effects of confining pressure and compaction make the sediments insensitive to differential horizontal stress.

Finally, I demonstrate the importance of accounting for azimuthal anisotropy and acquisition azimuth in 3D and 4D seismic modelling, feasibility, inversion, and interpretation studies. Azimuthal anisotropy does not affect the small angle reflection angles of 3D and 4D AVO, but it can have a significant effect on larger reflection angles. I show that this effect can influence 4D seismic interpretation where there can be an "apparent 4D effect" when reservoir properties do not change, and a "contaminated 4D effect" when reservoir properties do change.

The methods, techniques, and conclusions discussed in this lecture are likely to be useful in other regions where stress-induced azimuthal anisotropy is present.

Environmental geophysics

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Fake science

Welcome readers to this issue's column on geophysics applied to the environment. In this column I would like to continue a discussion about something that bothers me, but is not necessarily part of my remit as the Associate Editor for *Environmental Geophysics*. I am concerned about growing "fake science" and then, ultimately, how this fake science is applied to geophysics. I wrote about a similar subject quite early in my tenure as *Preview* Associate Editor, and it seems to me like the time is right to continue the discussion.

When I first started looking into this topic in 2015, I started a folder on my computer called "badscience"; every now and then someone sends me an interesting reference and I add it to the folder. One of the first (and most interesting) things that someone sent me isn't actually bad science. It is an article that appeared on page 1 of Volume 1 of the first issue of *Geophysics* (January 1936) titled "Black magic in geophysical prospecting" by Dr Ludwig Blau (https://library.seg.org/doi/10.1190/1.1437076). It is about some of the oil detecting scams perpetrated in the oil industry in the 1930s. It is an entertaining bit of writing that is still right on target today. Interestingly it was reprinted in the *Leading Edge* in its entirety in 1983 (and maybe should be reprinted yet again).

Another article that I have come across, that is also not in itself bad science but is part of the story, is by Greg Hodges who wrote a piece for the 2005 SAGEEP Conference titled "Voodoo methods: Dealing with the dark side of geophysics" (https://library.seg.org/doi/10.4133/1.2923476). Really, this article spells out everything you need to know about spotting the various bits of bad science/scientific scams that you are likely to come across in your career. Greg has a few "case histories" in there that are worth a look. Additionally, he has included a few interesting websites that make for some fun reading – particularly when you have actual work to do, but would prefer to be cruising the web.

I guess what has got me going on this subject is an article that a colleague recently spotted in the refereed journal *Applied Geophysics*. The article is titled "Vein width measurement of groundwater on Earth's surface using semiconductor laser light and proton precession magnetometer" (https://www.sciencedirect.com/science/article/pii/S0926985118306682?via%3Dihub). Sounds interesting enough from the title, but it goes downhill from there quite quickly. Most of us are at least accustomed to articles that conclude that using a number of tools to identify a given target is a reasonable approach. We are not accustomed to seeing that one of these techniques is "dowsing" or "water divining". This article acknowledges that there are a large number of studies that actually find that dowsing does not work, but nevertheless insist that their results on the Deccan Traps, in Pune, India are valid. It also introduces a laser-based survey technique that ostensibly measures the offset of a laser beam in an aligned box. Beam offsets are then related to temperature and pressure variation that apparently occurs over the edges of buried water in fractured rock aquifers; the locations of these offsets are used to detect the width of the fractures at depth. The workings of this laser box are not nearly well enough explained, although there are two mostly unrelated equations presented that give a theoretical "base" for the method. Small scale magnetics surveys were run to corroborate the existence of groundwater at the 15 locations where the dowsers indicated that fractures existed as, so far as I can tell, these authors, among others, feel that it is possible that dowsers react to variations in the magnetic field. The dual problem that a) water in fractures is rarely associated with magnetic field variation; and b) there is likely to be a large amount of magnetic field variation in the basalts of the Deccan Traps that are likely to obscure anything subtle. The presence of water is "confirmed" at two of 15 sites that found groundwater using resistivity soundings, which to me prove little other than that they need to drill to test these targets. I review quite a few articles every year, and for me one of the most frustrating aspects of this publication is that it appears to me that in this case the refereeing process has failed.

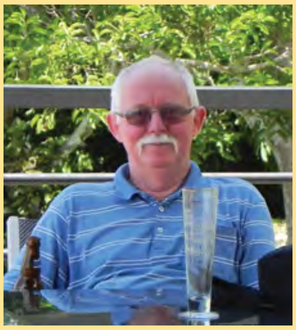
For those interested in reading about dowsing and its validity, the results of a study run in Germany in the 1980s is worth a look – interestingly this article is one of the references in the *AG* paper that I lambaste here. In the initial study the original authors concluded that there were a very small percentage of people who actually had the ability to find water by dowsing. The data were re-evaluated in 1995 (https://link.springer.com/article/10.1007/BF01134560) and these researchers found that there was no more than a random link between claims of dowsing ability and actual ability to locate water. This experiment involved modifying a two-story barn so that water pipes could be randomly located under the floor of the second story. Dowsers were required to locate the pipes. When the data were re-examined it was found that there were a number of people who located the water pipes at a rate that appeared statistically significant, but that, when the experiment was repeated a number of times, those that were successful during one run of the experiment were not successful again, while others suddenly were successful – suggesting that the results were random.

In the process of researching this piece I was amazed to find a larger than expected number of articles that espoused crazy science – mostly having to with dowsing, but also the ability of the human body to detect incredibly small variations in the Earth's magnetic field (for many this is the apparent base theory on how dowsing and feng shui works). Along the way I found the (apparently refereed) article that somewhat describes the development of the laser device described above (www.j-asc.com/VOLUME-6-ISSUE-1- JANUARY-2019/ article number 114). Three of the authors appear on both papers. The opening paragraph of the introduction is a good place to start (perhaps obviously), and I quote directly:

The earth's is composed of a magnetic –grid –like system somewhat like the segments of an organ with intersecting lines. These grid lines are called ley lines or geoelectromagnetic field (GEM) (Jishan 1995), and they can vary in intensity from place to place, based on variations in gravitational force, the presence or absence of large mineral deposits like quartz, and the presences of underground streams or large aquifers, all of which can alter the electromagnetic background on the earth surface (Hacker, 2008; Harvalik, 1978).

I just looked up "ley lines" and was dismayed. Interestingly, this article is not referenced in the article that I review here.

Minerals geophysics



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Force and finesse

Galvanic electrical geophysical exploration methods typically employ two completely separate circuits: one for injecting electric current into the earth (the transmitter circuit) and a second for measuring the voltage gradient generated by the passage of this current through the earth (the receiver circuit). Each circuit consists of appropriate instrumentation connected by wires to the ground via specialised electrodes. The electrical properties of both circuits can be described by Ohm's Law (**Voltage** = **Current** multiplied by **Resistance**), but the magnitudes of voltages and currents differ markedly between the two circuits.

With the transmitter circuit, the aim is to maximise the electric current passing through the target zone, thereby generating the maximum possible voltage difference for the receiver circuit. With the receiver circuit, the aim is to optimally measure this voltage difference to most effectively sample the target zone. Simply put, the transmitter circuit utilises force, the receiver circuit demands finesse.

Ohm's Law applied to the transmitter circuit tells us that to maximise the electric current injected into the ground, we will need to minimise the circuit resistance and maximise the applied voltage.

The transmitter circuit resistance is the sum of the resistances of the wires, the electrodes and the ground itself. Resistance in the wires can be reduced by using thicker wire, but there may be handling costs in lay out and retrieval. In practice, most attention is devoted to reducing the contact resistance of the electrodes – using larger and/or multiple plates, pre-soaking the electrode pits, using saline water and detergent, or even drilling to position the electrodes beneath blanketing cover. In the past, I've used electrodes placed in augered holes to bypass badly cracked black soil layers, and gelignite to fracture silcrete caps to increase permeability and water penetration. Ground resistance would appear to be out of our control, but sometimes strategic re-positioning of the electrodes such as interchanging the transmitter and receiver circuit locations can help.

The maximum available voltage output will be dictated by generator and transmitter hardware, and by safety considerations. Equipment limitations may take the form of maximum allowable voltage, maximum allowable current, or maximum allowable power (voltage multiplied by current). However, it is no longer a matter of just building bigger transmitters - increasing government regulation of electrical equipment used in mineral exploration is restricting the use of higher power units.

The application of Ohm's Law to the receiver circuit is a bit more problematic. We don't want to affect what we're measuring by the measurement process itself, so current flow through the receiver must actually be minimised, not maximised. To achieve this, instrument resistance is made as high as practicable.

Measurement of the resulting reduced signal strength requires accuracy and efficacy, particularly when the second order IP effect, where signal strengths may be orders of magnitude smaller, is also being measured. The receiver circuit needs to be as stable as possible, so attention will be directed to optimising the electrodes with pre-watering to minimise SP drift and using porous pots to eliminate unwanted electrode-related IP effects. We also need to be particularly clever in how we go about the measurements themselves. Signal processing techniques such as coherent signal enhancement and noise reduction using stacked repeat readings, data assessment to remove unwanted outliers, etc., will come into play. IP measurement parameters may also need to be tweaked to minimise unwanted EM coupling effects.

Finally, there is the interaction between the transmitter and receiver circuits (the array) to consider. This interaction is quantified by the mathematical formula for resistivity which is the intrinsic rock property that we are actually trying to recover. In general terms this formula is **Apparent Resistivity** = **Receiver Voltage** divided by **Transmitter Current** and multiplied by a **Geometric Factor**. The expression makes the necessary assumption of a uniform half-space, hence the term 'Apparent' Resistivity, and the Geometric Factor takes into account the spatial disposition of all four electrodes.

So, as well as optimising the electrical parameters of the transmitter and receiver circuits, we will need to strategically position the transmitter circuit electrodes to maximise the electric current flowing through the target zone and strategically position the receiver circuit electrodes to best sample the voltage differences generated by this current flow. There is a range of standard electrode arrays to choose from, or you could design your own, perhaps informed by forward modelling of your environment and target.

Having sorted out the measurement parameters, we can then systematically move the array to undertake a series of contiguous readings to cover the area of interest. Such a survey would aim to map the spatial distribution of resistivities (and IP effects) within the ground and hence throw light on the sub-surface geology. In modern geophysical practice, the results from such a systematic survey are typically processed with an inversion routine to facilitate this process.

Clearly there are both theoretical and practical factors to consider when designing and executing a resistivity (or IP-resistivity) survey.

Force or finesse - which factor do I think is more important? No fence sitting here, I'd want both!

Seismic window

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Flat reflections

This is the 50th anniversary of the ASEG, and if my calculations are correct it is also my 50th contribution to *Seismic window*. With this auspicious occasion in mind, I thought I'd give a brief history of the column. *Seismic window* was first written by Rob Kirk in the 1990s. Rob had a wealth of international experience at the forefront of seismic stratigraphy, and he shared some of his observations in the early issues of *Preview*. These were tutorial like and consisted mostly of annotated seismic displays. When Rob decided he could no longer continue writing there was a short period where guest writers contributed to fill the gap. Eventually I was approached, and I wrote the occasional short article about interesting things I had observed. These short notes were intermittent, but now I'm told the readers expect something in every issue. So, 20 years later, I have hit the 50 mark.

Now on to seismic flat spots.

Flat spots can be reflections from the base of a hydrocarbon column, so they are of interest to interpreters. Sometimes they are hidden amongst other reflections, or are not flat in two-way time because of velocity variations, but we can apply some appropriate filters to enhance the flat events.

Figure 1 shows a fairly obvious flat reflection in an offshore oil field, while Figure 2 has a hidden event closer to the edge of the oil field. A common practice is to apply an optical stack to the data. An optical stack applies a transparency to a number of adjacent traces (30–40 say) and sums them. The middle panels of Figures 1 and 2 show that the flat reflector is enhanced by this technique while dipping events are diminished.

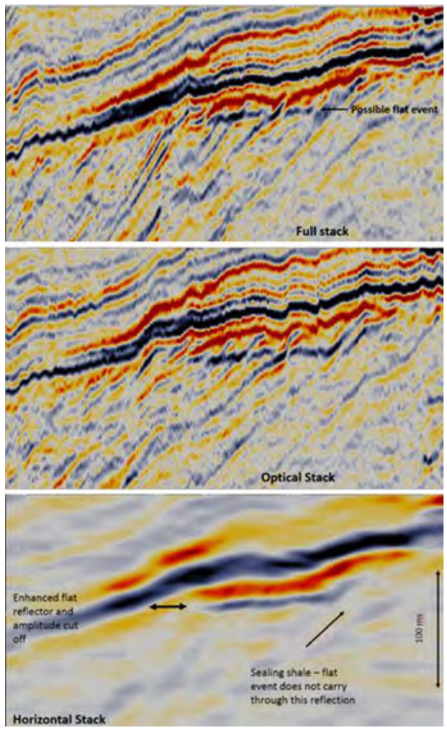

Figure 1. *Seismic line across an oil field .The full stack (top) data has an indication of a flat reflector cross-cutting a number of dipping horizons. Applying an optical stack (centre) enhances the flat reflector slightly, but the best enhancement is seen when a 20 x 20 averaging filter is applied (bottom).*

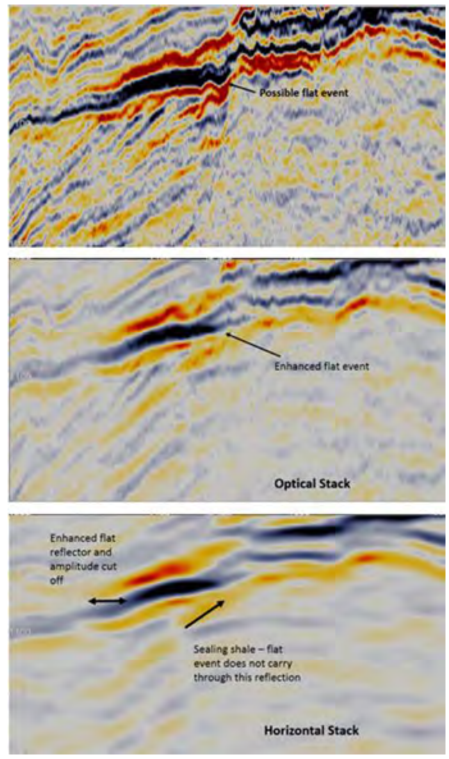

Figure 2. *Seismic line across an oil field. The full stack (top) data has a less obvious indication of a flat reflector. Applying an optical stack (centre) enhances the flat reflector slightly, but the best enhancement is seen when a 20 x 20 averaging filter is applied (bottom).*

Optical stacking is not available to everyone because it is not built into all software packages, but there is something just as good that can be applied using generally available filters. he lower panels of Figures 1 and 2 show that flat spots can be enhanced by applying a horizontal averaging filter. This filter has removed or smeared out most of the dipping events and significantly enhanced the flat events. The oil-water reflection is now quite obvious.

It is possible to go even further by applying a vertical averaging filter. Figure 3 is a time slice and shows a flat spot, but because of velocity variations the reflection is not truly flat and it dips

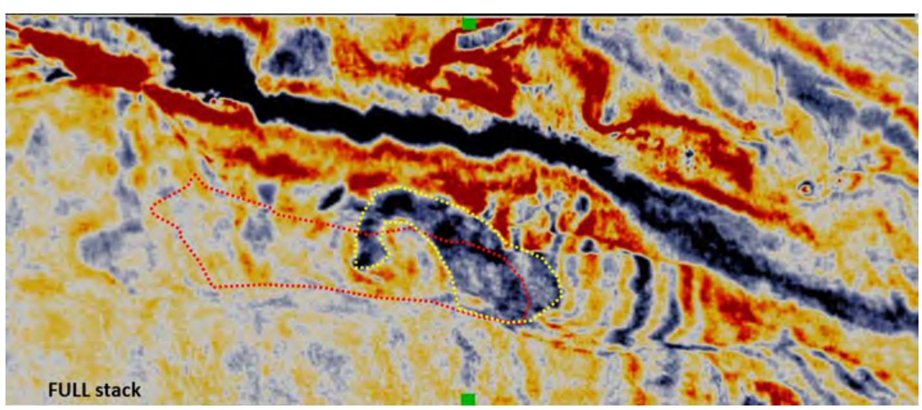

Figure 3. *Seismic time slice at the approximate TWT of the oil-water contact shows an area (the yellow polygon around the blob in the centre of the picture) dominated by a flat event but the field extends further.*

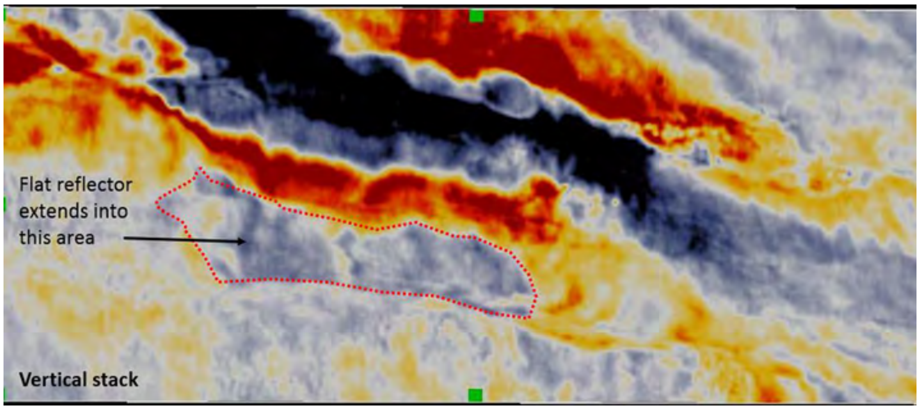

Figure 4. *After applying a vertical stack filter to the data a more extensive oil-water contact (red polygon) is recognised.*

below the time slice and its full extent is not visible. After applying a vertical stack, the area of the flat reflection is much larger than the time slice suggests (Figure 4).

Applying these horizontal and vertical stacks to the seismic data is a quick way to enhance reflections associated with hydrocarbon contacts and speed up the hunt for prospects.

Business directory

Data trends

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Raw radiometrics and ASEG GDF2 hiccups

The Geological Survey of South Australia (GSS) Chief Geophysicist, Gary Reed, recently took up the hobby of collecting every (legally available) element in the Periodic Table, which raised the question of whether he could legitimate his samples. This led him to the forum www.gammaspectacular.com, and the question of how to use USB Sodium Iodide radiation detectors with PC sound cards for 256 channels of gamma counts. After stocking up on smoke detectors to make a gamma source[1], and many calibration runs, he produced some excel graphs of counts. Unfortunately, the graphs are visually underwhelming outside the usual radioactive elements.

Longer measuring time is the only answer for low gamma emission elements, however, the graphs are swamped by the high emitters. Uniform and logarithmic scaling do not help. Then, the web site operator pointed out a non-uniform scaling trick. Effectively reverse the post measurement process and multiply each channel by its energy value in the IAEA 0 – 3 MeV range. The result accentuates elements higher up the channel numbers. Gary has since been able to discriminate elements in his non-radioactive rocks, such as South African PGEs.

Gary then asked for a script or program to apply this transform to GDF2 files of raw airborne radiometric data so we could take a novel look at re-gridding. A quick web search revealed the U.S. Nuclear Regulatory Commission has used airborne surveys for maps of specific elements, so it's not too novel an idea[2]. However, instead of having a nice C# program and novel grids to show you, we ran into the problem of unpredictable implementation of the ASEG GDF2 file format.

We started with a collection of relatively recent flights and found that every company had implemented the ASEG GDF2 file format differently. The most frequent problem concerned the first line in the DFN file, the definition of the comment column in the DAT file. That initial definition can treat separators randomly, and sometimes the entire definition is abandoned. The word DATA may or may not appear in the corresponding column in the DAT file, and spaces may not be defined for field width. Add that a comment can be any value, and checking for the word DATA is not a panacea.

We cannot blame company geophysicist for the mess. They have clearly been playing a guessing game for a while. If we want compliance then I think we need to take a good look at how this technical standard is presented, as it simply should not be so difficult to implement. The format was chosen because it is extremely versatile, Kim Frankcombe has produced two variations for electrical data[3] and we are considering it as a potential exchange format between the growing list of passive seismic formats. It is not meant to be the smallest, fastest or most efficient data file format, but clear, easily understood and readable by virtually any program or programmer now and into the future. The ASEG Technical Standards Committee will be reviewing how implementation of this format is described, and I will keep you informed of developments.

1 Soviet era smoke detectors are now hard to come by so if anyone out there has access to a supply would they please get in touch.

2 https://www.nrc.gov/docs/ML0301/ML030100071.pdf

3 https://www.aseg.org.au/technical/aseg-technical-standards

Webwaves

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Use of the ASEG website

Welcome to the first *Webwaves* of the Twenties. With the dawn of a new decade we'll reflect on the usage of the ASEG website during 2019. At a broad scale, we had 26 232 sessions during 2019, a 2.6% increase on the 2018 figure. This continued the growth seen in 2018 of both sessions and unique users on the website. The growth in the use of social media platforms also continued, with an increasing number of visits to the website originating from these platforms. LinkedIn, with a more professional focus, currently directs the most social users to the ASEG website.

The most common keyword that people use to search for the website is "ASEG", which has consistently been the most popular term. For the second year running "Amazon" is the next most popular (all these searches have come from the USA and who knows if they are looking for the company, the river, or the forest!). Passive seismic has also been a very common search term over the past two years, having knocked "caesium magnetometer" out of the top ten in 2018.

While website usage continues to be dominated by male readers (based on gender information from Google), female usage of the website has continued to increase over the past three years, from 30.3% of users in 2017, to 31.9% in 2018 and 32.1% of users in 2019.

Hopefully 2020 will continue to see an improvement in this regard.

Site speed varies across browser type (Figure 1). The fastest page loading times are observed by Safari users, and the slowest by Google Chrome - with pages taking almost three times longer to load. Chrome users represent the largest cohort of users, with over 50% of sessions. Bringing up the tail end of the browser market share in 2019, we had two users on a Playstation 4 and a solitary blackberry user (you know who you are).

The growing use of tablets and mobile devices resulted in 22% of users accessing the website from either a tablet or mobile device. Of these, 36.5% were iPhone users and 9.5% were iPad users. The next most common device was a Huawei P20 phone, with 5% of mobile sessions.

Browser	Avg. Page Load Time (sec)
1. Safari	2.77
2. Safari (in-app)	3.29
3. Edge	3.83
4. Firefox	4.22
5. Samsung Internet	4.95
6. Internet Explorer	5.74
7. Chrome	7.58

Figure 1. *Site speed by browser type.*

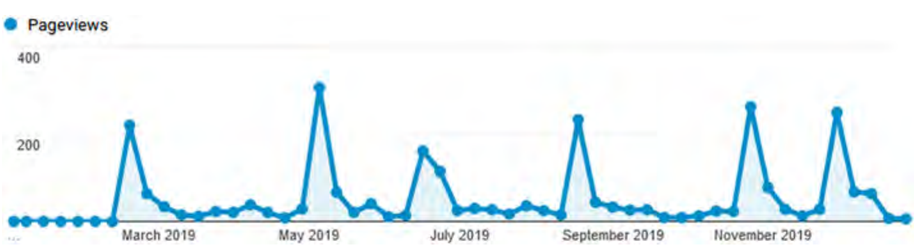

Figure 2. *Preview page views in 2019.*

Preview on the ASEG website

The hosting of *Preview* on the ASEG website has been a success. The *Preview* page is now the second most visited page on the website after the homepage, with 12% of all website activity being to view *Preview*. Views of the *Preview* page clearly spike at the release of a new issue (Figure 2), and over half of all these users download a PDF copy or view the flipbook.

Online *Preview* readers, while predominantly from Australia, are also coming from numerous other countries around the globe. The spread represents the success of the first year of the online launch. Figure 3 illustrates global *Preview* readership based on unique users in each country.

People are most likely to consume *Preview* between the hours of 0900 and 1300, with over a third of all readers accessing *Preview* during this time. There are some night owls amongst us, however, with 2.8% of readers accessing *Preview* between 0200 and 0400 in their time zone.

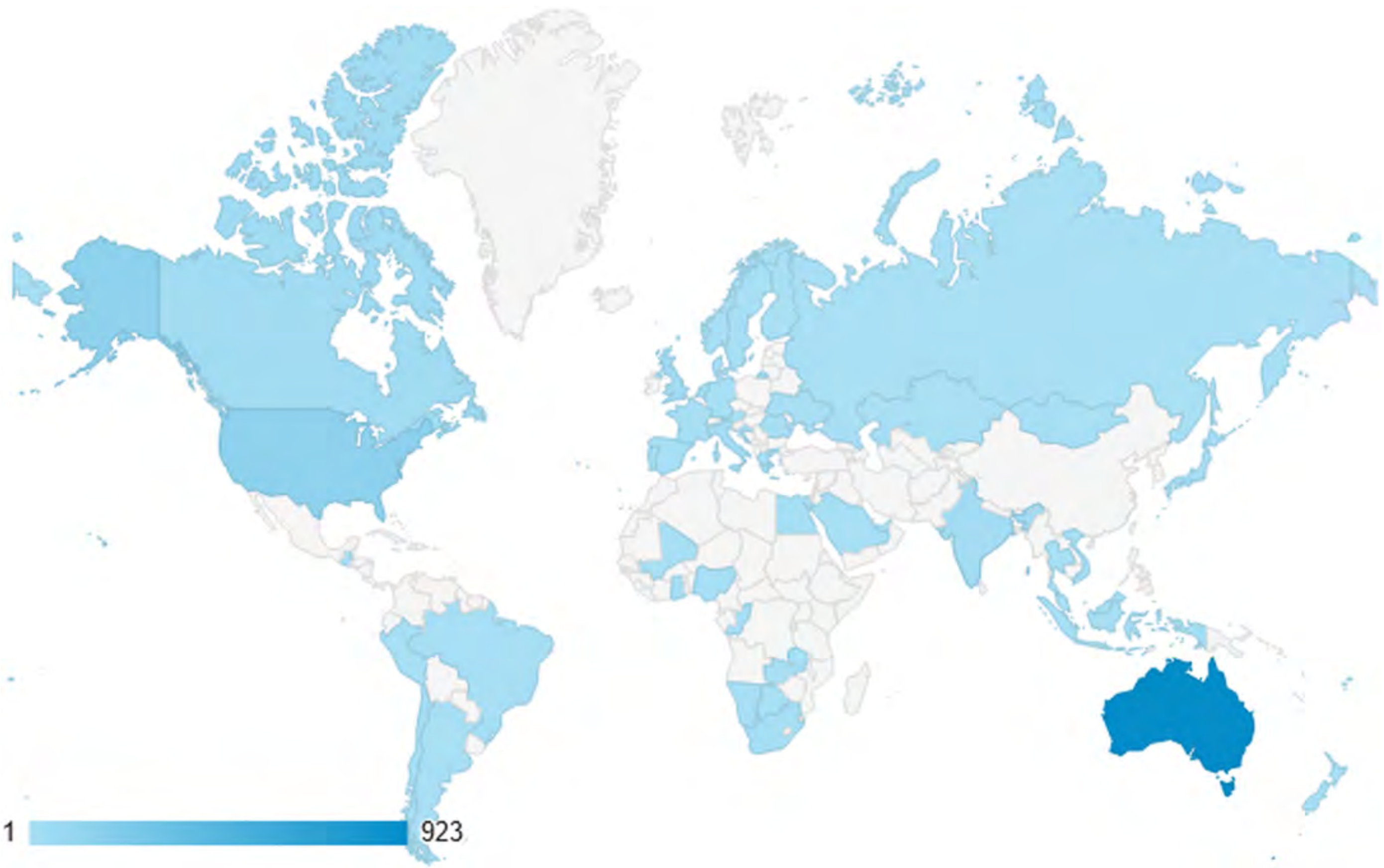

Figure 3. *Global distribution of Preview readers in 2019.*

Interesting link this month

The following short film produced by the National Film Board of Canada in 1959 is worth watching. It is surprising how little has changed in 60 years. Thanks to Kim F. for sharing.

The Modern Prospector https://www.youtube.com/watch?v=7-ERmGhAd7U *Instead of pick and shovel, the modern prospector employs all the resources of science to look for buried treasure. Aerial surveys, airborne magnetometers, instruments to measure the breadth and depth of ore bodies - with these the prospector can provide data to the company geologist to pinpoint the most promising drilling locations.*

The ASEG in social media

The ASEG has just joined Instagram https://www.instagram.com/aseg_news/ – so go on, give us a follow! We'd love to share your photos too, so please email Kate Robertson at communications@aseg.org.au if you have any images you would like featured.

We know not everyone is on Instagram, but you can also find us on a variety of other social media platforms too! We share relevant geoscience articles, events, opportunities and lots more.

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

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

LinkedIn group: https://www.linkedin.com/groups/4337055/

Twitter: https://twitter.com/ASEG_news

Youtube: https://www.youtube.com/channel/UC-dAJx8bXrX5BEudOQp4ThA

Ted Tyne's best of *Exploration geophysics*

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As part of our plans to celebrate the ASEG's 50th year and to also celebrate the extremely important scientific contributions captured in the 50 volumes of the Bulletin of the ASEG and *Exploration Geophysics*, we have chosen to publish a "Best of *Exploration Geophysics*" paper in each *Preview* issue in 2020.

In selecting a single "Best of" paper for this issue of *Preview*, I initially chose to set constraints to the period 1970 to 1990, covering the ASEG's first 20 years. This was not just a formative period for our Society and our science, but also a revolutionary period that ignited innovations in science, technology, engineering and mathematics that established exploration geophysics as absolutely fundamental to Australia's exploration industry in the search for and discovery of new mineral and energy resources. The discoveries attributable to exploration geophysics surveying over this period are continuing to underpin Australia's economic prosperity to this day.

Over the twenty year period, geophysical systems, practice and surveying and the recording of geophysical parameters, shifted from slow and tedious analogue processes to mini-computer/microprocessor automated digital sampling processes, significantly improving on signal quality and lower noise thresholds, spatial sampling, surveying speed and efficiency and improved data quality and extended search depth. Interpretation of geophysical survey data rapidly evolved along with the development of computers and our understanding of earth physics and mathematics. Exploration practitioners left behind the slow and subjective analysis of analogue systems such as chart recordings and manual tables of data and the use of interpretative type-curves and nomograms, to the implementation of the first automated inversion interpretations in the 1980s on portable mini/personal computers.

In my initial "Best of" short listing, I counted off more than fifty papers that were of real interest to me and, I would expect, to all of our ASEG Members. One of the most important papers in my very long short list is the excellent paper by Jim Dooley, a unique broad-brush insight and chronicle of the developments, innovations, breakthroughs and people in Australian exploration geophysics, across all areas of our exploration disciplines and covering this remarkable period in the rapid development of Australia's exploration science and technologies.

In the ASEG's first 20 years, the distinguished Editors of our Bulletin and *Exploration Geophysics* included Ross Crain, Ken Richards, Laurie Drake, Ken McCracken, Ted Lilley and Don Emerson. Over this period Don Emerson served as our Editor for 13 of those 20 years. In 1990, Terry Crabb as Chair of the ASEG Publications Committee, acknowledged Don Emerson's contribution with "much of the credit for the eminence of our journal must go to his unstinting efforts over this period to ensure that the quality of *Exploration Geophysics* was maintained". I have also chosen to include Don's Editorial for the issue which celebrates the first 20 years of *Exploration Geophysics* and reflects positively on our vibrant profession at the time, but also delivers a compelling, if not disquieting, snapshot of the decline in university training in the earth sciences that has continued to today.

I hope you enjoy reading Don's Editorial and Jim's excellent review paper from *Exploration Geophysics* 1990.

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Exploration Geophysics (1990) **21**, 219

Editorial – Our Bulletin

This issue of *Exploration Geophysics* marks 21 years of publication of the Bulletin of the Australian Society of Exploration Geophysicists. Ross Crain and Ken Richards were the first two Editors in the fledgling ASEG. I have the honour of being the current Editor in a now mature ASEG embracing eleven hundred members and subscribers from Australia and overseas. The passage of our first 21 years has seen the publication of over 900 geophysical and geoscientific papers, articles and notes by numerous authors in regular, special, conference and ancillary issues. I would like to pay tribute to all who have helped establish *Exploration Geophysics* as a respected geoscience journal. It has contributed much to educational initiatives and to the sciences and art of Australian resource exploration. Our many Authors, the former Editors (Ross Crain, Ken Richards, Laurie Drake, Ken McCracken and Ted Lilley), the Chair of the Publications Committee (Terry Crabb), Special Editors, Conference Editors, Conference Organizers, Reviewers, ASEG Executives, ASEG Members, Corporate Members, Advertisers, Sponsors, and *Exploration Geophysics* readers have all, by their diligence and support, promoted our journal and secured its place as an acceptable and reputable medium for geophysical science.

It is timely to reflect on the aims and functions of our journal which, in serving Australian geophysics, does need to take cognisance of factors peculiar to the Australian region. I have two comments to make. Firstly, Australia is home to the third largest number of mining geophysicists in the world (after USSR and China) and this component of our membership is reflected in the strength of their contributions to *Exploration Geophysics*. Despite the indubitably important contribution of minerals, petroleum and groundwater to the Australian economy, geoscientists generally, and the geographically scattered geophysicists, in particular, need to be vigilant to maintain and to safeguard the vitality and future of their profession. Currently there is a low appreciation of and little interest in the earth sciences by the bulk of the Australian population who reside in what are really coastal city-states. Over 80% of the 17 million Australians live in an area of a few thousand sq km in the east, southeast and southwest parts of our 7,882,300 sq km continent. Urbanisation demands energy and does provide some opportunities for environmental geotechnical geophysics, but resource exploration is increasingly hindered by political developments pushed by pressure groups. Unfettered exploration and uncontrolled exploitation cannot be condoned; indeed, reasonable environmental practices and care of the land are embraced by the profession. Rocks are materials; furthermore they are materials that provide the very basis and framework of the environment. If exploration geophysicists are to continue with their tasks of locating, defining, enhancing and evaluating anomalies; studying and compiling the responses and properties of earth materials; and documenting the nature and fabric of earth's subsurface then they need to be environmentally aware and pro-active, to address issues and to publish in *Exploration Geophysics* on the geophysical and professional aspects of the environment and environmental problems.

Secondly, it should be realised that scientific journals have much in common generally with universities – they exist to preserve, impart and extend knowledge. Journals have an advantage in that they exist in and deal with the real world. Journals also promote scholarship, i.e. knowledge of the works of others, and inspire significant advances in experimentation, observation, methodology and theory. The recent effective diminution in and redistribution of funding of Australian tertiary education has unfavourable implications for Australian university geoscience departments which are relatively expensive to maintain compared to most other disciplines. Geophysics staff in these departments are small in number – isolated individuals or small groups endeavour to carry out teaching and research with inadequate or outdated resources. The overall situation is unlikely to improve in the short term. As it has done in the past the ASEG can assist with or encourage undergraduate and postgraduate training by organising specialist lecturers and short courses, videotaped instruction sessions, research funding through the ASEG Research Foundation and substantial discounts for students attending ASEG activities. In this time of rapid technological change and expansion of knowledge other initiatives are required and one of these would be to encourage the considerable number of talented professionals in the geophysics community to publish appropriate tutorial and review papers in *Exploration Geophysics*. Such papers would be a permanent and valuable repository of relevant knowledge and expertise for students intending to enter our profession; many of us would profit by reading such papers.

Our 21st volume in 1990 is a cause for celebration. Our first quarter century of publishing activity will be attained in 1994. I trust that the ASEG will continue as a significant and dynamic scientific and professional society through the nineties and into the next century. I feel confident that *Exploration Geophysics* will continue to serve the ASEG well by striving for excellence in preserving, imparting and extending geophysical knowledge for the scientific and professional benefit of its membership.

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Abstract

The first twenty years of ASEG publications have been reviewed. The review has taken the form of summaries of developments over the period in a number of topics; these include petroleum exploration, coal exploration, potential fields, electrical and electromagnetic methods, and regional and deep crustal geophysics. The survey gives a good indication of the development of ideas and methods in these topics, and shows that the ASEG journals and conferences have played a significant role in stimulating and promulgating the practice of geophysics in Australia.

Key words: Australian exploration geophysics, petroleum exploration, coal exploration, gravity interpretation, magnetic surveying, electrical geophysical surveys, electromagnetic geophysical surveys, crustal structure

Introduction

Undertaking a review of the *ASEG Bulletin* and *Exploration Geophysics* since inception has proved to be a more formidable task than I expected, but nevertheless a very interesting one. There is a wealth of good material, some original, and some reflecting the use of methods developed and initially reported elsewhere. In order to keep the review within finite bounds, I have had to adopt several selection criteria; I am sure that not everyone would agree with these, and I apologise that many important topics and papers may have been omitted.

I have in general avoided case histories and papers dealing with policies of government, universities, industry, etc., and have concentrated rather on papers reporting or reflecting developments of new ideas, instruments, field techniques, or methods of interpretation. However, there is no hard and fast distinction, as many papers use new ideas in their case histories, or report field examples to illustrate the new techniques.

Another policy adopted was to follow through the period with stories of developments in a number of topics which have been developed in the Journal through the period; thus some papers have not received attention because they do not fit into one of these stories.

The selected topics include the important topic of oil exploration; my impression is that there is a smaller percentage of papers in this field in ordinary issues of the ASEG journals than, say, in *Geophysics,* but it features largely in conference proceedings. Other topics which have been well represented in the journals include geophysics in coal exploration (mainly seismic, but recently including radar methods), electromagnetic (EM) exploration (particularly transient EM, TEM), potential field interpretation, and perhaps surprisingly for an exploration journal, deep crustal geophysics and geomagnetism.

As regards references, I have not attempted to quote sources outside the Journal, though of course these would be necessary for a full report on the developments in any topic. I believe that the papers in our Journal indicate the general course of development in each topic, and make many important original contributions. Outside sources are of course adequately referenced in the papers quoted. In the nature of things, a complete list of all papers mentioned in the review would be nearly as long as the main text itself; therefore I have made use of the *ASEG Publications Index, 1970–1987.* In references to papers listed therein, the number of the paper in the index has been quoted, and it is assumed that readers will have access to a copy for further details.

For papers not listed in the index, a list of references in the usual format is given at the end of the review. These include of course papers published since 1987, and also papers in Vol. 2 No. 2 and Vol. 14 No. 2, nearly all of which for some reason escaped the indexing process. Most papers presented at Conferences have been treated differently from papers in "ordinary" issues. I have mentioned topics discussed where appropriate, but have not given references to the individual papers, but only to the issue reporting the Conference proceedings. This is partly a space saving device in view of the large numbers of presentations; also, many of the published contributions are in the form of abstracts or extended abstracts rather than full papers, and many of them have been published more fully later, either in our own Journal or elsewhere.

General

Early Reviews

The ASEG was formed at an International Conference on Geophysics of the Earth and Oceans, held in Sydney in January 1970. The first issue of the ASEG Bulletin was published as Vol. 1 No. 1 in September 1970. This was the only issue for Vol. 1.

The first number is largely taken up by formal matters such as constitution, membership of committees etc. On the scientific side, McNatt (1971, *454*) reviewed the state of the art in geophysical prospecting for petroleum, and the history of the developments leading up to that time. Refraction seismic had been used in the 1920's; reflection seismic was also used experimentally, but it was not until some 10 years later that it became firmly established. Improvements during the period 1940-1970 included AGC, multiple geophones and shotpoints, magnetic tape recording, surface energy sources, CDP, and finally digital recording which became established for general use during the late 1960's.

Three further review papers in Vol. 2 helped to set the scene as it was at the beginning of our 20 year period. Pettingel (1971, *521*) took a look at the state of the worldwide mineral exploration industry and its implications for the Australian scene. Seigel (1971, *589*) estimated that it would take 15 ground-based crews about 140 years to map the Western Australian greenstones at a reconnaissance scale, and suggested the use of airborne EM to speed this up. Wood (1971) reviewed the state of engineering geophysics; this paper is of some interest in view of the recent

issue (Dooley, ed., 1990) containing papers from a symposium on engineering geophysics. Wood discussed seismic and resistivity methods, gamma-ray logging, and measurement of effects of industrial vibrations; he briefly mentions remote sensing, and warns against overselling of geophysics and the need for checking results by drilling – topics which feature strongly in the recent papers.

Vol. 2 No. 1 contained also the first original scientific papers (Williams, 1971a, *718*; 1971b, *717*), which described a simplified method of interpreting TURAM results, and a nomogram and computer programs to assist in the interpretation.

Early Conferences

Two conferences, entitled Southwest Pacific Symposia, were held in Sydney in 1975 and 1977.

The proceedings of the first (Falvey and Packham, eds, 1975) consisted of extended abstracts. Most of the papers were divided into regional sections – East Australia, younger Pacific arcs, New Zealand, Solomon Islands, and Papua New Guinea, while a final section contained papers on the seismic, volcanic, and kinematic processes at plate boundaries. General acceptance of plate-tectonic theory and its applicability in this part of the world is evident.

The second meeting (Coleman, ed., 1978) consisted almost entirely of papers on the evolution of plates and plate boundaries in the offshore Australasian region.

An important contribution to mineral prospecting was the special issue on the Elura orebody (Emerson, ed., 1980, *203*). This massive sulphide orebody, at the northern end of the Cobar field, was located by geophysical methods, mainly magnetic and gravity, about 1972, and subsequently was subjected to a number of field tests by various geophysical methods to determine the most effective methods of locating a similar orebody in the particular environment. It is a dense, very conductive, moderately polarisable orebody, with a highly magnetic core, lying at depth under a thick weathered conducting layer. Electrical and EM methods showed distinct anomalies which could be associated with the orebody, but careful field and interpretation procedures were necessary to avoid confusion from anomalies due to weathering and some other rock types.

Beginning in Adelaide in 1979 (Emerson, ed., 1979b), ASEG has held a series of general geophysical conferences, initially biennially but more frequently recently; proceedings from most of these have been issued either as Journal numbers or as special publications. Papers from these, together with those from specialist conferences on various topics, have been included where appropriate in the topical summaries below.

Petroleum Exploration

The main method used here is of course seismic reflection, though aeromagnetic surveying, and possibly electrical measurements, also play an important part.

Gray (1971) described what was believed to be the first use of Geoflex in the desert areas of Australia, near Lake Hope in the Cooper Basin. Drilling was difficult because of the long distance to the nearest water supplies, and the sand dunes restricting mobility. Severe sandstorms were prevalent. It was found that Geoflex records imparted less energy into the ground than dynamite sources, with higher frequencies and less noise. The rate of traversing was increased by a factor of 2.5 compared with conventional drilling practice in this area.

In an account of the discovery and development of the Mackerel Field, Gippsland Basin, Maughan (1980, *434*) sounded a few warnings on interpretation of seismic results. Two holes targeting supposed crests found gullies instead. The importance of accurate velocity analysis was emphasized here, as well as in the succeeding paper (Denham, 1980, *151*), in which it was shown that random errors incurred during velocity analysis might exceed errors in reflection times. The situation could be improved by smoothing velocity anomalies rather than average velocities. Denham illustrated this point with reference to the Kingfish Field, Gippsland Basin. Further warnings on possible misinterpretations of seismic results, with a few examples of past problems, were given in the account of the first Petroleum Geophysics Workshop held in Melbourne in February 1983 (Smith, ed., 1983).

Spathis (1983) showed how to design digital filters which approximate ideal low-pass Butterworth filters, and to derive high-pass, band-pass, and band-reject filters from these by simple frequency transformations. Computer programs were listed.

Haren (1984, *295*) reviewed the use of electrical methods in petroleum search in Australia, including several tests conducted by CSIRO in Australian sedimentary basins. The most promising parameter was apparent resistivity; this often correlated with chargeability over hydrocarbons. Negative SP effects were also associated with hydrocarbon accumulations. The effects were claimed to be related to chemical changes in the overlying rocks, caused by a plume of escaping hydrocarbon vapours. Henderson *et al.* (1984, *315*) claimed that low-amplitude, high-wavenumber magnetic anomalies occurred over hydrocarbons, owing to reduction of haematite to diagenetic magnetite.

Nelson (1984, *493*) proposed that the seismic reflection technique might be used for deep targets in mineral exploration, partly for stratigraphy, but also for direct orebody detection. Reflections in the latter case might be due to density variations rather than changes in elastic constants. Experiments suggested that seismic data should have a white spectrum over more than two octaves, and upper limiting frequencies greater than 200 Hz.

Papers presented at the 1985 Conference in Sydney (Gunn, ed., 1985) included discussions of the problems in acquisition and processing of seismic data, such as velocity determination and elimination of noise from artificial sources. Three-dimensional surveys, both reflection and refraction, received substantial attention. The tau-p and Nth-root stack methods of analysis were presented. A triaxial downhole system for acquisition of S as well as P data was described by James and Nutt (1985a, *353*). James and Nutt (1985b, *352*) also described extension of downhole vertical seismic profiling to inclined boreholes and offset surface-energy sources.

Blackburn (1986a, *50*) discussed the possibility of direct hydrocarbon detection in the Gippsland Basin by seismic reflections. Gas is present in most Australian crudes, and only a small quantity is needed to produce a satisfactory impedance contrast. Their high API gravities should also be favourable for

direct detection. A careful study of the rock properties and other factors would be needed for successful application. Blackburn (1986b, *49*) showed that Miocene channelling distorted time-depth mapping in the Gippsland Basin; a linear velocity function method offered advantages over traditional methods in depth conversion.

At the ASEG/SEG Conference in Adelaide, 1988 (Middleton, ed., 1988), seismic papers presented included discussions of deconvolution techniques, use of directed energy sources, estimation of velocity structure by tomography, analysis of amplitude variation with offset, improved methods for statics corrections, shear waves and their relation to fractures, and vertical seismic profiling.

A 2D seismic modelling facility was developed at Flinders University, SA for studies of elastic waves travelling through simulated geological structures (Pant *et al*., 1988). Signals were recorded digitally from piezo-electric sensors, and both P and S waves could be processed and analysed by the usual procedures. Tests were carried out on models of a cavity, a horizontal linear target, a fault, and a basement mound.

Three-dimensional seismic work was well to the fore at the Melbourne 1989 Conference (Asten and Denham, eds, 1989), with discussions of isochronous models, velocity estimation, statics corrections, and amplitude-offset analysis, all applied to 30 situations. Other topics included interactive interpretation using "artificial intelligence", determination of porosity from seismic data, and F-K migration using variable velocities.

The problem of conversion of seismic time depths to true depths away from control by well velocity surveys was tackled by Megallaa (1989). The interval velocities derived by one of the existing methods were checked by preparing a smooth, geologically representative map of normal move-out (NMO) velocity for each horizon; this was then used to prepare depth maps from which depth-interval velocity functions could be prepared. Deviations from original NMO and T_O were then used to revise the models, and the process was repeated until convergence was reached. The method was applied to the Snapper gas field in Bass Strait.

Coal Exploration

Coal is one of Australia's most important minerals, both for local use and for export. It is not surprising therefore, that much attention has been devoted to the use of geophysics in exploring for coal and for locating structural features which could affect the planning of mining operations. The main method used was seismic refraction, but reflection techniques, cross-hole seismics, and radar mapping have all come into use.

Packham and Emerson (1975, *508*) gave the results of a seismic survey and eight-hole drilling program in the central part of the Sydney Basin. Two sedimentary units were identified: a lower unit with thin sandstones and dirty coals, and an upper unit with sandstones and conglomerates, and cleaner coals. Reflections from the upper measures tend to obscure the deeper reflections; White (1975, *704*), using synthetic seismograms, showed that better penetration of the upper layers could be achieved by using lower frequencies.

King (1979, *374*) reported on an application of the Mini-Sosie technique to shallow reflection mapping of coal seams and structural features in the Gloucester Basin, NSW. This survey was part of trials of the method, which was introduced into Australia in late 1978. Pinchin *et al*., (1983) used both Mini-Sosie and conventional explosive techniques in a high-resolution shallow seismic survey at the Wambo Colliery, Hunter Valley, NSW. Doubt was cast on the existence of a postulated fault. It was found that both methods could be used in this area, and a choice of method for use in any area would depend on the particular circumstances.

Hatherly (1980, *303*) described computer programs for processing seismic refraction data. The generalised reciprocal method of Palmer was used for velocity and time-term analysis, and a migrated depth section could then be plotted. Greenhalgh *et al.* (1980, *267*) discussed the fitting of various mathematical functions to empirical refraction data where continuous velocity variation with depth is indicated. Greenhalgh and King (1980, *263*) showed how to determine velocity-depth distributions from curvilinear refraction data.

Buchanan *et al.* (1981, *70*) reviewed the use of channel waves in coal seams for predicting fault surfaces ahead of mining: they quoted several cases from overseas. Greenhalgh and King (1981, *264*) developed theoretical dispersion curves for in-seam channel seismic waves.

Use of an interactive computer system was described by Asten (1983, *23*) to deal with the vast quantity of data collected from borehole logs during exploration. This approach combines the ability of the computer to undertake rapid calculations for mathematical correlations, with the intuitive judgement of the earth scientist to recognise significant features visually and to assess their structural and economic importance.

Harman (1984, *300*) reported on shallow reflection surveys by BHP in the Cook Colliery, Bowen Basin, Queensland, which showed complex faults. By comparison with borehole data, it was possible to trace coal seams and identify areas of splitting.

Huber (1985, *336*) reviewed the applicability of geophysical methods to coal exploration, and concluded that seismic (including high-resolution shallow reflection), and gravity methods could be used for direct detection, while magnetic and electrical methods were useful indirect methods. Palmer (1985, *512*) described the use of GRM in anisotropic situations.

Mason *et al.* (1985, *431*) described experimental seismic in-seam surveys at West Wallsend Colliery, NSW. One seam transmitted leaky P, SH, and SV waves. Structures mapped were interpreted as a dyke, and a sand channel. An old water-filled heading acted as a barrier to SH waves, and transmitted P waves at 100 Hz. A corridor of competent rock 75 m wide was mapped as having a width between 40 and 90 m.

At the Conference in Perth, 1987 (Middleton and Pridmore, eds, 1987) topics discussed included the use of vertical seismic profiling (VSP) to correlate well data with surface data, procedures for analysing cross-hole seismic data, and the development of a triaxial downhole geophone for use in identifying and separating different types of seismic waves.

Several papers were delivered on topics related to coal at the ASEG/SEG Conference, Adelaide, 1988 (Middleton, ed., 1988). These included the effects of discontinuous seams on absorption of seismic waves, a comparison of the use of radio EM wave tomography with mine mapping, and cross-hole tomography, including a study of curved ray paths and the use of damped least squares in interpretation. At the 7th ASEG

conference, Melbourne, 1989 (Asten and Denham, eds, 1989), further developments in cross-hole seismics were introduced, including the use of a swept-frequency source; also an application of the 30 seismic method, techniques using crooked lines in mountainous areas, and trials of a high-frequency vibrator, were described. The use of a downhole radar probe was reported as useful in locating fractures in crystalline rock at ranges of 50 to 150 m, and more generally, radar was used at the surface and in underground workings for horizon control, locating old workings, and mapping geological structure in coal measures.

The use of radio waves at frequencies of 10 to 30 MHz for mapping orebodies from underground mine tunnels was described by Nickel and Cerny (1989). In the example quoted, radio waves were transmitted from one tunnel to another at right angles to it; aerials were placed in boreholes from the tunnels, with at least 3 locations for both transmitter and receiver. A body with anomalous electrical properties appears as a radio-wave shadow. Rock thicknesses of the order of 100 m were penetrated, and an anomalous zone was found, which proved to be the extension of a vein.

Turner (1989) showed how stacking procedures could be used to improve the signal in ground-probing radar surveys. The standard procedure is to move transmitter and receiver along a profile at constant separation. A localized object gives a hyperbolic series of traces on the radargram. These can be concentrated to a few traces nearly above the object by procedures similar to seismic-reflection diffraction-stack migration. The signal can be further improved by using the coherence of signals around the hyperbola, or by using tau-p migration.

Potential Fields

Gravity and Magnetic Interpretation

Papers on this topic include modelling the effects of geometric shapes of anomalous bodies, signal-to-noise ratio improvement, and analysis of field data covering large areas.

The gravity field of a circular disc with vertical axis is not expressible in terms of elementary functions; it involves elliptical integrals. Lee (1971, *400*) showed that the formula may be transformed into a simpler integral involving Bessel functions; by applying an inverse Hankel transform, an expression was found from which the parameters of the disc could be readily obtained.

Moore (1972, 474) gave a comprehensive review of the methods proposed by various authors for direct and indirect interpretation of gravity and magnetic anomalies. This was followed shortly by Crain (1972, *122*), in a paper which complemented rather than duplicated Moore's discussion in that it described computer methods of reduction, processing, applying corrections, and display methods such as automatic contouring and stacked profiles.

Stanley (1977, *624*) proposed a method of interpreting potential field anomalies due to dykes or contacts. It was based on the similarity of the formulae for various derivatives of gravity and magnetic effects of these bodies, and he claimed that only relatively short lengths of traverse need be measured. Horizontal gravity gradients, based on the difference between pairs of stations, were measured, rather than the total gravity field. These ideas were developed further by Stanley (1978, *622*), who showed that vertical and horizontal gradients were related through the Hilbert transform. Plotting vertical versus horizontal gradients for a contact (fault) anomaly leads to ellipses or circles from which the parameters of the contact could be derived.

A symposium on 20 gravity interpretation was held in Sydney in 1977 (Emerson and Falvey, eds, 1977). The usefulness of 20 models in the real world, their applicability and limitations, and some estimates of the errors incurred by departures from the ideal conditions of the models, were discussed at length. Crustal structures, continental margins, and sedimentary basins were among the problems considered.

In 1978, a symposium on magnetic interpretation was held, also in Sydney (Emerson, ed., 1979a). In some respects, this was complementary to the gravity symposium. Emphasis was placed on the importance of realistic geological models rather than computer-generated depths to and shapes of sources, though of course these are an essential step in the interpretation process. In order to arrive at models helpful to the explorationist, much more information was needed on the susceptibility and remanence of minerals and rocks, their relation to petrophysical and petrological properties, and the modes of occurrence of magnetic minerals in ores and host rocks.

Horizontal and vertical magnetic gradients of the total field anomaly were also used as the basis for interpreting magnetic anomalies by Atchuta Rao and Ram Babu (1980, *26*; 1981, *553*). In the first paper, they combined the two gradients into a complex vector, and studied the derivation of the model parameters of a horizontal cylinder from the anomaly profile. In the second paper, two functions derived from these gradients are used to interpret the anomaly due to a buried sloping step.

Mohan *et al.* (1980, *472*) used Fourier transform methods in a study of the gravity effect of a 2D inverted triangular prism. Atchuta Rao *et al.* (1982, *554*) derived the Fourier transform of the magnetic anomaly of a 2D prismatic body. Properties of the energy density and phase spectra were used to derive the parameters of the model body. Mohan *et al.* (1982, 471) used the Fourier transform of the square of the magnetic anomaly of a buried sphere to interpret the parameters of the body.

The Olympic Dam copper-uranium deposit in the Stuart Shelf of SA, one of the major discoveries in recent years, was found by drilling of coincident gravity and magnetic anomalies. It is covered by some 350 m of Adelaidean sediments. Anderson (1980, *11*) discussed the basement features corresponding to these anomalies, and shows that there are many other variations in density and magnetic susceptibility giving rise to anomalies in the area, so that interpretation of similar anomalies cannot be conclusive. Rutter and Esdale (1985, *575*) also gave an account of this discovery, including the geological thinking which led to analysis of the existing geophysical data and to further surveys.

A very comprehensive set of formulae for the magnetic effects of bodies of various shapes and directions of the earth's field and of magnetisation were presented in a special issue by Emerson *et al.* (1985, *207*). Programs were given for evaluating these formulae on a HP 41C hand-held computer.

A method for extracting weak magnetic signals from a noisy background was devised by Dass *et al.* (1986, *545*). The filter used was derived from the horizontal gradient of the anomaly field and its Hilbert transform. This was successfully applied to a survey in the Cuddapah Basin in India.

Aina (1986, *4*) proposed the use of reduction to equator and "orthogonal" reduction of magnetic anomaly fields in addition to the usual reduction to the pole. Reductions to pole and equator give rise to symmetrical anomalies over a symmetrical body, whereas orthogonal reduction (i.e. reduction to an inclination of 45°) leads to an antisymmetrical profile with zero crossing over the centre of a symmetrical body.

The formulae for the gravity and magnetic fields of uniform triaxial ellipsoids of arbitrary orientation were given by Clark *et al.* (1986, 100). These models are useful for general modelling of compact bodies because of the flexibility of shape, and also because self demagnetisation can be treated analytically. Programs for a HP41CX calculator were presented.

Topics on potential fields discussed at the ASEG Conference, Perth, 1987 (Middleton and Pridmore, eds, 1987), included presentation and analysis of magnetic and gravity anomalies over the WA goldfields, magnetic image processing by computers, the use of an automatic gain control (AGC) technique to deal with the large variation in amplitudes prevalent in magnetic gradient displays, and application of the Australian Geomagnetic Reference Field in the reduction of magnetic field data.

At the Adelaide Conference in 1988 (Middleton, ed., 1988), the effect of magnetic fluctuations along the southeast Australian coast on magnetic surveying was shown to be significant. Papers were presented on the benefits of studying magnetic rock properties to improve geological interpretation, improvements in image processing, advantages and limitations of one-dimensional upward continuation applied to aeromagnetic data, and the use of "terrace functions" in inversion of potential-field data to convert smoothly varying data to step functions.

Mudge (1988) developed a method of analysing magnetic data measured on a sloping surface, as in steep topography or an inclined borehole. Apparent dip and declination were calculated from the induced and remanent magnetisation and the orientation of the survey plane.

At Melbourne, 1989 (Asten and Denham, eds, 1989), magnetic and gravity terrain modelling as used in interpretation were compared.

Magnetic Surveys

A vehicle-borne alkali-vapour magnetometer, capable of high resolution, rapid traversing and digital recording, was described by Stanley (1975, *623*). A Hilbert transform was automatically applied to the recorded data to facilitate interpretation.

By plotting the trends of magnetic anomalies from three large areas (two in the WA shield and one in eastern NSW) on rosette diagrams, Emerson (1976, *206*) showed that trend analysis could be useful in studying tectonic provinces and their boundaries, and evidence for past relative movements.

Aeromagnetic trends were displayed as simplified second-derivative maps in the Broken Hill area (Stewart and Boyd, 1983, *628*). These maps facilitated resolution of closely spaced anomalies and recognition of trends. Long lineations in NE and NW directions could be used to subdivide the basement of the Willyama Complex into a mosaic of blocks.

Retard and Butt (1983, *556*) claimed that use of aeromagnetics in oil exploration had dropped considerably since the 1960's. Results of some older surveys suggested that there was scope for increased use of the method, and that many of the newer high-resolution techniques should be introduced.

The concept of airborne magnetic susceptibility mapping was propounded by Silva and Hohmann (1984, *601*). The total field anomalies were reduced to pole, and an equivalent layer of poles is computed. This is converted to a susceptibility map assuming that there is no remanent magnetisation present. The technique works best for magnetic bodies with vertical sides extending to infinite depth and flat tops, but fair results could be obtained with departures from these conditions.

Arafin (1984, *20*) used a relatively cheap Develco fluxgate magnetometer comprising 3 orthogonal sensors which could record continuously when used in a moving vehicle. Accurate angles between the sensor axes were determined by rotating the magnetometer about three axes. The total field and three components could then be calculated.

Hoschke (1985, *329*) developed a downhole vector fluxgate magnetometer, which was used in the Tennant Creek area. It consists of 3 fixed orthogonal sensors, and 3 inclinometers used to correct for probe rotation and drillhole inclination changes.

Rock Magnetisation

Studies of the magnetic properties of rocks and minerals are essential for reliable interpretation of field data into geological features; these are represented in the following papers.

Ridley and Brown (1980, *561*) described a transformer bridge developed in CSIRO for measurement of low-field susceptibility of rock specimens. A low operating frequency reduces errors due to specimen conductivity; however conductivity can be inferred from in-phase and quadrature components of the signal.

Clark (1983, *99*) summarised knowledge of the magnetic properties of rocks such as susceptibility, remanent magnetisation, and their relation to the domain state of the magnetic grains, e.g. superparamagnetic, single domain, or multi-domain. Components carried by different mineral grains can often be separated by palaeomagnetic cleaning techniques. Magnetic petrophysics can assist in interpretation of anomalies, dating of mineralisation, fabric studies, stratigraphy, recognition of chemical processes, and quantitative mineral analysis.

Geomagnetism

If the present rate of decrease of the Earth's magnetic dipole moment continues, it would become zero about 3900 A.D. Facer (*1971*) discussed the nature of the geophysical world when quadrupole and octupole moments will predominate.

Corrections to regional magnetic observations for diurnal variations have always been hampered by the sparsity of magnetic observatories in Australia, and a lack of knowledge of the area of applicability of recordings at a fixed site. Lilley (1982, *413*) analysed the recordings made as part of projects to examine natural EM induction in the Earth. The effect of the conducting sea water was present at all coastal sites, but disappeared about 100 km inland. Smooth patterns persisted over substantial inland areas, but two zones were identified where the pattern was not uniform. A study of the Cobar area (Lilley, 1984, *415*) showed changes of up to 25% in the amplitude of the fluctuations over distances of about 30 km. The changes were attributed to a slate formation of high

conductivity which lies along the eastern edge of the Cobar Trough.

Lilley and Barton, eds (1986, *414*) edited an account of a Workshop on Geomagnetism held in Canberra in May 1985. This issue contains several papers on ionospheric magnetic fluctuations, which may seem remote from practical exploration geophysics. However, these fluctuations on the one hand form the source of induced currents in the Earth, which are used to study subsurface variations in conductivity by magnetotelluric and related methods; and on the other hand, they are the cause of magnetic disturbances for which corrections must be made in magnetic surveying. Hence it is important that the nature of these phenomena should be understood for effective applications in both the above cases. Several examples of induction studies of crustal conductivity were reported, as well as magnetic surveys at sea, in the air, and from satellites. The latter led naturally into a discussion of global reference fields, and the origin of the Earth's main field as a result of dynamo action in the Earth's fluid outer core.

Barton (1988) defined the international adopted reference field (IGRF) for magnetic charts and secular variation. He also explained the need for a more detailed reference field for the Australian area (AGRF), and presented the charts for 1985.0 for the total field and declination components and their secular variation. A workshop on magnetic field variations and problems in their applicability to exploration data was held in Canberra in December 1987 (Barton *et al*., 1988), and the proposed Australia-wide Array of Geomagnetic Stations (AWAGS) was introduced. Improvements in methods of presenting the data were also discussed.

Electrical

Resistivity and Induced Polarisation

Direct current or very low frequency alternating current methods of measuring resistivity are among the oldest methods of mineral prospecting. The more recent method of including measurements of time variations in response caused by electrochemical phenomena, known as induced polarisation (IP), gives valuable additional information in appropriate situations.

A very thorough discussion of the theories of the factors causing IP phenomena was given by Lynam (1972, *425*). Treatment of univalent interfacial electrochemical reactions for both metallic and normal IP effects led to the presence of secondary current generators at the metal-electrolyte interface, which produce the IP voltage decay.

The various array configurations used in resistivity and IP prospecting were reviewed by Whiteley (1973, *709*), who concluded that the response of different systems in complex geological conditions was not well understood, and that there was considerable scope for further research into their properties and possibly for design of improved systems. The characteristics of many array configurations were calculated by Pratt and Whiteley (1974, *528*) using surface-integrals as a basis for computer modelling. The response in two distinct geological situations were calculated.

Whiteley (1974, *705*) described an offshore resistivity method for continuous profiling in shallow water. In contrast to previous methods, this development used electrodes towed near the sea surface instead of dragging a cable along the bottom.

Merrick (1974, *462*) presented a "pole-multidipole" array, in which only a remote current electrode is moved, while several potential electrodes remained stationary with a range of separations. This technique was tested successfully in several shallow groundwater investigations in NSW.

Tyne (1977, *662*) developed a set of nomograms for calculating the geometric factor for resistivity logging of inclined drill holes.

A method for interpreting IP soundings over horizontally layered media was presented by Dixon and Doherty (1977, *162*). They showed that use of linear filters simplified the calculation of chargeability functions.

Davis *et al.* (1980, *147*) derived a filter function for use in interpreting resistivity soundings over layered structures. It can be used in digital convolution interpretation with any of the standard collinear arrays.

Edwards (1983) calculated modelled curves for magnetic IP and magnetometric resistivity for a dipping dyke under a conductive overburden. He gave a FORTRAN program for calculation of further curves.

Using digital filter methods, Pal (1984, *509*) derived formulae for the apparent resistivity measured by Wenner and Schlumberger surface arrays over an anisotropic, inhomogeneous earth. Banerjee and Pal (1986, *29*) investigated the contribution to measurements by various resistivity arrays made by thin vertical sheets extending to infinite depth. Sheets at some locations do not make any contribution, and even negative contributions were found.

At the Adelaide Conference, 1988 (Middleton, ed., 1988), measurements of the IP effects of several minerals were reported to aid in inversion of survey data, and the advantages and disadvantages of various electrode arrays were examined. At Melbourne, 1989 (Asten and Denham, eds, 1989), a technique for removal of an EM coupling effect from dipole-dipole IP data was presented, and it was suggested that the effect could be used to gain more information about an anomalous body.

An alternative to standard methods of resistivity mapping was presented by Macnae and Irvine (1988). Using UTEM instrumentation, an ungrounded inductive loop source was combined with a grounded electric field receiver. The advantage was that the primary electric field was independent of the resistivity structure. In the one survey, electric and magnetic field data could be used to explore for both resistive and conductive bodies. The method was tested at Mt. Aubrey, NSW, and successfully mapped two quartz veins.

Merrick (1989) developed a method for direct interpretation of resistivity soundings of a horizontally layered earth. The top layer was resolved by two-layer curve matching and then stripped off. Successive two-layer curve matching was applied to the whole section. Merrick did not claim better interpretations than other methods, but the process could be done on a calculator rather than a computer.

Electromagnetic

Transient, Time Domain

One of the major spheres of activity in mineral exploration has been the development and application of transient EM (TEM) methods, largely in an attempt to penetrate the ubiquitous near-surface high-conductivity layer.

A preliminary version of a CSIRO-built transient EM system (later to become SIROTEM) was described by Buselli (1974, *77*). Improvements over the Russian TEM equipment MPP01 included the use of multi-channel signal averaging and recording signals to longer decay times, and use of a second receiver loop to aid in rejection of artificial or natural noise. Comparison tests with MPP01 were made in conjunction with BMR near Cloncurry. The signal-to-noise ratio was improved by a factor of 44. Further comparisons were conducted at Woodlawn, NSW, in which noise sources and the effect of different loop sizes were investigated (Buselli, 1977, *80*).

The first completed SIROTEM model was described by Buselli and O'Neill (1977, *78*). The instrument was portable, an order more accurate than other models, could record signals to delays of 150 ms, could use a variety of loop geometries, and had a high tolerance to artificial noise. A built-in microprocessor controlled the operations, and could convert the measurements, e.g. to apparent resistivities. Examples of two field tests were presented.

The variation with height above ground of the response of a TEM loop system was investigated by Raiche (1978, *541*). He concluded that measurements from a helicopter should be feasible.

Lewis and Lee (1978, *410*) showed that the transient electric field excited by a TEM loop above a half space is concentrated in a toroidal zone which moves slightly inwards at first, and then moves outwards along a 30° cone, eventually reaching a maximum, at which time the rate of change of magnetic induction is zero.

The Newmont TEM system was described by Dickson and Boyd (1980, *158*). The effects of a uniform half-space and of a buried tabular body were calculated and compared with field results.

Srinivas *et al.* (1980, *615*) used scale modelling to study the TEM effect of truncation and of non-perpendicular profiling on the anomaly curve due to a vertical sheet conductor.

Several field applications of SIROTEM were reported by Buselli (1980, *74*,) including profiles over the Elura deposit near Cobar NSW, at Teutonic Bore in WA, at Mt Bulga, and a deposit in the Willyama Complex. Interpretation was assisted by a modelling facility, which used SIROTEM equipment to record the response over a thin dipping layer in air or in a conducting medium.

Lewis and Lee (1981, *409*) showed that conducting material around an orebody modified the transient EM field in two ways: in the early stages of decay it strongly directed the primary field, and later it swamped the target field. It was possible to design field measurements so as to make use of these effects.

Nagendra *et al.* (1981, *489*) analysed the transient response of a horizontal conducting cylindrical shell, and prepared a nomogram for estimating the optimum measuring time for a given model.

Displacement currents are usually neglected in TEM calculations. Lee (1981, *402*) showed that the effect of these currents would be noticeable (but small) only at early decay times for highly resistive rock.

Ramaprasada Rao and Kabra (1983) gave results of modelled curves over sheet conductors with varying depths and inclinations for dipole-dipole TEM measurements.

Previous calculations on TEM response over a layered earth assumed a step-function cut-off. Raiche (1984, *538*) considered the effect of a ramp-function cut-off. It was shown that the ramp-derived voltages are higher, particularly at early decay times.

Extension of TEM surveys to depths of 1–2 km was tested in the Sydney Basin (Strack, 1984, *629*) using a newly developed system using a fixed grounded wire transmitter and a movable loop receiver. 300 transients were recorded at 8 stations in two days, and the geoelectric models correlated well with basin topography.

Irvine and Staltari (1984, *344*) found a distinctive anomaly at Mt Windsor (NE Queensland), which appeared on the basis of SIROTEM and Geonics EM 37 measurements to be due to a steeply dipping bedrock conductor. However further measurements with different loop arrangements showed that it was caused by the edge of a conducting surficial layer.

McCracken *et al.* (1984, *438*) showed that noise recorded by EM prospecting systems comprised natural geomagnetic and EM variations, and mechanical movement of the receptors. Seasonal, diurnal, and regional variations could give an overall variation of about 10^4.

Whichello (1986, *700*) developed an iterative computer program for inversion of SIROTEM data in a horizontally layered model, and tested this on two coal deposits in South Australia. The results agreed satisfactorily with the known geology.

A workshop on downhole EM (DHEM) methods was held in Melbourne in Dec. 1985 (Eadie and Staltari, eds, 1987). DHEM had become widely used where surface methods were limited by large depths or conductive overburden. However, many DHEM profiles were not being interpreted properly because of lack of knowledge and/or experience. The special issue based on the workshop illustrates some successes and problems in application of DHEM, and its potential as an ore finder. Case histories and theoretical papers were included, together with a comprehensive review by the editors.

Buselli *et al.* (1987, *75*) presented a method for calibrating a downhole SIROTEM probe by placing it inside a solenoid in which a decaying current is produced. The same apparatus can be used for checking the polarity of connections to the probe.

Lee and Thomas (1988) reviewed the basic phenomena related to decay of transient EM signals and the methods used to analyse them. Decay curves were affected where permeability of the rocks was frequently dependent, such as in areas where superparamagnetism existed, and negative effects could be explained. Anomaly separation was justifiable for a body more conductive than its host rock. Supplementary data might be necessary to define a model adequately. Smith and West (1988) explained the negative response in terms of a larger initial polarisation followed by a rapid decay, causing a negative vertical-field response if the receiving loop is coincident with or inside the transmitting loop. In a complementary paper, the TEM response of a thin conductive dipping sheet was tackled by Wait (1989), who carried out a first-order analysis for a step-function source. He also found that the IP slow tail could be of opposite polarity to the main EM response.

At the Perth 1987 conference (Middleton and Pridmore, eds, 1987), there was continued emphasis on down-hole EM methods. Several mathematical models and techniques of

interpretation were introduced. Papers presented for surface surveys included the use of surface-integral methods in EM modelling, a survey of step and impulse systems, and a description of a laboratory modelling facility.

At Adelaide in 1988 (Middleton, ed., 1988), topics discussed included filtering of SIROTEM data, and an attempt to explain the negative TEM anomalies often found with coincident-loop surveys. Further responses of models of anomalous bodies were presented, and a three-component down-hole TEM system was described.

At Melbourne in 1989 (Asten and Denham, eds, 1989), a method was outlined for preparing conductivity-depth sections for TEM, and use of the finite element method for modelling the response of complex structures was described. The use of first and second spatial derivatives together with decay times for interpretation of TEM data was presented, and the problems of inversion of layered models near a contact were analysed.

Cull (1989) described some tests of a SIROTEM system mounted in an airship. A transmitter loop 25 m x 12 m was mounted on the airship, and a receiving coil, wound on a plywood former, could be lowered by a winch to offsets of 20 or 40 m. Measurements were taken at a height of 200 m. Good signals were obtained over a conducting body near Dookie, Vic., which had been mapped previously by ground SIROTEM.

Frequency Domain

A full description of the TURAIR EM prospecting method was given by Seigel Associates (1971, *588*). A fixed ground energising source was used in conjunction with an airborne receiver. This led to lower efficiency and limited mobility compared with other airborne EM methods where only moderate depths were involved. However greater depth penetration could be obtained with TURAIR, and the system was less affected by near-surface conductivity, and could be used with a helicopter in mountainous terrain.

Raiche (1973, *542*) developed a general method for calculating the EM fields due to either electric or magnetic dipole sources embedded in a horizontally layered earth. Both horizontal and vertical dipoles were treated.

Hall and Davis (1974, *290*) described briefly the principle of a rotating EM dipole source, which radiates in all directions, thus enabling both radial and azimuthal profiles to be surveyed, and facilitating determination of dip of a conductor. An instrument for model experiments was described by Hall *et al.* (1978, *289*). Results of tests at various azimuths for the effect of a graphitic model in an electrolytic tank were presented.

A large scale-modelling facility for electromagnetic experiments was constructed in CSIRO Division of Mineral Physics. Duffin and Drinkrow (1976, *179*) described the problems in devising models with appropriate electrical properties, and Drinkrow (1976, *176*) described the design and operation of the system.

Vozoff and Jupp (1977, *673*) developed a theory of error bounds for model parameters derived from geophysical measurements. They applied this to the resolution obtainable from DC and MT measurements in three cases: a buried permafrost layer, an EM waveguide, and a sub-Moho layer. Both DC and MT data were found essential for the waveguide case. DC data may be helpful in the permafrost case, but add nothing to MT for the sub-Moho layer.

EM scattering was generally modelled by an integral equation of which the Green's function needed for a solution is a cosine transform. Numerical solutions were slow to converge because of the oscillatory nature of the cosine. Lee (1982, *404*) presented closed expressions for the Green's function which avoided this problem and enabled calculations on a mini-computer.

Thiel (1984, *644*) investigated the effect of anisotropy on the surface impedance measured using VLF radio waves. A simple technique was proposed to determine the degree and direction of the anisotropy.

At the Adelaide Conference, 1988 (Middleton, ed., 1988), the measurement of EM impedances to high frequencies (100 kHz) was related to delineation of inhomogeneities in the ground, such as variations of permeability.

General

A joint Australian/US workshop, held at Macquarie University in Dec. 1977, was summarised by Braham *et al.* (1978, *63*). Topics included problems associated with deep weathering, noise reduction, modelling, and description and comparison of various EM and MT equipment.

Gunn and Brook (1978, *276*) compared the results of surveys by several methods over a sulphide ore body in WA. The mineralisation was detected by MPP01, Crone, SP, MIP, and Turam methods, but the location and definition of the body varied considerably between the methods. Gunn (1980, *273*) described further test comparisons, this time between electrical IP and Pulse EM (PEM). Murali *et al.* (1980, *479*) compared telluric field anomalies with time-domain IP effects over a mineralised zone in India.

The problem of finding ore bodies under the conducting weathered layer, prevalent in much of Australia, was reviewed by Smith and Pridmore (1989). The overburden was highly conducting, and formed a barrier for electrical and EM methods and led to spurious IP effects. Maghemite was formed, which caused erratic magnetic anomalies, and superparamagnetic phenomena in TEM surveys. Radioactive elements might also be present. High-resolution low-level airborne magnetic surveys could smooth out the near-surface magnetic effects, and allow geological mapping and in some cases direct detection of ore bodies. Airborne EM had not been widely used in Australia, though the INPUT system had been modified by increasing the transmitter power and number of channels recorded, digital recording, and shorter integration time. INPUT had been used for massive sulphides, geological mapping, and kimberlite exploration. Several ground EM systems had been used, with various loop configurations. Superparamagnetic effects simulated those of a deep conductor, i.e. higher response and slower decay rate at later times, but offsetting transmitter and receiver loops by 1–3 m, or using an in-loop configuration, was commonly enough to eliminate these effects. Negative TEM response could be modelled by a weakly polarisable body with suitable parameters. IP had not played a major role in Australia since the introduction of SIROTEM; the method was hampered by inductive coupling in many weathered areas, but a few successes had been achieved with careful field procedures. Downhole measurements commonly included magnetic susceptibility, conductivity, and IP; these gave information which assisted interpretation of surface-mapped anomalies. EM methods used a large transmitting loop near the surface and a downhole receiver; this combination might detect conducting bodies not intersected by the hole.

Radiometric

Radiometric surveying has been widely used in Australia, often being operated in conjunction with aeromagnetic surveying, and also in ground-based surveys. Obviously, the main objective is direct detection of radioactive minerals, but many cases have been reported where small amounts of radioactivity have led to indirect discovery of other minerals, including petroleum. In view of the wide-spread use of the method, it is surprising that only a relatively few papers in the ASEG journals have been devoted specifically to this topic; in particular, there are very few papers relating to developments in the technique.

In an early paper, McSharry (1973, *456*) showed that the corrections to airborne gamma-ray spectrometer measurements for the contribution of the air between ground and aircraft varied according to the system used; those systems with narrow spectral windows were the most reliable.

Dickson (1979, *157*) suggested that, as near-surface ore-bodies were progressively discovered, the search for deeper bodies would need changing techniques. These would include geochemical sampling for end products of the decay chains such as He and Pb isotopes, and use of "sniffers" for detecting radon gas escaping to the surface. Webb (1980, *686*) examined the use of total-count and spectrometer gamma detectors in various situations. From a discussion of the various spectral peaks of the radioactive elements and their decay products, and the properties of sodium iodide crystals used in the detectors, he concludes that a total-count detector with a low energy threshold should always be used; spectrometer channels may give additional useful information depending on the area, but may not be of much use in some geological environments.

Other papers include the establishment of calibration facilities for gamma-ray detectors (e.g. Kirton and Lyus, 1976, *378*; Wenk and Dickson, 1981, *699*; Dickson and Lovberg, 1984, *156*), and the radioactive properties of rocks, e.g. coal ash (Agostini, 1977, *2*), kimberlites (Kamara, 1981, *368*), and granitic rocks (Webster, 1984, *693*; Leys and Spencer, 1985, *411*).

Solid-Earth Geophysics – Regional and Deep Crustal

This topic is of interest to thinking explorationists, in that its findings are relevant to understanding of the processes involved in basin formation and the development of mineral provinces. Deep seismic sounding is the most useful and accurate tool, but important contributions are made by regional gravity and magnetic surveys, and by magnetotelluric (MT) investigations.

Boyd and Thomas (1973, *62*) reported a telluric investigation in the Otway Basin of Victoria. Results were consistent with a very low resistivity of the sediments to a depth of about 2400 m. Johnson (1973, *362*) conducted a time-term analysis of the Bass Strait Upper Mantle Project (BUMP) seismic refraction results, and deduced a crustal thickness of 30–35 km for Victoria and Tasmania, with thinning to 20–25 km under Bass Strait.

Hall (1976, *286*) pointed out the relevance of crustal studies for exploration, and gave examples – mapping faults in the basement of the Dnyeper-Donetz Basin in USSR, which affect facies distribution and hence locations of petroleum accumulution in the sediments; and a revision of regional geology in the Canadian Shield. He suggested that investigations of even deeper features in the lithosphere and asthenosphere could be relevant, particularly if taken in conjunction with geothermal measurements.

Finlayson and Collins (1980, *299*) described a portable seismograph designed and constructed in BMR for use in recording deep crustal events at unattended sites. Frequency modulated analogue tape recording was used; the playback system could be used at up to 32 times recording speed, and enabled analogue-to-digital conversion. This system was used for many years in BMR's deep seismic investigations. The playback system was described by Liu and Seers (1982, *419*). A novel speed control system, combining frequency and phase control, ensured accurate tracking, rapid response, and a wide acquisition dynamic range.

The International Lithosphere program for the 1980's decade was described by McElhinny (1982, *441*). A proposal for Australian participation was introduced, comprising transects in various parts of the continent, a study of intra-plate igneous activity in Australasia, and a study of recent plate movements and deformation in the Australasian region.

Ingate and King (1982, *340*) used long-period P waves recorded at Charters Towers, Queensland, to estimate gross crustal structure. The spectrum of a seismic wave train was factored into contributions from various sources, one of which was the crustal transfer function, which could then be isolated. The thickness of the crust was estimated as 40±4 km, and the ratio of crustal to mantle velocities as 0.8.

Denham and Lilley (1983, *150*) reviewed current work in solid earth geophysics, in the form of a list of workers in the field, together with the projects on which they were working.

Gravity and magnetic data in the Adelaide Geosyncline were identified by Gunn (1984, *278*) as representing an Atlantic type passive margin. Sinuous extensive coincident gravity and magnetic anomalies from the west of South Australia appeared to represent an ancient Proterozoic rift system which did not develop to crustal separation.

Filloux *et al.* (1985, *228*) described a MT survey in the Tasman Sea, using equipment designed at Scripps Institute of Oceanography. The survey indicated an unusually high conductivity in the mantle, possibly due to thermal effects of the nearby chain of sea mounts.

Wake-Oyster *et al.* (1985, *679*) reported on the progress of the major lithospheric transect across southern Queensland, from the Cheepie Shelf to Oakey, a distance of 670 km. Seismic reflection and refraction, aeromagnetic, and gravity methods were used. Several records showing deep (sub-basement) reflections were displayed. Processing of the data was still in progress.

Large intraplate mafic volcanoes in eastern Australia and New Zealand were found to be underlain by large intrusive complexes with positive gravity and magnetic anomalies (Wellman, 1986, *697*). They were thought to be associated with uplift of the country rock.

At Perth, 1987 (Middleton and Pridmore, eds, 1987), the structure of the basement of the Clarence-Moreton Basin was deduced from gravity and magnetic anomalies, and a hypothesis was advanced for the formation and development of the Perth Basin. Preliminary results were given of a major deep seismic survey in central Australia and of the 600 km profile across southern Queensland. Seismic reflections from

the lower crust under the Eromanga Basin, Queensland, were interpreted as due to the top of a major intrusion. A procedure for estimating the thermal conductivity of saturated rocks was described, and a model for the thermal evolution of the southern Cooper Basin was presented.

At Adelaide in 1988 (Middleton, ed., 1988), a structure for the upper mantle under northern Australia was developed from earthquake wave arrivals at closely spaced seismic arrays. A new method for stacking deep seismic data was outlined, and lateral velocity variations in central Australia were found from seismic profiles. Estimation of transfer functions for natural EM sources used in magnetotellurics was described.

Chant and Hastie (1988) recorded MT data from 1 kHz to .01 Hz at a site in the Bowen Basin, Queensland, for four months. Data were analyzed by two methods – the conventional method, and a method due to Spitz which gives two principal axes. The two methods gave different resistivity-depth profiles. It was found that divergence of the two Spitz axes indicated geological complexity.

At Melbourne in 1989 (Asten and Denham, eds, 1989), conductivity under the Tasman Sea was derived from marine electromagnetic measurements, a residual gravity map of Tasmania was presented, and a conductivity anomaly under the Eyre Peninsula, SA, was shown to extend to the north. A positive gravity anomaly in the Sydney Basin was interpreted as a mafic body in basement extending to 13 km depth.

Wright *et al*. (1989) described the recording of seismic expanding-spread reflections to a maximum offset of 25 km, in the northern part of the Amadeus Basin. Although some of the outer shots could not be used because of lack of coherence, a good vertical velocity profile was derived for the sediments to a depth of 8.6 km. Two low-velocity zones were identified, at depths of about 3.8 and 8.0 km. The main reflecting horizons were correlated with known sedimentary formations.

Conclusion

The ASEG publications present a picture of Australian, and to some extent of overseas, developments in many branches of geophysics. To the topics reviewed above, could be added many more, including remote sensing, geothermal investigations, underground water search, engineering site investigations, marine geophysics, detection of ores by vapour emissions, and computer-aided display of geophysical data.

In the review process, I was continually reminded of interesting papers read long ago but half (or more) forgotten, and I also became very interested in reading gems which I had skipped at the time of publication, through lack of time or not being in my field of interest at the time.

Although not mentioned specifically in the above stories, the influence of developments in computing hardware and software has obviously been vital in the facilitation of nearly all of them. Digital computers were well established in Australia by 1970, representing a major improvement on the situation only ten years previously. But now, with a personal computer on every geophysicist's desk which can equal the performance of the largest computers of 25–30 years ago, and connections to even larger computer systems or networks, and the portability of powerful computers for use in the field, the possibilities of handling huge quantities of data and performing complex operations on them, have improved immensely. One shudders to think of the developments of the next 20 years – will geophysicists still be necessary?

Finally, I wish to express my appreciation of the devotion of the authors and editors over the years who have put so much effort into the Journal.

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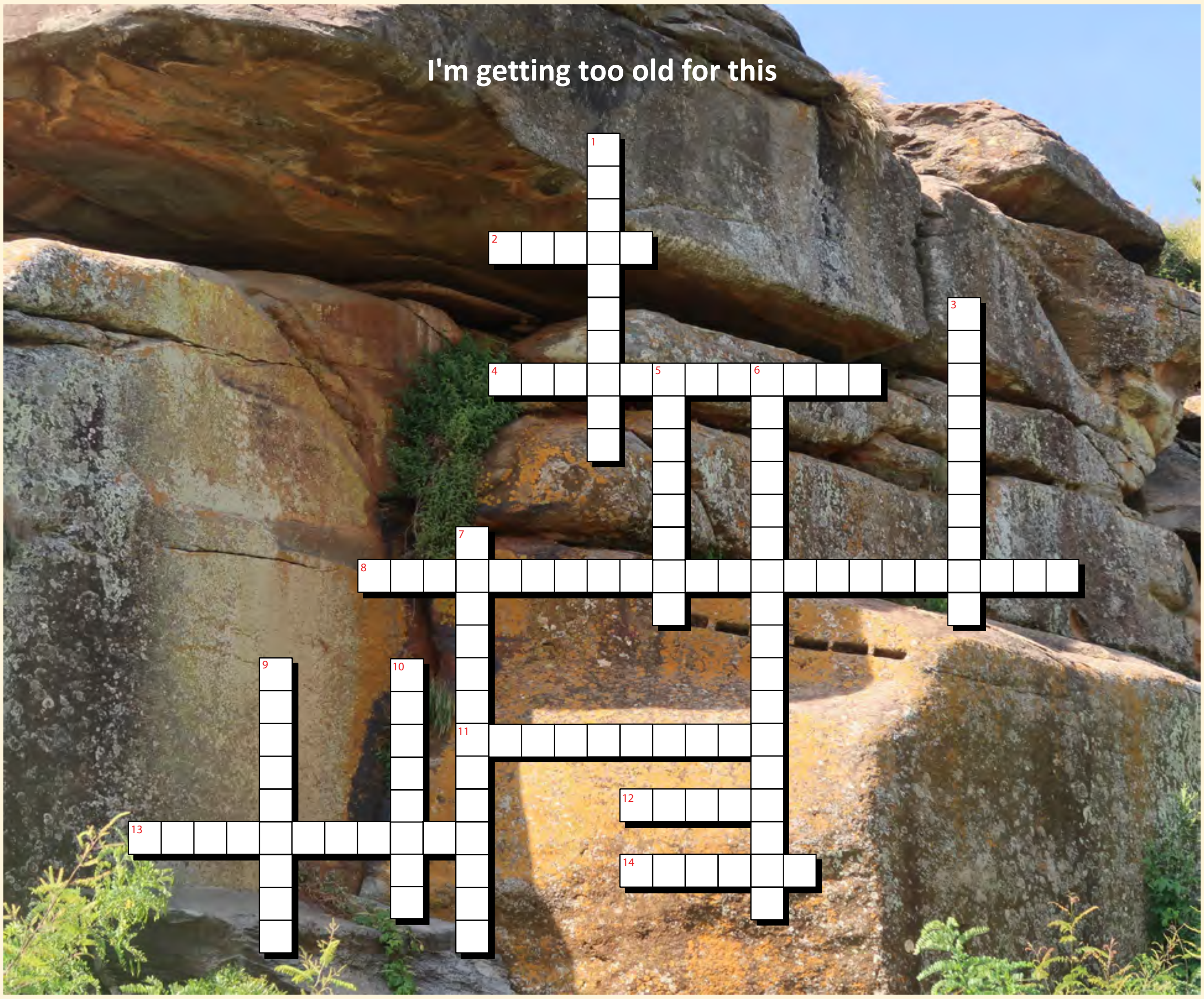
Preview crossword #6



Across

2. Topographic area which has been created by the dissolution of carbonate rock terrain. It is characterized by caverns, sinkholes, and the absence of surface streams.
4. Also called matrix density; the density of a unit volume of rock matrix at zero porosity.
8. A geophysical method in which bursts of electromagnetic energy are transmitted downwards from the surface, to be reflected and refracted by velocity contrasts within the subsurface.
11. Any device that converts an input signal to an output signal of a different form.
12. Volcanos formed when lava erupts through a thick glacier or ice sheet.
13. The technique for forcing radiation, like gamma photons, into a beam.
14. The material thrown out from the crater during the impact that formed it.

Down

1. A measure of the offset between two periodic signals of the same frequency.
3. An empirical relationship linking formation resistivity, formation water resistivity and porosity.
5. A contact-resistivity probe that provides data from which the strike and dip of bedding can be determined.
6. Porosity developed in a rock after its deposition as a result of fracturing or solution.
7. Formed in the region where found.
9. In geophysical interpretation and mathematical modelling, a problem for which two or more subsurface models satisfy the data equally well.
10. An igneous rock occurring as a natural glass formed by the rapid cooling of viscous lava from volcanoes.

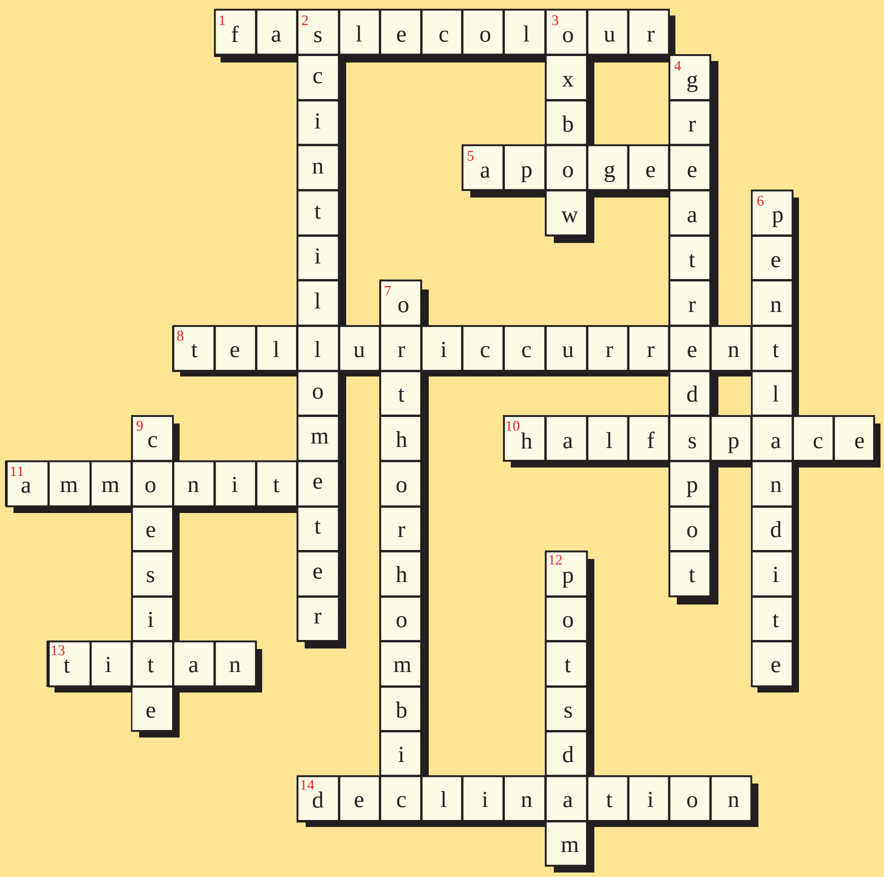
Play to win!!

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 #5 solution

Rocking games



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International calendar of events 2020–21

February	2020		
12–14	AGS Workshop on InSAR and its Application for Understanding Ground Movement https://australiangeomechanics.org/courses/ags-tasmania-radar-interferometry-workshop/	Hobart	Tasmania
23–25	SPG 13th Biennial Conference & Exposition https://www.spgindia.org/forthcoming-conferences	Kochi	India
25–27	1st AAPG/EAGE Papua New Guinea Petroleum Geoscience Conference & Exhibition aapg.org/global/asiapacific/events/workshop/articleid/51699/1st-aapgeage-png-petroleum-geoscience-conference-exhibition	Port Moresby	Papua New Guinea
March	**2020**		
1–4	PDAC https://www.pdac.ca/convention	Toronto	Canada
3–8	36th International Geological Congress https://www.36igc.org/	New Delhi	India
11–16	SEG International Exposition and 90th Annual Meeting	Houston	USA
15–20	International Symposium on Deep Seismic Profiling of the Continents and their Margins (SEISMIX 2020) http://www.seismix2020.org.au	Fremantle	Australia
23–26	DGG 80th Annual Meeting https://dgg2020.dgg-tagung.de/englisch/	Munich	Germany
24–27	Offshore Technology Conference Asia (OTC Asia) http://2020.otcasia.org/welcome	Kuala Lumpur	Malaysia
29–2 April	Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP) https://www.sageep.org/	Denver	USA
April	**2020**		
6–9	Saint Petersburg 2020 Geosciences: Converting Knowledge into Resources, (9th International geological and geophysical conference) https://eage.eventsair.com/saint-petersburg-2020/	St Petersburg	Russia
19–21	AI Earth Exploration Workshop: Teaching the Machine How to Characterize the Subsurface https://seg.org/Events/Artificially-Intelligent-Earth-Exploration	Muscat	Oman
24–27	Offshore Technology Conference Asia (OTC Asia) http://2020.otcasia.org/welcome	Kuala Lumpur	Malaysia
May	**2020**		
3–8	European Geosciences Union https://www.egu2020.eu/	Vienna	Austria
8–11	82nd EAGE Annual Conference and Exhibition https://eage.eventsair.com/eageannual2020/	Amsterdam	The Netherlands
12–13	2nd Joint SBGf-SEG Workshop on Machine Learning https://seg.org/Events/Second-Workshop-on-Machine-Learning	Rio de Janeiro	Brazil
17–21	1st Asia-Pacific Geophysics Student Conference (APGSC) http://apgsc.ustc.edu.cn/index/lists/001	Hefei	China
September	**2020**		
7–11	ISC (International Conference on Geotechnical and Geophysical Site Characterization) conference www.isc6.org	Budapest	Hungary
28–02 Oct	Australian and New Zealand Geomorphology Group Conference https://www.anzgg.org/conferences	Alice Springs	Australia
October	**2020**		
11–16	SEG International Exposition and 90th Annual Meeting https://seg.org/AM/2020	Houston	USA
April	**2021**		
19–22	Australasian Exploration Geoscience Conference (AEGC 2021)	Brisbane	Australia

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